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A Taxonomy of Curricular Discourse:
A Classification of Science Textbook Discourse

by

©

Frank Jenkins

A Thesis

Presented to the Faculty of Graduate Studies and Research

in Partial Fulfillment of the Requirements for

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"Concepts mark the path by which we move most freely in logical space."

Kaplan (1964)

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **A Taxonomy of Curricular Discourse: A Classification of Science Textbook Discourse** submitted by Frank Jenkins in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Heidi Kass
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Date: 1987-03-27

To Karen, Keir and Trevor
and to all others who love to learn.

Abstract

The purpose of the study is to develop a Taxonomy of Curricular Discourse by taking a multi-perspective view of science textbook discourse. The approach used is conceptual analysis. The five theoretical perspectives which are the basis of sentence by sentence analysis of textbook discourse are: epistemology of science, normative perspectives, curriculum emphases, practical inquiry, and science-technology-society (STS) education. These perspectives provided criteria for testing the validity of the taxonomy which evolved in the course of analyzing and classifying six chapters of high school chemistry text. The taxonomy represents an attempt to make epistemology accessible through the language of the practical, as distinct from the language of philosophy. The major findings of the research was epistemological. An epistemological triad of resultant knowledge, procedural knowledge and required action was discovered to be present in all science textual discourse. The triad conceptualizes the relationship among the "what?", the "how?", and the "action required" components of discourse.

From a normative perspective, ten knowledge forms were initially identified as being valued by various interest groups within chemistry. From a curriculum emphases perspective twenty-two knowledge forms are subsumed within five curriculum emphases: science, technology, society, communication, and pedagogy. An alternative definition of science-technology-society science education in terms of conceptual, empirical, process, and epistemological knowledge forms is developed. A research-practice dialectical relationship with an ongoing curriculum project was employed. Epistemological harmony with practitioners was sought by developing a language for explicitly introducing epistemology into science teaching. The Taxonomy of Curricular Discourse is presented as a point of departure for the examination of the nature of curricular knowledge in science and its ongoing pedagogical purposes.

Preface

The researcher began this research with a pluralistic commitment to a multi-perspective view of knowledge forms in science education to STS science education, to the concept of curriculum emphases, to the epistemology of scientific and technological knowledge, and to practical inquiry into educational activities. The research study was limited to the purpose of formulating a taxonomy for classifying knowledge forms found in curricular discourse. Chemistry textbook discourse was chosen as both the source and the test of an evolving taxonomy of curricular discourse. A taxonomy called the STSC Taxonomy of Curricular Discourse was developed. Concurrent with its development the taxonomy was used by the authors of the STSC **Chemistry** textbook to guide their textbook writing. The dialectic between the research project and the curriculum project was of mutual benefit. Hopefully, the STSC Taxonomy will continue to evolve and continue to be of use to others.

Acknowledgements

First I would like to express my thanks to my wife Karen and my two sons Trevor and Keir for adapting their life style to that of a Ph.D. candidate. The economic and social impact of completing this research study was eased by their support and patience. The magnitude of the project also required the assistance of the following people.

I am indebted to the guidance and support provided by my supervisor, Dr. Heidi Kass, who believed in me and in the viability of the research from the beginning. Her expertise gave me confidence that this lengthy and complex research study would "come together" in the end. Peter Fensham and Leo West also provided some initial reaction to the research which helped in organizing the report presented herein.

From a technological perspective my thanks go to Liz Makaryshyn, Peter Wood, Karen, Trevor and Keir. Liz provided the seemingly endless expertise and time to process and print the thesis from an Apple IIe computer using the Gutenberg wordprocessing program. Karitann Publishers, Inc. and The Author Group, Inc. are acknowledged for their permission to use excerpts from the **STSC Chemistry** textbook in this report. **STSC Chemistry** is a registered trademark of The Author Group, Inc.

The deliberative inquiry that I enjoyed as a member of The Author Group during the development and evaluation of the ALCHEM and **STSC Chemistry** textbooks had a considerable affect on the outcome of this research. The current members of the author group are Michael Dzwiniel, Dr. Michael Falk, George Klimiuk, Dr. Oliver Lantz, C. R. (Dick) Tompkins, Hans van Kessel and I. This association has existed for thirteen years and hopefully will continue for many more.

My classroom-in-use practical mode also had considerable influence on the research project. Without classroom discourse with students and without the chance to evaluate textbook discourse with students, the STSC Taxonomy of Curricular Discourse could not have evolved the way it did. Thank you to my students past and present for their patience with my "weird" discourse and for their enthusiasm for learning.

It has always been my good fortune to be associated with excellent people. This holds true for the members of my advisory and examination committee, Dr. Heidi Kass, Dr. Marshall Nay, Dr. Wytze Brouwer, Dr. J. A. Plambeck, Dr. Margaret McNay, and Dr. Glen Aikenhead (the external examiner). My thanks for responding to a lengthy and complex research report.

F.J.

1987-03-01

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The STSC Taxonomy of Curricular Discourse

Emphases and Knowledge Forms	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
	The K-KW-W (Epistemological) Triad		
Science			
1. Theoretical	The K	K The W	The W
2. Empirical$_E$ (experiential)	Emp K_E	K Emp W_E	Emp W_E
3. Empirical$_E$—Theoretical	Emp K_E—The K	K Emp W_E—K The W	Emp W_E—The W
4. Empirical$_L$ (laws)	Emp K_L	K Emp W_L	Emp W_L
5. Empirical$_L$—Theoretical	Emp K_L—The K	K Emp W_E—K The W	Emp W_L—The W
6. Process	Pro K_S	K Pro W_S	Pro W_S
7. Epistemological	Epi K_S	K Epi W_S	Epi W_S
Technology			
8. Technological	Tec K	K Tec W	Tec W
9. Empirical	Emp K_T	K Emp W_T	Emp W_T
10. Process	Pro K_T	K Pro W_T	Pro W_T
11. Epistemological	Epi K_T	K Epi W_T	Epi W_T
Society			
12. Societal	Soc K	K Soc W	Soc W
13. National	Nat K	K Nat W	Nat W
14. Historical	His K	K His W	His W
15. Ecological	Eco K	K Eco W	Eco W
16. Reconstructional	Rec K	K Rec W	Rec W
17. Epistemological	Epi K_{SS}	K Epi W_{SS}	Epi W_{SS}
Communication			
18. Communication	Com K	K Com W	Com W
19. Epistemological	Epi K_C	K Epi W_C	Epi W_C
Pedagogy			
20. Pedagogical Purpose	Ped K_P	K Ped W_P	Ped W_P
21. Pedagogical Reference	Ped K_R	K Ped W_R	Ped W_R
22. Epistomological	Epi K_P	K Epi W_P	Epi W_P

Chapter 1: The Problem

A. The Problem

Empirical research in science education can be classified in terms of the four commonplaces of education.

> "Of the four topics of education-the learner, the teacher, the milieu, and the <u>subject matter</u> (that which is intended to be taught or learned)-none has been so thoroughly neglected in the past half century as the last . . . ." (Schwab, 1964: 4)

The Shulman and Tamir (1973) review of science education found evidence for a lack of use of subject matter as a significant research variable. Subject matter in science education includes the ". . . concepts, laws, and theories that provide knowledge necessary for explaining and predicting events in nature as well as the language necessary for the description of nature" (Stewart et al, 1982). Besides <u>conceptual knowledge</u> and language, subject matter also includes the <u>empirical knowledge</u> that is used in the formation of and the testing of conceptual knowledge. Subject matter as a research initiative could take many forms. The current study will examine the various kinds of knowledge that are presented in science education textbooks.

The initial purpose of the present study was to look for evidence of the authors' epistemological approaches in science textbooks. Before this purpose could be fulfilled it became apparent that an epistemological analysis of the knowledge forms present in textual discourse would have to be completed. The general purpose for the study, thereafter, was to develop a taxonomy of knowledge forms present in STS chemistry textbooks.

The specific purposes of the study included an attempt to use epistemology as a conceptual organizer of knowledge components in chemistry textbook discourse. A second specific purpose of the study was to develop a taxonomic description of a science, technology, and society (STS) high school chemistry textbook that could be used by the researcher and others to guide the subsequent development (writing), evaluation, and implementation of such textbooks. Through heightened consciousness, the taxonomic description could help to promote a more balanced presentation of curricular emphases, a more balanced presentation of content and context, a more logical presentation of substantive knowledge and procedural knowledge, and a greater consciousness of epistemological approaches in curricular discourse than exists at the present time.

The specific purposes of the study can be summarized as intentions:

1. to identify theoretical perspectives that may be used as conceptual organizers and as a source of evaluation criteria for the development of an analytical framework for describing science, technology and society (STS) chemistry textbook discourse
2. to develop an analytical framework in the form of a classification system or taxonomy that may be used to describe academic science, technology and society (STS) chemistry textbook discourse

3. to add to the research base on the epistemology of subject matter in general and academic science, technology and society (STS) subject matter knowledge forms in particular

4. to make epistemology accessible to students and teachers by developing descriptive concepts and a language for the epistemology of textual discourse that exhibits epistemological harmony with practitioners of pedagogy

5. to assist textbook authors in general, and the Author Group* in particular in their quest to write an academic STS textbook

If one values the type of curricular experiences conceptualized by the science, technology, and society science education movement, then means need to be found to reach this end. Not only must the conceptual and empirical research base be firmly established but the science education community must be convinced of the importance of acting on the potential of a science, technology, and society approach and of epistemology as a source of unifying concepts in science education.

The problem stated for this particular study has been delimited from the general purposes stated above. The current study examined chemistry textbook discourse to determine the knowledge forms presented to students. A taxonomic system is developed and continually tested and revised over the time of the study. The tests of the taxonomy involved the classification of six units (chapters) of textual discourse taken from the ALCHEM* 30 (Grade 12 chemistry) and the **STSC Chemistry 10**** (Grade 10 chemistry) textbooks. The primary focus of the study is on the development of a classification system

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* ALCHEM Description

The content and format of the ALCHEM materials are unique in at least three ways: a) applied and descriptive chemistry are integrated with chemistry theory: b) the academic level of the chemistry content is kept at a university entrance level even though the context for the chemistry content is applied and descriptive chemistry, and c) the three student core books consist of pages which can be inserted into student loose leaf binders. In its present form there are three core books and seven elective units in the ALCHEM program. The core books are called **ALCHEM 10**, **ALCHEM 20**, and **ALCHEM 30**, and can be used as the basis of two half-courses and one full course, respectively, or with two full courses. Within each unit, student laboratory work, teacher demonstrations, and student exercises are integrated with the textual material. The textual materials were written and edited by a group of teacher-authors, The Author Group, Inc., in Edmonton, Canada in the time period (1973 - 1982).

** STSC Chemistry Description

The STSC **Chemistry** textbooks were written by a group of seven teacher-authors, the Author Group, Inc., in Edmonton Canada commencing in 1984 and again comprising a two one-semester and one full-year course sequence in high school chemistry. The textbooks are used in high school academic chemistry education courses. The textbooks move beyond the applied and descriptive chemistry contexts of the authors' previous textbooks to subsuming all content and contexts into four curriculum emphases. The curriculum emphases that serve to organize the textual material are science, technology, society, and communication (STSC). These STSC emphases were chosen not only to coincide with the current STS science education movement, but because each emphasis is defined by epistemological content to be learned by students. The nature of each STSC emphasis is presented implicitly and explicitly within the textual discourse.

for chemistry textbook knowledge and textbook emphases and not on the evaluation or description of the particular chapters and textbooks analyzed.

The research in this study is guided by the two questions which follow. The research design within which these questions are answered involves the initial conceptual development and then evolution of a classification system through the sentence by sentence analysis of the six selected chapters of chemistry textbook discourse. The goal of the research is to classify knowledge forms found in chemistry textbook discourse.

1. What theoretical perspectives (systematic conceptualizations) may be employed as conceptual organizers for developing an analytical framework to describe science textbook discourse?
2. What are the characteristics of the analytical framework which is developed to describe science textbook discourse?

These guiding questions are addressed by means of a research strategy built around the conceptual analysis approach proposed by Roberts and Russell (1975). According to Mahung (1980) the first two steps of conceptual analysis as applied to the description and evaluation of curriculum materials are the identification of a theoretical perspective and the development of an analytical framework. These steps are used and reused throughout the study in an iterative way to develop and refine the analytic framework of the taxonomy.

The concepts by which the guiding questions are formulated will be defined in context as this thesis report is developed. The definitions of terms and concepts are complex and context imbedded. Hence, presentation of summary definitions or even definitions from within the context of the study at this point in the thesis report is not considered useful.

B. Background to the Problem

Periodically in any discipline a series of integrative thrusts are made to try to encapsulate what has been achieved to that particular point in the discipline. In science education curriculum such a thrust is currently made possible by the conceptualization of science, technology and society (STS) science education. Typically the science education discipline has been split into various factions (e.g., theorists and empiricists). The knowledge claims upon which the various science education factions support their particular curricular emphasis is both theory and value laden (Kuhn, 1970). The concept upon which the stand is taken is usually epistemological, i.e., based upon the nature of science and/or the nature of pedagogy. The blend of the scientific and pedagogical foundations of knowledge is what makes for interest and diversity in the study of science education. A particular curricular emphasis chosen and often narrowly followed is value laden in much the same way that conceptual and empirical knowledge in the scientific field can be claimed to be theory or value laden. For example, observers claim that the high school "alphabet courses" (e.g., CHEM Study and PSSC Physics) of the 1960s reflect a valuing of university chemisty, resulting in school textbooks which resemble university textbooks in their approach.

The kinds of knowledge and corresponding ways of knowing valued by various groups of science educators have been categorized by Jenkins and Kass (1981, 1983 and 1986) as theoretical, empirical, technological, procedural, pedagogical, reconstructional, and epistemological. These categories are defined and described in the background papers presented in Appendix A. Each of these knowledge forms has its own pressure group in science education. As described by Jenkins (1981), the particular subculture to which each of us belongs will depend upon our general cultural heritage, our chemistry education experiences, and our stage of conscious growth as chemistry educators. The variety of emphasis placed on different values is healthy, but every curriculum developer and every author should be conscious of his/her values and identify them in his/her work.

In chemistry education these subcultures have included those who emphasize descriptive chemistry, applied chemistry, environmental chemistry, process-skill chemistry, theoretical chemistry, laboratory chemistry, critical-thinking chemistry, science-in-society chemistry, technological chemistry, nature-of-science chemistry, contextual chemistry, pedagogical chemistry, historical chemistry, nationalistic chemistry, household chemistry, equilibrium chemistry, gas-law chemistry, bond-theory chemistry, and something called modern chemistry. Each of these themes or emphases have had corresponding chemistry education textbooks with titles or subtitles that reflect the primarily singular emphasis for that particular book; e.g., ALCHEM: Applied and Descriptive Chemistry (Jenkins et al, 1982), Chemistry: A Cultural Approach (Kieffer, 1971), Chemistry: An Experimental Science (Pimintel, 1960), Chemistry, Man and Society (Jones, 1976), Environmental Chemistry (Pryde, 1973), Modern Chemistry (Metcalfe, 1974), Foundations of Chemistry (Toon, 1968), Applied Chemistry (Stine, 1978), and Chemistry for Changing Times (Hill, 1972). One chemistry textbook claimed an integrative approach—IAC: An Integrative Approach to Chemistry (Gardner, 1973)—but has been perceived, for example by the Alberta Education 1977 Chemistry Ad Hoc (Curriculum) Committee, to have too low a level of chemistry content for a high school academic chemistry course.

No formal studies seem to have been conducted on the connection between the extent of applied and societal chemistry material in textbooks and the level of chemistry content in those textbooks. Chemistry educators familiar with the range of textbooks available would probably agree with the generalization that the higher the level of chemistry content in high school chemistry textbooks the lower will be the extent of applied and societal chemistry context. Thus the problem of integration not only appears to be the splintering of themes and emphases, but also the perception that the "good" students get theoretical chemistry and the "poor" students get applied chemistry. Social critical theorists in science education do not seem to have picked up on this connection yet, but teachers such as the authors of the ALCHEM and **STSC Chemistry** materials seem to disagree pedagogically that these connections are necessary or desirable.

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motivation by teachers, for example, to move independently and individually to a multi-perspective science education curriculum. Many of these people indicate, however, that they do not understand what is meant by STS science and want to see a structured outline of what it means. More importantly, they want to see what some classroom oriented textual materials would look like. Many classroom teachers feel that they have been "stung" before on faddish curriculum trends, which in the end they were responsible for implementing without adequate pedagogic classroom materials.

A comfortable and creative classroom climate depends very much on the pedagogical effectiveness of the curriculum materials selected. If the teacher is uncomfortable with the materials, then new content or contexts introduced in a new curriculum are unlikely to be integrated into the teachers' "functional paradigms" (Crocker, 1983; Lantz, 1984). The researcher's experience in and around the classroom indicates that the student also has certain expectations of what a curriculum should look like. If the new materials are not easy to learn from or if they stray too far from the norm, the majority of the students and particularly those headed for university will object, at least covertly, to the change. For these reasons and others relating the nature of science to pedagogy (Jenkins, 1980), pedagogy can not be ignored when developing a curriculum or curriculum materials. Unfortunately, as evidenced by Roberts' survey of Departments of Education science education objectives (Roberts, 1982), the pedagogic component is most often taken for granted or, at least, not stated formally or explicitly. In this study the pedagogic component is conspicuous and structured as content and context. When specifically sought within science education textbooks, the frequency of statements giving instructions to readers is found to be high. Kuhn (1970) has indicated the importance of pedagogy to the acceptance of scientific paradigms (knowledge forms) within the scientific community. When this pedagogic component is defined and integrated with the STS contents and contexts, one gets what might be called STSP, i.e., scientific, technological, societal, and pedagogical, science.

Context can have many meanings in science education. In one sense context can refer to knowledge given to people which provides a specific situation, circumstance, relevance, meaning, or way of joining something together (Houghton Mifflin dictionary, 1982). For example, a geographic place where a chemical is found naturally or produced technologically may be provided as a context for the main content of a sentence in a textbook or in a verbal statement in a classroom.

A second contextual framework can involve the use of epistemological language in the structure of the sentence. The limitations, extent of evidence, validity, appeal to logic, or way of knowing for a particular piece of knowledge may be provided as context in a sentence as illustrated below (The Author Group, 1984). This epistemological context is different from epistemological content given to someone as the main thrust of a sentence. The epistemological context becomes a way of speaking or writing which is characteristic of the language of a scientist, engineer, social scientist, or pedagogue. An example of identifying language expressing epistemological context is an exercise given to STSC Chemistry 20 students. Grade 11 chemistry students are required to underline epistemologically oriented scientific language in a Gillespie (1974) article defending VSEPR Theory. The discourse underlined relates to the nature of science, appeals to evidence, and expressions of uncertainty. Common phrases encountered include, "According to . . .", "The evidence suggests that . . .", and "We are still uncertain as to . . .". Further examples from science classroom and science magazine discourse are presented in Appendix B. The Author Group has also conducted workshops with teachers on the topic of epistemological language in scientific discourse, providing techniques on how to incorporate such language into classroom and testing discourse.

Much has been written in the last few decades concerning epistemology in relation to scientific versus other fields of study, the nature of science, the nature of science education research, and the nature of instruction in science education. The works of Kuhn and Popper from within the field of the epistemology of science have had considerable effect on the epistemological studies in several areas of educational endeavor. Many educational papers and research studies have dealt with the presentation of the nature of science in the classroom setting (Nay, 1971; Aikenhead and Fleming, 1975; Benson, 1985; Brouwer and Singh, 1983; Factor and Kooser, 1981; Kass and Jenkins, 1986; Munby, 1982; Miller, 1984). However, few have looked at the full spectrum of knowledge and ways of knowing required of science students in the classroom setting (Roberts, 1980 and 1983; Jenkins, 1981; Kass and Jenkins, 1982). The present study has made an attempt to provide some of the empirical and conceptual background necessary to this multi-perspective view of science education.

A related development in science education has been to consider science-in-society issues in the classroom. However, the approaches taken by teachers have been individual and guarded. Many films and video tapes now exist that cover science-in-society issues (e.g., "Ascent of Man", "Connections", and "Renewable Society"). These are often shown to people in the classroom setting, but a starting structure is generally missing for teachers who are afraid to tackle these issues. Most science teachers are also unsure of where they should leave off and where the social studies, art, electronics, automotive, or computing science teacher should take over. The Author Group (1986) started with Aikenhead's and Flemming's (1975) classification of seven ways of knowing and revised and reapplied this list to include a series of twelve perspectives on science-in-society issues. The ways of knowing identified by Aikenhead (1980) are artistic, political, philosophical, economic, technological, religious, and scientific. The perspectives identified by The Author Group include aesthetic, ecological, economic, emotional, ethical, legal, militaristic, mystical, political, scientific, social, and technological. This list of perspectives has been used with students to classify perspectives taken on such science and technology in society issues as acid rain, nuclear power, and alternative energies. The goal of this approach is to have students (people) take and demand a multiperspective approach to problem solving of issues. The multiperspective, multi-knowledge-form, multi-emphasis, and multi-epistemological approaches advocated by this researcher make the research reported herein consciously and explicitly value laden in that direction.

The description of any part of the educational system must by its nature be complex, but that should not deter the educational community from trying to describe and understand this interesting human activity. The goal in such a study should be to make the educational community more conscious of the breadth and depth of the types of subject matter content and contexts presented within classrooms. This consciousness should provide evidence of what we seem to value more and what we seem to value less. If the analysis provides evidence to support the contention that the goals and objectives are being attended to, then the educational community can feel satisfied with its goals and objectives. However, an increased consciousness of most human activities usually provides some suprises and some reasons for action.

The debate over the content and contexts that should be provided within science curricula has lacked structure, perhaps because of the strong individual initiatives on behalf of singular curriculum emphases. Structure has been developed to describe what is meant by a nature of science or a process skill or a scientific content emphasis. A descriptive structure as to what knowledge forms comprise a balanced science curriculum seems to be needed at the present time. In the present study it is proposed that a classification scheme be developed within the context of a particular set of chemistry textbook materials to classify the kinds of knowledge given to people, the ways of knowing required of people, the contexts provided, and the epistemologies and curricular emphases employed.

C. Personal Ground

Since constructs like the classification system developed and tested herein are seen by an increasing number of philosophers of science as being theory and value laden, my personal ground is presented to keep the conceptual and value oriented background of the researcher "up front". The context of the study is also firmly set in the context of my professional and business pursuits. There is an overlapping of influence among my involvements in research, teaching, authoring, and publishing.

My interest in the epistemological analysis of knowledge presented in science education textbooks stems from my work as a teacher-author of chemistry and physics textbooks. I worked as an author and editor of the <u>ALCHEM</u> (see Appendix B for a description) chemistry curriculum materials for the eleven year period from 1973 to 1984. During this period of time the teacher authors of the ALCHEM materials attempted to integrate applied and descriptive chemistry contexts into "theoretical" chemistry content. The contexts were integrated in an ad hoc way into the examples, exercises, laboratory activities, and demonstrations within the ALCHEM textbooks. The idea was that every question within the curriculum materials should have an applied or descriptive chemistry context. The content of the course was not changed and the academic flavor of the curriculum was maintained. The contexts were essentially "added on".

My authoring efforts also included writing applied electives to complement the ALCHEM core materials. I was involved in writing the electives titled The Athabasca Tar Sands, Ethylene and its Derivatives, and Nuclear Chemistry. ALCHEM elective units that I edited were Analytical Chemistry, Foods and their Analogs, and Metallurgy and Corrosion. The difference between the core ALCHEM 10, ALCHEM 20 and ALCHEM 30 materials and the elective units was that the core materials were structured around the content line and contextual material was incorporated on an ad hoc basis, while the electives were structured around the context line and content was brought in as appropriate. This experience had a definite part in shaping the integrative, multi-perspective approach to textbook writing and research that I currently value. I found classroom evidence that pedagogically efficient and motivating ways of presenting content and context simultaneously are available. This evidence has sustained The Author Group and its individual members in their science education pursuits.

Even during the ALCHEM years the textual materials were still far behind the conceptualization of the authors. Although the topics for the elective units were chosen on the basis of interest and social importance, the treatment of science-in-society issues was absent from the ALCHEM materials. Only in the very late stages of development of the continued revision of the ALCHEM materials was any explicit attention given, for example, to the nature of science.

During the early 1980's the other ALCHEM teacher authors and I incorporated as The Author Group (ALCHEM), Inc. and started preparing for the writing of a new chemistry textbook (**STSC Chemistry: Science, Technology, Society and Communication Chemistry)** "from scratch". The authors felt that ALCHEM "had been revised to death"-a new start was needed. The authors started reading and trying ideas in the area of what was later to become STS science education. The combination of university work, writing sabbaticals and author group seminars led to the conceptualization of a nature of science emphasis for high school chemistry education. Later the authors matched each unit of work in the Alberta chemistry curriculum to an STS emphasis. Writing of the **STSC Chemistry** material began in the summer of 1984. At this time the nature of science emphasis had been fairly well outlined by The Author Group but the technological and societal emphases lagged behind. The discussion papers written as part of the Science Council of Canada science education study were used to gain some commonality of language and concepts.

I was working on a Ph.D. in curriculum during this time and doing considerable reading in the area of nature of science. My emphasis was on finding pedagogic ways of introducing to students the epistemology of scientific, technological and societal knowledge and ways of knowing. The use of scientific language in the classroom, science magazines, films, videos, oral scientific presentations, and textbooks became a focus of research for me during this time. Any ideas which seemed worthwhile were quickly tried out in my classroom.

During 1980, besides attending university on a Ph.D. program, I completed my share of the writing and editing of a solar education elective textbook for Grade 11 physics. This provided me with another opportunity to consolidate my belief that a science and technology in society context could be integrated with academic science content. Energy Mines and Resources Canada contracted The Author Group in 1985 to complete a computer program and curriculum resources project to simulate the design of a low-energy, passive-solar home (LEPSH). This project also allowed me to develop a better concept of Canadian context. The modern LEPSH is a Canadian invention containing Canadian technology; i.e., double wall construction, Larsen trusses, air-to-air heat exchangers, high efficiency stoves and furnaces, and air tight construction. Science, technology, and society were an automatic part of the everyday discussions and activities of the students. For example, students were asked to classify perspectives on the issue of alternative energies.

All of these curricular involvements strengthened my belief in the ~~STS~~ science movement. However, as I looked around at examples of STS science education I was discouraged to see the narrowness of the approaches being taken. Either science or technology or social issues were focused upon and the closer the textbook or course was to being STS, the less academic was the content line. Balance became a new catch word in science education, but again balance was often narrowly defined as balanced content (either equal amounts of chemistry, physics and biology in a course or equal amounts of science, math, english and social studies in a curriculum). Balance to me (like Roberts, 1983) meant a balance of content and context, a balance of curriculum emphases, and a balance of curriculum interests.

Over and over the pendulum of education interests swings. It seemed to me that STS science was the opportunity of a lifetime (maybe several lifetimes) to finally put together what we have learned from all of our pendulum swinging. Scientific and technological process skills, environmental science, the nature of science, science-in-society issues, applied science, modern science, academic science, descriptive science and any other emphasis can be brought together by STS science. It was my feeling that this opportunity must not be lost, and it is this feeling that still motivates me in my authoring and research.

My research interests are primarily empirical and practical. This study began with a paper I wrote for a plenary session at the Sixth International Conference on Chemical Education at the University of Maryland in 1981. The paper was titled, "Custom Tailoring the Chemistry Curriculum to the Culture". The point of view presented in the paper was reflected by the subtitle-"A Classification of Chemistry Education Subcultures". This classification of science education values was revised many times following 1981 and grouped in a variety of ways until the STS concept came on the science education scene. The STS framework seemed to be a natural set of emphases for grouping these categories. The next step was testing the classification scheme against what is written, sentence by sentence, in science textbooks. This testing process is what this study is about.

The testing was done on the ALCHEM and **STSC Chemistry** materials. The dialectic relationship, between the evolution of the **STSC Chemistry** materials and the evolution of this research to describe STS science education, has been mutually beneficial. The research has helped guide the **STSC Chemistry** writing and the writing has helped guide the research—consciously and with purpose.

D. Design of the Study

The design of the study is similar to that developed by Roberts and Russell (1975) and described by Mahung (1980) as conceptual analysis. Conceptual analysis involves three stages. The identification and conceptualization of a theoretical perspective (or systematic conceptualization) to guide the study is the first stage. The development and testing of an analytical framework is the second stage, and the application of the analytical framework is the third stage.

The nine stages of the current study as presented in Table 1.1 can be subsumed within the three stages of conceptual analysis. In Stage 1, the current study identifies five theoretical perspectives to guide the study. During Stages 2-9 an analytical framework called the Taxonomy of Curricular Discourse is developed and tested. The theoretical perspectives are used to establish criteria against which the analytical framework is tested and developed. The Taxonomy of Curricular Discourse is applied to the analytical classification of chemistry textbook discourse for illustrative, testing, and evaluation purposes.

The design of this study was influenced by the continuing teacher-author professional life of the researcher and by the writings of Schwab. A study was sought that could be classified in Schwab's terms as a "deliberative enquiry" or "practical enquiry", grounded within the real-life context of an evolving curriculum project. The researcher sought a study that would reflect a personal commitment to uncovering a multi-perspective view of curriculum. As a student of the philosophy of knowledge and as a professional in the field of pedagogy, a union of these interests was sought. Although the study itself had to remain scholarly, there were concomitant objectives for the study which were firmly grounded in the practical, i.e., the writing of a chemistry textbook.

> The method of the practical (called "deliberation" in the loose way that we call theoretic methods "inductions") is, then, not at all a linear affair proceeding step-by-step, but rather a complex, fluid, transactional discipline . . . . (Schwab, 1970: 291)

This study includes elements of the practical described by Schwab, e.g., the evolution of the classification system described in Chapter 4. The report gives the study an appearance of being linear, but, in fact, the study was not as linear as the list of stages in Table 1.1 might suggest. The study promoted an intense <u>dialectic</u> relationship between the scholarly rigor of the research context and the practical of the classroom context. A complex deliberative process was followed in both an explicit and an implicit sense with the ultimate goal of informing practice.

The study involved a nine-stage development and evaluation of a taxonomic system for classifying knowledge forms and curricular emphases found in chemistry education textbook discourse. During each stage of the study the current classification system was tested conceptually and empirically for its completeness and fit. The criteria for the testing came in the form of using the evolving taxonomy to classify textbook discourse sentence by sentence. If the taxonomic categories as conceptualized were not supported by the evidence, the taxonomy was usually changed in the middle of that stage of testing. Due to the complexity of the classification system and the variety of tests to which it was subjected, the criteria for making additions and deletions are pluralistic. Conceptual and empirical criteria from the research study are mixed with the same kinds of criteria from the practical perspective of the **STSC Chemistry** project. This dialectic relationship between the research project and the practical art of textbook authoring is purposeful and powerful but very difficult to communicate as part of a formal research design.

Due to the continued changes in the taxonomy, the data generated may not accurately describe each unit of textbook discourse in relation to the "final" evolving Taxonomy of Curricular Discourse. The study was more designed to develop a classification system that could be used concurrently during the writing of the **STSC Chemistry** textbook and pedagogic tool for students and the researcher's use of epistemology as a research tool for this study gave even greater mutuality to the dialectic relationship between the authors and the researcher.

Although the relationship between the author group and the research is difficult to describe as part of a research design, the stages of the research can be tied directly to the authors' textbook products. The stages of the study (described in detail in Chapter 3) are presented in Table 1.1. The nature of the interplay between the conceptual and the empirical aspects of the study could be described as dialectic. An overall view of the study may be achieved by thinking of the study as a cyclic progression from the conceptualization of the classification system through a series of empirical tests to the final (for the current study) reconceptualization of the taxonomic system. The taxonomic system had a life cycle similar to the life cycle of a scientific theory, law or generalization.

The fundamental philosophical and pedagogical orientation of the researcher influenced the methodology of the study and the results sought. The researcher felt that epistemological knowledge in curriculum discourse is essential to directly informing students about the origins and nature of knowledge. More indirectly, teachers and authors need to be informed about what epistemology tells them about the nature of curricular discourse. Epistemology also influenced the writing of this research report. The thesis itself is used as a vehicle to present the origin and nature of the knowledge developed during the current research study.

Table 1.1
The Stages of the Research Study Resulting in the Taxonomy of Curricular Discourse

Stage	Development and Evaluation Activity
Stage 1.	identifying the theoretical perspectives for guiding the development of the analytical framework, and conceptualizing the first draft of the taxonomy
Stage 2.	evaluating the initial taxonomy by classifying the discourse in the 1982 edition of ALCHEM Unit L (Grade 12 thermochemistry)
Stage 3.	evaluating Draft 2 of the taxonomy by classifying the discourse in the 1975 edition of ALCHEM Unit M (Grade 12, thermochemistry)
Stage 4.	evaluating Draft 3 of the taxonomy by classifying the discourse in the 1984 edition of STSC **Chemistry** Unit A (Grade 10, periodic laws and atomic theories)
Stage 5.	evaluating Draft 4 of the taxonomy by classifying the discourse in the 1984 edition of STSC **Chemistry** Unit B (Grade 10, communicating and predicting chemical formulas)
Stage 6.	evaluating Draft 5 of the taxonomy by classifying the discourse in the 1984 edition of STSC **Chemistry** Unit C (Grade 10, communicating and predicting chemical reactions)
Stage 7.	evaluating Draft 6 of the taxonomy by classifying the discourse in the 1984 edition of STSC **Chemistry** Unit D (Grade 10, communicating and predicting stoichiometric reactions)
Stage 8.	conceptualizing the categories of the 22 x 3 taxonomy by writing definitions and examples for each of the 66 categories
Stage 9.	gathering evidence of the validity of the taxonomy in an attempt to refine the conceptual and operational definitions of the curricular emphases and knowledge forms identified over the course of the research

D1. Delimitations

Of the four commonplaces of educational research identified and described by Schwab (1974)—the learner, the teacher, the subject matter, and the milieu, the one studied in this research study is subject matter. The subject matter is not, however, studied in terms of topics (e.g., departments of education) concepts and subconcepts (e.g., Gagne, 1967), logic (e.g., Inhelder and Piaget, 1958) meaningfulness (e.g., Ausubel, 1970), or hidden curriculum (e.g., Apple, 1974). The subject matter is analyzed and classified in this study in terms of its epistemological structure.

In order to make this study manageable, its scope was restricted to the contexts enumerated below. These restrictions are consistent with the professional interests and activities of the researcher, i.e., teaching, authoring, and publishing in the chemistry education field in Alberta, Canada.

1. The curriculum knowledge studied was delimited to science education, and chemistry education in particular. This is the professional area of interest and expertise of the researcher.

2. The science curriculum was delimited to high school chemistry education in Alberta—a provincial minister of education (diploma) examination course. A review of the literature and research in the area of study indicated that STS researchers and authors were shying away from the integration of STS contexts into academic content. This research was delimited so as to focus toward this neglected area of research and development.

3. The curriculum and instruction components of high school chemistry in Alberta were delimited to student textual material. The researcher was involved in writing textual material and aware that basic research on subject matter is lacking in the field of science education.

4. The textual material was delimited to the 1982 and 1975 ALCHEM 30 (Grade 12) Energy units and the 1984 **STSC Chemistry 10** student materials. The research results were also used within the context of the textbook writing activity by The Author Group. This use adds a concomitant research-practice dialectic context to the study.

5. The study was restricted to the evaluation of The STSC Taxonomy* as it was developed. The curriculum materials on which it was tested were not themselves evaluated within the formal context of this study.

6. The classification system developed during the study should not be used to classify people on the basis of their science education talk. The values of people and of textbook authors may not be explicitly reflected in what is said or written. The STSC Taxonomy can only be applied to determining the relative success of textbook authors in achieving stated objectives or goals (i.e., congruence testing).

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* "The STSC Taxonomy" is terminology used in the context of the evolving forms of the Taxonomy of Curricular Discourse. Its purpose is to keep in view the components of the curriculum emphasis dimension of the analytical framework.

7. There was no attempt made within this research study to measure student outcomes, to analyze student responses to the textual discourse, or to analyze classroom discourse. These aspects, although important, were left for future research.

8. There was no attempt made to analyze the sequencing of knowledge forms, procedural knowledge and questions within the sentence to sentence discourse of the textual material. It is hypothesized that sequencing characteristics could be important for learning. This, however, is an area left for future research.

9. No attempt was made to analyze or conceptualize the relationship among various curriculum emphases, knowledge forms, ways of knowing, and epistemological approaches. Recommendations for further research on these topics are presented in Chapter 6.

Each of the areas of research mentioned above that are not covered by the present study is richly deserving of study. It was felt that the outcome of the research described herein would be a necessary first step and beneficial to subsequently pursuing, for example, research questions on classroom discourse or on the relationship between the way of knowing intended and the way of knowing used by students when responding to textbook questions.

D2. Assumptions

The following assumptions were made during the course of the development of the taxonomy.

1. The textual material chosen for analysis would display sufficient diversity to fill the open-ended array of knowledge forms, including ways of knowing (i.e., the number of empty cells within applications of the taxonomy would not be excessive).

2. The frequency counts of various knowledge forms are not equated with importance of knowledge forms. For example, if a cell of the classification system matrix receives an null frequency during the analysis of textbook discourse, then this knowledge form will not automatically be dropped from the classification system.

D3. Limitations

Any use of the results from this study are subject to the limitations as described below. Schwab (1970: 296) describes limitations as weaknesses of the "theory" that are resolved in practice by employing a mode of operation he calls "the eclectic". "The weaknesses of theory arise from two sources: the inevitable incompleteness of the subject matters of theories and the partiality of view [taken by users]." In this study observed weaknesses were, in part, resolved by employing an eclectic of theoretical perspectives. Without the use of five theoretical perspectives to eclectically guide the evolution of the taxonomy, the classification system would have had many more weaknesses. To counter Schwab's sources of weakness, attempts were made to provide a completeness of breadth if not depth to the taxonomy and the partiality of view was deliberately a partiality to a multi-perspective view of chemistry education subject matter. Although limitations are often difficult to see from close-up, the following is a partial list of recognized limitations of the research results.

1. The taxonomic system developed can not be used to determine the success of a textbook in terms of its ability to communicate well. For example, if the sequencing and logic of the presentation is not adequate, then people will have difficulty learning from the textual material. To write a science education textbook that also is pedagogically efficient requires more than a classification system.

2. Before the the Taxonomy of Curricular Discourse can be used to assist in the sequencing of sentences within textbook discourse, further study will be needed to determine the interaction of the various categories, subcategories and dimensions of knowledge identified by the current study.

3. A general limitation of the research product—the Taxonomy of—is that at this point it is still largely "pre-theoretic", in the Kuhnian sense. The classification system was empirically developed to describe science education textbook discourse. An empirically developed classification system should not be used to explain a science education event without first developing a theoretical framework for such phenomena.

4. The usefulness of the taxonomy developed will not necessarily be proportional to the ability of the taxonomy to classify each and every sample of curricular discourse encountered "correctly", i.e., without argument. The usefulness of the taxonomy will be

reflected in its general articulation of new concepts and in its creation of a language by which to communicate these concepts.

E. Conceptual Framework for the Study

The current study makes a thrust at describing the knowledge components of a science, technology, and society chemistry education textbook. An epistemological description of chemistry textbook discourse is generalized in the form of a classification system. The knowledge components of the system were interactively developed and tested during six stages of the study. The empirical testing and the concurrent conceptual evaluation were conducted in dialectic fashion during the analysis of six chapters from two chemistry education textbooks. The framework for the description was a classification system employing categories which, for the most part, had been previously defined in the educational literature. In some cases the definitions of the categories (e.g., scientific process skills) had to be restricted from their general meaning. In other cases (e.g., pedagogical reference) a category was created for which no reference was available in the literature. The taxonomy of textbook knowledge developed in this study defined a variety of knowledge forms and should help to establish the means for systematically manipulating and controlling subject matter variables.

Knowledge may be classified in terms of the way of knowing used to produce that knowledge. One piece of knowledge may be produced from several different ways of knowing (Olson, 1972). The teacher and the student have alternate ways of knowing available to them to produce knowledge. Often only one way of knowing is made explicit while other ways of knowing are not mentioned or may be actively suppressed.

In Figure 1.1 four ways of producing one piece of knowledge are illustrated. The same resultant knowledge could be obtained by employing a theoretical, empirical, or pedagogic way of knowing. For example, the chemical formula for water may be determined by several alternative ways of knowing. The question being answered in Figure 1.1 is, "What is the chemical formula for water?"

The chemical formula for water may be determined theoretically (from Lewis Molecular Theory), empirically (from Hoffman's Apparatus), empirically (from a law of combining masses), and/or pedagogically (from referring to a reference book or memorizing). People using a school textbook may not be told which way of knowing is required of them. A question often asked by students is, "How am I supposed to know that?". Usually the teacher tacitly makes the judgement as to which way of knowing is appropriate without letting the student in on how that decision was made. The teacher chooses from among the alternative ways of knowing by delimiting the choices to one. However, if the student knows the choices available or the teacher tells the student which choices are available, an epistemological filter has become available. The procedural knowledge becomes focal rather than tacit. The more conscious the student is of the choices available, the more explicit the epistemological filter becomes. The act of consciously choosing between the alternative ways of knowing available is evidence of employing an epistemological way of knowing. This pedagogic act is the usual beginning of the study of epistemology for students.

The original purpose of this research study was to infer the epistemological preferences of textbook authors from the discourse in the textbook they wrote. But it was soon realized that before an investigation of what alternative ways of knowing are filtered by various participants in chemistry education can be done, a study of what ways of knowing are available must be completed. As a result the present study concentrates on describing and classifying the ways of knowing portrayed in the discourse in two chemistry textbooks.

The framework for the present study involves a set of parallel contexts for testing the developing classification system. The contexts for testing the classification system are:

1. classifying the discourse in six units of the ALCHEM and STSC **Chemistry** textbooks, sentence by sentence
2. writing and revising the **STSC Chemistry** materials
3. teaching the **STSC Chemistry** materials
4. reconceptualizing the classification system based upon the above experiences

The researcher was doing this research at the same time as he was co-authoring and teaching the **STSC Chemistry** materials. However, the formal results reported here are restricted to testing and revising the Taxonomy of Curricular Discourse in the context of textbook analysis.

The classification and analysis of discourse has been restricted in past research to classifying objective statements and complete textbooks (Roberts, 1982), policy statements (Orpwood, 1983), paragraphs and complete textbooks (Factor and Kooser, 1981), classroom discourse (Munby, 1982; Benson, 1985), achievement-objectives congruence (IEA Study, 1986), textbook-objectives congruence (EPIE, 1971), and textbook-objectives-emphases congruence (Science Council Study, 1985). The present study is restricted to the phrase by phrase description and classification of textbook discourse. The analysis of the textbook discourse is very specific—the unit of analysis is the sentence or part thereof. The small unit of analysis was found necessary because of the rapid changes from one knowledge form to another found within textbook paragraphs.

Of the four commonplaces of education described by Schwab (1964), this study concentrates on the subject matter. Schwab declared that research on subject matter is the most neglected of the four commonplaces. There are many perspectives that can be taken on subject matter and these perspectives can be translated into different research studies. In the current study kinds of knowledge, ways of knowing and curriculum emphases are described and classified. The results from the study are seen by the researcher as being fundamental to the further study of chemistry education subject matter.

F. Significance of the Study

The placement of this study into the field of science education research would likely be at the fundamental research level. The study started at a "micro" level—the sentence by sentence classification of chemistry textbook discourse. The study of the fundamental aspects of knowledge presented as textbook subject matter seems central to the study and use of subject matter in general. Subject matter is often used in educational research as a controlled variable. The difficulty has often been that the subject matter is inadequately described for purposes of generalizability or further research. Previous epistemological research had been at a "macro" level; e.g., paragraph counts by Factor and Kooser (1981). The researcher felt that before further subject matter research could be done on, for example, the sequencing of sentences in textbook discourse or on epistemological approaches or normative perspectives presented in subject matter textbooks, a description and classification of knowledge forms was required.

A second area of significance for this study is in the realm of textbook development and evaluation. The description of the various kinds of knowledge found in chemistry textbooks has already benefited the writing of one textbook, **STSC Chemistry**. The kinds of knowledge could also be nested to represent currently popular curriculum emphases. One such nesting of kinds of knowledge into curriculum emphases was done in this study. The curriculum emphases described herein are conceptualized by science, technology and society (STS) plus communication (C) and pedagogy (P) emphases—STSCP emphases. The method of defining popular emphases such as STS science by knowledge form subcategories should assist curriculum designers and textbook authors in the future, regardless of the particular current emphases being pursued. The Taxonomy of Curricular Discourse developed herein is not content specific, nor should it be. It is not concept and content analysis in the usual sense of breaking the concept into subconcepts. The taxonomy developed classifies concepts at a more general epistemological level.

A third significant contribution which may result from this study is the heightening of consciousness of science educators to the ways of knowing science and about science available to students. The explicit inclusion of ways of knowing and of epistemological categories of knowledge in science textbooks is relatively new. Whether curriculum emphases can be categorized by epistemological preferences, whether epistemological content exists over a range of curriculum emphases, and whether resultant knowledge, procedural knowledge, and required action categories are useful for describing textbook discourse are questions addressed by this study. Epistemology is only one of the five theoretical perspectives used to guide this study, but epistemology is the most pervasive perspective throughout the study. An attempt was made to make "epistemology" accessible through the language of the practical, not just through the language of philosophy.

G. The Organization of the Dissertation

This dissertation has been organized into six chapters. The main body of the dissertation deals with the development and testing of a system for classifying kinds of knowledge, ways of knowing, and curriculum emphases found by the sentence by sentence classification of chemistry textbooks. There is, however, a second parallel context for the researcher—the concurrent writing of the **STSC Chemistry** materials. Although the classification was not content specific, examples of epistemological content were necessary to operationally define some categories. These examples came from the piloting of the **STSC Chemistry** textbook. The influence of this concurrent writing activity on the development of the classification system and vice versa will be reported in a separate section of Chapter 4. The report focuses on the development and testing of the Taxonomy of Curricular Discourse in the context of the classification of textbook discourse. The taxonomy is tested against criteria established by the five theoretical perspectives used to guide the study.

In Chapter 1 the problem is presented and set within an educational research context and within a professional context for the researcher. The personal ground section of Chapter 1 includes a brief history and description of the two chemistry textbook projects which provide the context for the work. The design of the research is summarized as one of conceptual analysis, and the delimitations, assumptions and limitations are then presented to further define the area of study. Justification for the need for the study is provided at the end of Chapter 1 in the two sections dealing with the conceptual framework for and significance of the study.

A survey of selected literature is presented in Chapter 2 to provide the conceptual basis for the study. The literature surveyed is categorized into literature relevant as background to the problem (i.e., kinds of knowledge found in textbooks), and to the methodology (i.e., the classification of textbook discourse), and as research on science, technology, and society (STS) science education and textbook discourse. The review of the literature is also specific to the five theoretical perspectives used to guide the development of the taxonomy: epistemology, normative perspectives, curriculum emphases, STS science education, and practical inquiry.

The detailed design of the study and the procedures that were followed appear in Chapter 3. The instruments used to classify the six chapters of discourse from two chemistry textbooks are presented and described. The rules used to classify the textbook discourse, sentence by sentence, are summarized and reference is made to the classification instruments presented in Appendix C. The methods used for data collection and analysis are described at the end of Chapter 3.

Chapter 4 presents the evolution of the Taxonomy of Curricular Discourse through the nine stages of the study. Stage 1 resulted in the conceptualization of the first draft of the Taxonomy of Curricular Discourse and the identification of the five theoretical perspectives used to guide the evolution of the taxonomy. The results of Stages 2-7 are presented as the empirical data obtained from classifying the six units (chapters) of textbook discourse, sentence by sentence. The criteria for evaluating the taxonomy after each stage are discussed and revisions to the Taxonomy are justified on the basis of these criteria. The criteria were derived from the five theoretical perspectives identified in Stage 1.

Chapter 5 presents the results of the Stage 8 and Stage 9 procedures. Stage 8 involved the development of formal rules of use of the Taxonomy of Curricular Discourse, along with a description of and two examples for each of the 66 categories in the 22 x 3 taxonomic matrix. The results of the tests of inter-rater agreement and content validity performed in Stage 9 by the six expert judges are also presented in Chapter 5. The "final" form of the Taxonomy of Curricular Discourse is presented at the end of Chapter 5. The descriptions and examples developed in Stage 8 were revised as a result of the judges comments in Stage 9. A current status report is also presented for all five curriculum emphases and twenty-two knowledge-forms.

The final chapter, Chapter 6, summarizes the study and the major findings and presents recommendations for further research and application. This chapter includes a critique of the taxonomy and how it might be used by others for various purposes. The strengths and limitations of The Taxonomy as currently perceived are presented.

A series of appendices appear at the end of the dissertation. Appendix A presents the Stage 1 conceptualization papers. Appendix B presents descriptions of the ALCHEM and STSC Chemistry projects and textual materials. Internal documents from the STSC Chemistry project are also presented in Appendix B. Presented in Appendix C are the research instruments including sample tally sheets from stages 2-7, and inter-rater agreement and content validity instruments. Appendix D presents adjunctive results from the current study.

Chapter 2: Conceptual Basis of the Study

A. Introduction

Chapter 2 presents a review of the literature that serves to outline the conceptual basis for the study. The review informs Question 1 of the study— an identification of theoretical perspectives to guide the study and to provide criteria for judging the developing taxonomy of curricular discourse. The complexity and diversity of a taxonomy of curricular discourse requires a wide range of conceptual arguments. These conceptual arguments initially formed the basis for developing the taxonomy and now form the basis or understanding the current study.

The literature reviewed is categorized conceptually and chronologically around the study methodology, a procedure called conceptual analysis (Roberts and Russell, 1975; Mahung, 1980). Conceptual analysis involves three phases—the identification of guiding theoretical perspectives (or systematic conceptualizations), the development of an analytical framework, and the application of the framework to a curriculum or instruction segment. The literature review follows this same sequential organization. The review of the literature includes a description and critique of the literature in each grouping plus an indication of how the selected literature applies to the current study. The first group of literature reviewed concerns the conceptual analysis methodology. Then the literature pertaining to each of the five theoretical perspectives used to guide the study is reviewed. The theoretical perspectives are organized from the most general to the most specific as displayed eventually in The STSC Taxonomy which has been developed. This order does not necessarily indicate the order of importance of the theoretical perspectives as eventually determined in the results of the study. The order of the five theoretical perspectives within this literature review is curriculum emphases, normative perspectives, epistemology, STS science education, and practical inquiry.

Following the review of theoretical perspectives is a review of the literature on analytical frameworks specific to this study (i.e., taxonomic frameworks of curriculum). A section on content analysis is then followed by a review of the relevant literature on reliability and validity. Although reliability and validity were ongoing concerns during the evolution of the analytical framework, the formal tests of inter-rater agreement and content validity were not completed until Stage 9 of the study.

The general purpose of this study was to describe and classify discourse in science education textbooks. The evaluation of the descriptions and classifications involves both empirical and conceptual criteria. The conceptual criteria for evaluating the STSC Taxonomy that was developed in the study are provided in the review of the literature which follows.

B. Conceptual Analysis

Conceptual and philosophical analysis of curriculum and textbooks has been advocated by, for example, Roberts and Russell (1975), Kilbourn (1971), and Mahung (1975). Mahung (1980) suggests conceptual analysis as an alternative to the measurement of learning outcomes for evaluating curricula. The methodology of conceptual analysis involves three steps. The first step is to search for a "theoretical perspective" in one or more of the four commonplaces of education—the subject matter, the learner, the teacher, and the milieu. Philosophical analysis may be a source of these theoretical perspectives or systematic conceptualizations (e.g., Schwab's conceptualization of the nature of scientific inquiry has been used by Mahung (1975)). In the present study, for example, the theoretical perspective concentrates on the subject matter—kinds of knowledge and ways of knowing—displayed in textbook discourse. The current theoretical perspective is however, an eclectic of related perspectives—normative perspectives (Kass and Jenkins, 1986), balance in setting goals for school science programs (Roberts, 1983), STS science programs (Bybee, 1985; Aikenhead, 1986), epistemology as content in school science discourse (Gowin, 1978; Munby, 1982; Nadeau and Desautels, 1984), and practical STS chemistry education textbook writing. These perspectives translate into an epistemological look at kinds of knowledge and ways of knowing found in "balanced" STS chemistry textbook discourse. This eclectic of theoretical perspectives is appropriate for the theory-practice interface within which this study is set. The analytical framework developing out of this theoretical perspective was both pragmatic and flexible—reflecting the last element of the eclectic, the practical perspective. For example, the taxonomic framework developed in the present study is capable of being collapsed or expanded to match the practical purpose of the user.

The second step of conceptual analysis as outlined by Mahung is the development of an "analytical framework"—a scheme for analyzing the curriculum or instruction. In the studies mentioned above the analytical framework is a set of questions or statements derived from a theoretical perspective. The methodology involves studying the theoretical perspectives and isolating the structure (e.g., substantive and syntactical) of a curriculum to formulate the framework itself. In the case of the present study, a series of two dimensional frameworks has evolved in the form of a nested taxonomic classification of knowledge forms and accompanying K-KW-W (epistemological) triads. The two dimensions to the framework and the nesting are necessary because of the eclectic of theoretical perspectives. Knowledge forms were nested into STS emphases (an integration of Bybee's STS science education concept and Roberts' curriculum emphases concept) to take care of the STS theoretical perspective; knowledge forms were categorized in terms of the normative perspectives of Kass and Jenkins (e.g., theoretical, empirical, process and epistemology); epistemological content is used as the criterion to create the final list of curriculum emphases; and a practical perspective is used to create and retain some of the knowledge form categories. In this way the present study qualifies for the label of conceptual analysis—an eclectic of theoretical perspectives leading to the formation of an analytical framework.

The complexity of the textbook discourse analyzed in this study requires a multi-perspective view of curriculum. Practical curricula are most often an eclectic of ideas and values. A description of such curricula requires the identification of the many perspectives displayed in the corresponding content outlines and textbooks. The description of conceptual analysis by Mahung is appropriate for studying a small component of curriculum but is not appropriate for analyzing knowledge forms in a complete textbook. Textbooks reflect a plurality of perspectives because of the normative stands of curriculum developers, textbook authors and publishers' marketing departments. A single theoretical perspective (or systematic conceptualization) was not appropriate for a study that was investigating the discourse produced from such varied views. A multi-perspective approach was necessary in order to try and capture the totality of knowledge forms found in textual discourse. To be widely accepted the taxonomy developed had to be judged using a variety of criteria derived from different perspectives.

The third stage of conceptual analysis is the application of the analytical framework, for example, to evaluating curriculum materials. However, both in Mahung's case and in the present study, the application of the analytical framework is for purposes of evaluating the framework itself. "For this reason the segments of material selected for analysis were chosen primarily for their relevance to the various questions comprising the analytical framework" (Mahung, 1980: 109). The same holds true for the present research. The complete discourse in the **STSC Chemistry** 10 student textbook, with claims of science, technology, society, communication, and pédagogy emphases (The Author Group, 1986), was classified, sentence by sentence, in the current study. It was felt that the **STSC Chemistry** textual discourse is well suited to testing an analytic framework that professes to describe discourse that reflects a plurality of knowledge forms. An eventual application of the STSC Taxonomy developed as an analytical framework in this study might be for the evaluation of textbooks. In the current context the application of the analytical framework in this study was for the sole formal purpose of testing the content validity of the framework.

Overall the conceptual analysis methodology seems to fit the present study. However, this study was not a linear application of the three stages of conceptual analysis. The practical evaluation of the analytical framework (i.e., the taxonomy of knowledge forms) could best be described as a continuing dialectic among Mahung's three stages—the theoretical perspectives, the analytical framework, and the evidence gathered. The practical evaluation of the STSC Taxonomy was followed by a series of internal and external evaluations at later stages in the study.

C. Curriculum Emphases

Roberts and Orpwood (1980b) and Roberts (1982) characterized the various orientations taken by science educators as curriculum emphases and as aspects of scientific literacy. The seven curriculum emphases identified by Roberts are 1. everyday coping, 2. structure of science, 3. science, technology and decisions, 4. scientific skill development, 5. correct explanations, 6. self as explainer, and 7. solid foundation emphases. The intent is evident in the subtitle of Robert's 1983 discussion paper, "Towards balance in setting goals for school science programs". Roberts and Orpwood (1980: 12) describe curriculum emphases as "the pervasive overall curricular intentions" expressed explicitly in goals of education or perhaps implicitly in textbooks. The emphases could be employed "in sequence (though, by definition, not simultaneously)" (1983: 14). A curriculum emphasis would extend over a full unit of work several weeks in length.

Roberts also describes (1983: 24) other schemata for representing a composite view of scientific literacy. These schemata were all developed by completing historical reviews of the science education literature and policy documents. The reviews were completed for the indicated span of years by the following researchers—Gabel (from 1957 to 1976), Ogden (1918-72), Ogden and Jackson (1918-72), and Roberts (from 1900 to 1983). These schemata were obtained from a classification of curriculum objectives. However, Roberts and Orpwood have applied the concept of curriculum emphases to specific units of school work and even to individual lessons. The current study takes the application of curriculum emphases one step further and has created curriculum-emphases subcategories to classify knowledge forms found sentence by sentence in chemistry textbook discourse. Kaplan (1964: 53) sees this progression as typical of the evolution of classification systems which seek deeper similarities among objects.

Another classification of what might be called curriculum emphases is that of Eisner and Vallance (1974) who list five conceptions of curriculum which are portrayed in the general curriculum studies literature. They categorize the conceptions as 1. development of cognitive processes, 2. technology and/or technique, 3. self-actualization or consummatory experience, 4. social reconstruction-relevance, and 5. academic rationalism. Eisner and Vallance see these as "conflicting conceptions of the goals, content, and organization of curriculum" that manifest themselves in the "complexity of educational thought" (1974: 1). The intent of the schema is that of providing an analytic tool "to profile [the orientations in] an existing curriculum" (1974: 199). Although the Eisner and Vallance schema seems to successfully classify various movements in education regardless of subject matter, the classification is not seen by this researcher as being very useful, empirically or conceptually, for classifying textbook discourse. However, the schema is viewed as an example of an analytical framework that was developed by integrating several theoretical perspectives (systematic conceptualizations).

Factor and Kooser (1981) have analyzed college textbooks for chemistry non-majors for what they call value presuppositions. "In scientific texts there are explicit and also tacit normative assertions . . . [including] evaluative opinion as well as descriptive facts. . .. It is not at all obvious that texts carry moral messages or normative prejudices." (1981: 1) For the science and society textbooks, Factor and Kooser identify four approaches taken by the authors: 1. the truth and progress approach (belief in technological "fixes"), 2. the issues approach (scientific "fixes" of societal problems), 3. the naturalist approach (belief in natural "fixes"), and 4. the theory and puzzle approach (an employment of pedagogical "fixes"). Factor and Kooser categorize the approach taken by science textbook authors by analyzing the statements made explicitly or implicitly about scientific method, history of science, and technology. The second major textbook variable which they studied was the references within the texts to science and society issues. Any reference to such an issue was noted, and a frequency count allowed the researchers to broadly categorize the chemistry texts into science and society texts or skills and drills texts. There was no attempt made by Factor and Kooser to classify the epistemological preferences of the authors. The intent of the analysis appeared to be to "inform teachers about the explicit value judgements and tacit presuppositions which are part of their professional pedagogic life" (1981: 1). The action recommended by Factor and Kooser was the employment of case studies to "show the reality of science's growth and interaction with society" (1981: 45).

The Factor and Kooser study provided valuable evidence of value presuppositions held by textbook authors and displayed explicitly and implicitly in textbook discourse. However, the study did not provide detailed knowledge of the kinds of knowledge and ways of knowing presented within textbook discourse. Factor and Kooser, not unlike Roberts and Orpwood, classified inferred messages rather than observed knowledge forms. The current study attempts to accomplish the latter.

The Author Group has since 1981 used the concept of curriculum emphases to organize units of curricular work. Each unit or chapter of work in their **STSC Chemistry** textbook has been assigned a particular curriculum emphasis—science, technology, society, or communication (see Appendix B). Each unit includes content and context from all of the four curriculum emphases areas, but each unit has one particular curriculum emphasis. The STSC emphases are repeated every four units of work, and content on the nature of science, for example, is increased progressively from cycle to cycle. These authors claim that the use of curriculum emphases allows for a more systematic handling of epistemological and contextual content related to the nature of science, technology, society, and communication. From their experience they claim that the ad hoc presentation of this type of information in textbooks is not only pedagogically inefficient but also inhibits the development of concepts such as the nature of technology. The Author Group had previously written the ALCHEM chemistry textbooks which had used the ad hoc approach before writing the **STSC Chemistry** textbooks which used the curriculum emphases approach. Because of this systematic variation of curricular emphases in the writing, the STSC **Chemistry 10** textbook was used in this study as the major source of textbook discourse for classification.

At the time of writing this report (1987) Alberta Education is also using the concept of curriculum emphases to nest a list of aspects of scientific and technological literacy. Although they too are using specific STS curriculum emphases, it should be noted that the concept of curriculum emphases is not restricted to STS. If, for example, a different classification of curriculum emphases appears sometime in the future, the concept of curriculum emphases should survive the STS or any other era.

A summary of the curriculum classification schemata reviewed above is provided in Table 2.1. The STSC Taxonomy as developed in this study is provided for reference in the last column of Table 2.1. The comparison of the various schèmata is not entirely legitimate in that a different unit of curriculum is being classified in each. However, the comparison does reinforce the point that the available schemata were judged inadequate for sentence by sentence classification of textbook discourse during Phase 1 of this study. The criteria for making this judgement were derived from the five theoretical perspectives being described in this chapter. A fuller description of the empirical and conceptual evaluation of these schema is presented in Chapter 4 which deals with the evolution of The STSC Taxonomy.

Curriculum emphases, curriculum conceptions, and value presuppositions provide the present study with one of the theoretical

Table 2.1
A Review of Curricular Emphases

Jenkins (1981) (Epistemological Approaches)	Eisner and Vallance (1974) (Curriculum as)	Factor and Kooser (1981) (Approaches)	Roberts (1982) (Curricular Emphases)	Jenkins (1986) (STSCP)
1. Theoretical 2. Empirical 3. Process 4. Epistemological	1. Academic rationalism 2. Cognitive processes	1. Truth and process	1. Correct explanations 2. Scientific skill development 3. The structure of science	Science 1. Theoretical 2. Empirical$_E$ 3. Emp$_E$–The 4. Empirical$_L$ 5. Emp$_L$–The 6. Process 7. Epistemology
5. Applicational			4. Everyday coping	Technology 8. Technology 9. Empirical 10. Process 11. Epistemological
6. Parochial 7. Ecological 8. Reconstructional	3. Social reconstruction and relevance	2. Issues 3. Naturalist	5. Science, technology and decisions	Society 12. Societal 13. National 14. Historical 15. Ecological 16. Reconstructional 17. Epistemological
			θ	Communication 18. Communication 19. Epistemological
9. Pedagogical 10. Psychological	4. Technology 5. Consummatory experience	4. Theory and puzzle	6. Self as explainer 7. Solid foundation	Pedagogy 20. Purpose 21. Reference 22. Epistemological

perspectives used to guide the study and the development of an analytical framework for classifying and analyzing textbook discourse. The term favored in this study is curriculum emphases. Curriculum emphases is a term and concept that fits well with the STS science education concept and with the nesting of knowledge forms (within curriculum emphases). Since the knowledge forms classified in this study had their origins in the normative perspectives of Jenkins and Kass (1982 and 1986), and since knowledge forms were eventually nested in curriculum emphases, selected literature on normative perspectives is reviewed next. The integration of the concept of normative perspectives with the concepts of STS science education and curriculum is a major goal of the present study. The success of this attempt is reviewed in Chapter 6.

D. Normative Perspectives

Jenkins (1981) identifies nine classes of science education subcultures to illustrate the epistemological values of various interest groups that had been personally encountered during the development of the ALCHEM chemistry education project. The Jenkins paper is presented in Appendix A. These interest groups are portrayed as emphasizing particular kinds of knowledge. The kind of knowledge emphasized is not exclusive of others but it dominates the prime space of the textbooks and is the primary kind of knowledge tested.

The nine classes of knowledge identified by Jenkins were theoretical, empirical, applicational, process, pedagogical, reconstructional, existential, epistemological and parochial (national). A further refinement of the scheme was accomplished by Kass and Jenkins (1982 and 1986, see Appendix B), resulting in the initial set of knowledge forms that are employed in this study. At that point in time the knowledge form categories were designated as "normative perspectives on the nature of knowledge in science" (1982: 4). Kass and Jenkins suggest that a lesson which can be learned by science educators from Kuhn (1970) and Ravetz (1971) is that the subtle, yet powerful influences of human subjectivity and value orientations upon the creation of scientific knowledge may also apply equally well to curricular knowledge. They also emphasized that "context stripping" often accompanies the design of curriculum materials, leaving only an emphasis on logical and theoretical characteristics of the subject. An action component identified was that students should learn explicitly within the sanctions of official schooling that there are different varieties of scientific and technological knowledge and that different value perspectives on science and technology in society issues can be held.

A brief overview of some of the literature that is related to the initial list of knowledge forms employed within this study for classifying textbook discourse follows. Theoretical, empirical and process knowledge forms are illustrated by Bruner (1960) and Schwab (1962) in the conception of the phrases "structure of the discipline" and "scientific inquiry". Although Bruner and Schwab both meant to emphasize more than theoretical ways of knowing and theoretical knowledge, that interpretation of their views by members of the "theorist interest group" has carried over to the present time, some twenty years later. The intent of Schwab over the many years of his writings seems to continually come back to ideas of liberal education. An action that can be related to the writings of Schwab and Bruner was the development of the National Science Foundation (NSF) science courses—CHEM Study, PSSC Physics, and BSCS Biology. The result of these courses seem to be science educators whose epistemological preferences are either theoretical, empirical, and/or process knowledge. In chemistry education these textbooks modernized the content to include "theoretical" topics such as quantum mechanics, reaction kinetics, and chemical equilibrium. Descriptive and technological chemistry were "out" and theoretical and inquiry-oriented chemistry were "in".

The above group of epistemological preferences was initially referred to as an <u>academic</u> emphasis within the context of the present study (not unlike Eisner and Vallance's academic rationalism). This label was never adaquate (e.g., process skills were part of many nonacademic science courses) and was later dropped, but it did serve as an initial step in the nesting of knowledge forms into curriculum emphases. Schwab in particular appears to have envisaged something much wider in scope than an emphasis on theoretical, empirical and process knowledge, but the evidence seems to suggest the courses developed at the time of his writing tended to polarize the epistemological preferences of science educators rather than merging them.

Hughes (1975: 113) suggests that "teachers regard themselves as experts in academic chemistry and would ask if courses . . . for prospective nurses or engineers are really chemistry". Typically the academic proponents have been the most vocal and the most political group both from inside and outside the schools. Their major way of influencing the curriculum has been through tradition and training. The universities, as required, have a strong academic emphasis and science educators are a product of this environment. The academic emphasis group has also traditionally layed claim to the stamp of rigor or "the basics". This is reflected in the current Alberta Education diploma examinations at the end of Grade 12 which test theoretical, empirical and process knowledge exclusively.

The Author Group (1986) in writing the **STSC Chemistry** textbooks has identified six ways in which theoretical knowledge are communicated through theories, models, analogies, theoretical definitions, predictions from theory, and explanations from a theory. Students are required to know these ways in which theoretical knowledge is communicated as well as being required to classify scientific knowledge as empirical or theoretical. The definition of theoretical knowledge which The Author Group employs in their textbooks is different from the lay term that is often used. Any form of abstract knowledge or prediction regardless of whether the knowledge is empirical or theoretical is often referred to as theoretical in science education contexts. For example, a prediction from an empirical construct such as a law or generalization is often, in the researcher's experience, referred to as theoretical. The Author Group reports that the distinction between theoretical knowledge as "unobservables" and empirical knowledge as "observables" has been helpful in assisting student learning and understanding. Some research in this area might be fruitful in linking kinds of knowledge with ways of knowing and learning.

The preference for theoretical knowledge may have grown stronger in the last twenty years, but its companion empirical and process preferences within the original Jenkins and Kass academic emphasis have not fared as well. A fragment of the empirical approach, that is clothed in increased laboratory experience and an increased awareness of a Piagetian-pedagogic inter-relationship with concrete learning situations, appears to have gained some ground in science classrooms. However, if the many papers presented at the 1978 McMaster University, International New Directions in the Chemistry Curriculum Conference are any indication, the descriptive chemistry empiricists appear to have lost status and influence. The difficulty in categorizing empirical knowledge is that it appears in so many forms. Empirical knowledge may include components of descriptive chemistry, laboratory chemistry, process skill chemistry, industrial chemistry, household chemistry, and experiential chemistry as well as laws, generalizations, principles, hypotheses, and "facts". A balance of the various types of empirical knowledge within a chemistry textbook has been elusive. Perhaps the problem is that textbook writers and curriculum developers have not had a taxonomy of empirical knowledge to guide their conceptualization and curricular application of this knowledge form. The Author Group (1986) has made a thrust in this direction by categorizing empirical knowledge, not just for themselves as textbook authors but for their student audience as well. For example, the **STSC Chemistry 10** materials list six ways of communicating empirical knowledge—observational statements, tables, graphs, empirical definitions, generalizations, and laws (see Appendix B). These ways of communicating empirical knowledge are assessed in the accompanying STSC **Chemistry** test package.

The third academic interest group described by Jenkins and Kass, the scientific process-skill group, seems to keep fighting small battles and are winning supporters. Most of the process skill attention has centered on the elementary and junior high school level. Elementary science programs such as SCIS and SAPA have enjoyed varying degrees of success with teachers who have little or no formal education in the sciences. At the high school and university levels the acceptance of a process approach appeared to lose ground after the initial thrusts of the inquiry oriented NSF programs of the 1960s. In Alberta high schools there has been a recent increase in scientific process skill teaching since the Alberta Education diploma examinations were reinstated. Teachers in the Calgary Public Schools have developed process skill documents in high school chemistry, physics, and biology. Nadeau and Nay (1985) studied high school chemistry process skills in the ALCHEM and adapted materials, and Galbraith (1985) has prepared an inventory of process skills and a process skill cycle for Alberta Education for use in Alberta school.

Examples of process skills research are provided by writers such as Nay (1971), and Risi (1982). While Nay emphasizes his self-developed, pedagogically oriented sets of process skills, scientific attitudes, and critical thinking skills, Risi puts the emphasis on imagination, creativity, independent thinking, and divergent thinking. The Author Group used the research of Nay and the Calgary and Alberta Education documents to integrate process skills into the **STSC Chemistry** textbooks. Their previous emphasis on technology in the ALCHEM materials led the members of The Author Group to divide process skills into scientific and technological process skills. For example, process skills that involve the use of a technological device are classified a technological skills. This split is consistent with current trends to define technological literacy in addition to scientific literacy as a major goal of science education. As yet the integration of sociological and historical process skills into part of the science program have not been given major consideration in academic science courses. The Social Studies Program of Studies for Alberta schools lists process skills which the student is expected to learn as part of their course work. Whether such skills in a restricted sense will be integrated into the new STS science program remains to be seen.

Several problems remain to be investigated when classifying knowledge as theoretical, empirical, and process knowledge forms. One problem is that process knowledge is procedural knowledge and might be classified as empirical and theoretical procedural knowledge. However, if this is done some important information as to the required amount of student laboratory work would be lost when classifying textbook discourse. For practical reasons the process category needs to be included in any taxonomy of knowledge forms found in textbook discourse. In the present study the process category is used for this purpose—to gather evidence for the amount of laboratory work, and in particular the amount of independent laboratory work, done by students. However, since textbook discourse does not include the knowledge gathered by students in the laboratory nor the answers to process-like questions in the textbook, process knowledge (produced by students) is not recorded as data in the current study. This serves to point out clearly the relationship of process knowledge to presented knowledge found in a textbook. Process knowledge is not presented, it is obtained independently by students. The extent to which this kind of activity is required of the student is an important research question. The taxonomy developed herein could assist in providing this kind of information.

The above review of the theoretical, empirical and process knowledge forms was initiated by the Jenkins and Kass lists of chemistry education subcultures (1981), multiperspective approaches (1982), epistemological approaches or preferences (1983), and normative perspectives (1986). This group of knowledge forms found in chemistry education textbooks was originally classified as part of an academic curricular emphasis by Jenkins (1983), but appears later in this report as a nature of science emphasis. Whatever way these three knowledge forms are nested, they may play a central and significant role in current science textbooks and in current curriculum and testing programs and need to be included in any classification of knowledge.

The second major grouping of knowledge forms from the Jenkins and Kass list used to initiate this study is the application group. This group or emphasis was initially composed of applicational, parochial, and ecological knowledge forms (Jenkins, 1983). Examples of literature that espouse an applicational epistemology are Botting (1980) and George (1981). Typically the applicational epistemological preferences are held by pedagogues who see applications as being a way to motivate students or to illustrate the tremendous power of science in providing a technological fix for citizen or societal problems. George's engineering view of science education condemns a "narrow approach to science, which emphasizes only basic scientific principles, [and] is drying up both the supply of young scientists and public appreciation of and support for science and technology" (1981: 30). George not only argues for a better balance between content and context, but also extends an interesting argument of a particular engineering (applied) way of knowing that differs from the scientific norm presented in science textbooks.

Harrison (1983) at a World Trends in Science Education Conference with an emphasis on technological literacy has expressed the need for a technologically literate citizenry in a democratic society. Pacey (1983) has expanded the restricted meaning of technology from the strictly technical aspects to a more general meaning including cultural aspects and organizational aspects. Kline (1986) expresses the concern that "we cannot get on with our work in STS studies even reasonably well until we 'unpack' the word 'technology'." Kline identifies four usages of the term, technology. The first usage is to denote technology as manufactured articles such as household chemicals, commercial machines, and industrial plants. Kline prefers to use the words "hardware" or "artifacts" to refer to manufactured articles. The second usage of technology identified by Kline is the process of manufacturing hardware. The full usage of technology in this context usually implies a system of people and machinery, referred to by Kline as a sociotechnical system of manufacture. Kline's third category describing technology is technological skill or methodology or know-how. His fourth category of technology is sociotechnical system of use, such as a transportation system or a militaristic system. This last category seems to subsume the previous three categories, but puts the emphasis on the use of technological products, processes, and skills to accomplish a social goal. From Kline's perspective, the development of sociotechnical systems is a characteristic which distinquishes humans from other animals on our planet. The views of Harrison, Pacey and Kline have helped to characterize technology and to establish the importance of technological literacy as a curriculum component in schools. What remains is to establish the content and activities that would be included within a school science program that recognizes the importance of technological literacy.

Toward this purpose, a newsletter, the S-STS Reporter, was established along with an annual technological literacy conference initiated in 1986 by the S-STS (Science through Science, Technology and Society) project of the USA National Science Foundation. Technological literacy is described in the S-STS Reporter (1986-01) as "an easy familiarity with the whole range of contempory techniques and devices which affect the daily lives of all citizens" plus "the understanding of the major scientific and technological forces shaping contemporay life", and "the ability to take responsible citizen action to promote and preserve the common good in a technological age". Alberta Education (Popowich et al, 1984) uses the term "science-technology literacy" to conceptualize a study of technology as part of a student's science education. Six dimensions of technological literacy are listed—technological skills, problem-solving processes, scientific knowledge, technology as change agent, STS decision making processes, and technological products. The Author Group (1986) identifies eight categories of technological understanding—technological information of interest, products, processes, skills, communication, technology-science interdependence, technology and societal change, and technological problem solving. The Kline, Alberta Education, and The Author Group lists have a lot in common. Both the Alberta Education and The Author Group lists are broader in scope than Kline's due to the more pedagogic perspective taken. The Author Group categories go beyond the Alberta Education dimensions by including technological communication and technological information of interest.

The **STSC Chemistry** textbook provides some specific examples of textbook content that could be categorized as technological literacy. Students are asked, for example, to list five defining differences between science and technology. These differences help to establish the difference between the nature of science, which students have studied earlier, and the nature of technology. **STSC Chemistry** students are also asked to classify questions as scientific or technological, classify technological contexts as consumer, commercial, or industrial, list the characteristics of a technology acceptable to the engineering community, and evaluate a technology from a multi-perspective point of view. This nature of technology content is in addition to the standard technology content related to products, processes, skills, and problem solving. The Author Group has declared a technology emphasis for one unit in each of their Grade 10, 11 and 12 textbooks. The technology emphasis is developmental from one level to the next.

In summary the technology knowledge form includes a very broad range of different kinds of knowledge. The study of technology is not restricted to science or vocational courses in the schools. Burke (1978) in the book and television series "Connections" makes the point that the history of civilization can be studied by studying its technological inventions. He choses ten major technological inventions (e.g., the plow, the airplane, and the computer) to illustrate the connections among science, technology and society. As a result, the study of technology is also important in social studies, business education, home economics, industrial arts, and vocational courses. What remains is for science educators to establish what part of the technological literacy curriculum is appropriate to be studied within the structure of science education. One thing that appears fairly certain is that, after a decline in emphasis for twenty-five years, the study of technology will be returning to a position of increased importance in science textbooks and curricula. Science educators have the task of determining what this means in terms of specific content in textbooks and curricula. This step is necessary before provincial examinations can make technological knowledge part of a testing program which would firmly establish technological knowledge along side scientific knowledge in curricula.

Jenkins and Kass next identify an interest group which values knowledge specific to a particular region of our planet. The Symons Report (To Know Ourselves) (1978) and Page's A Canadian Context for Science Education (1979) both favor the inclusion of a greater proportion of Canadian content and contexts in our science curricula. Although both of these writers concentrate on recommendations for the university level rather than the school level, the debate over the distinction between Canadian content and local context seems to have been a necessary stage in the deliberations conducted by the Science Council of Canada science education study. The study has collected analytic data on the amount of Canadian context provided by science textbooks used in Canadian schools (1983, Volume I: 213-267). One obvious generalization that emerges from the analysis of the data is that there is a strong correlation between the amount of Canadian content in textbooks used in Canada and the nationality of the textbook authors. Canadian authors, in general, include more about Canada in science textbooks than do foreign authors.

The nationalist interest group has always come under criticism for being narrow in their conception of science education. However, they can respond that all science curricula are socially constructed and that this social underpinning should be conscious and explicit.

Kuhn (1970), Ravetz (1971), and Latour and Woolgar (1979) make this same point with regard to scientific knowledge itself. Once this is recognized, all textbooks can supposedly be seen as being nationalistic. Science educators now recognize that the NSF science projects of the 1960's and now the NSF projects of the 1980's are socially driven. They are a product of their times. This interpretation is often not obvious at the time a textbook is written.

The science and technology of low-energy passive-solar homes are components of a Canadian invention that is only sparsely taught in Canadian schools. Some of the relevant science content is taught in the context of calorimetry and thermochemistry in school curricula. What has not been recognized is that an acontextual approach reflects just as strong a bias as the Canadian context advocates are accused of possessing (i.e., not including Canadian contexts is a bias). The advent of the STS movement has once again brought the national content issue to the forefront. However, this time the inclusion of national content and context has been accompanied by the advocacy of gaining knowledge in order to produce democratic citizens who are better prepared to make decisions on science and technology in society issues. The claim is that global perspectives are more likely to be developed within students who learn their science lessons within a national context than from the current acontextual curricula.

The original 1982 Jenkins and Kass classification of applicational and national knowledge together as an application emphasis is obviously inappropriate from a 1987 perspective. The idea of nesting knowledge forms within curriculum emphases is still appropriate, but the application knowledge form is now called technological and nested within a technology emphasis, and the national knowledge form is now nested within a societal emphasis. What this illustrates is that the knowledge form categories may be more stable over time and that the emphases may change more often.

The original Jenkins and Kass pedagogic emphasis included pedagogical and psychological knowledge forms which were represented in the literature by Herron (1978), Jenkins (1980), and Rothe (1978). Herron points out the incompatibility between logical order of chemistry content and psychological order. Jenkins examined what Factor and Kooser refer to as pedagogic license within the ALCHEM materials and described some ALCHEM pedagogic models and theories. These are restricted or modified scientific models or theories which according to Jenkins not only increase learning efficiency but also involve teachers and students in the process of scientific theory development (i.e., Kuhn's normal science). Rothe on the other hand argues for personally meaningful curriculum and instruction. "Students may respond to the curriculum content with confidence if they are aware of its relevance to their future" (1978: 29). A shift seems to have occurred in the literature from the curriculum requiring specific personal relevance to the students' past or current interests to the curriculum providing an explicit context from which students can assimilate the content within personal-meaning structures.

The Author Group (1986) has gone to the point of identifying pedagogic ways of knowing within their textbooks. Students are asked to classify given, memorized and referenced ways of knowing in addition to empirical and theoretical ways of knowing. These "other" ways of knowing are in effect pedagogic. If a student does not have an empirical or theoretical way of knowing available to him or her, it is important that alternative ways of knowing be consciously available. For example, the chemical formula for water may be empirically determined from a Hoffman Apparatus or theoretically determined from Lewis Molecular Theory. If these two ways of knowing are not available, then the student must be given the formula, must memorize the formula, or must look up the formula in a reference book. When the student does not know how the formula for water could be determined empirically or theoretically, then the certainty with which the knowledge is held is suspect. The Author Group believes that, if students are made conscious of how they know something, they will gather a healthy skepticism for how certain any knowledge is. The concept of pedagogic knowledge can also be helpful to textbook authors and curriculum developers who are searching for progressive ways of introducing scientific and technological knowledge in science courses.

The last of the major knowledge forms identified and described by Jenkins and Kass was epistemology. Rather than include epistemology in with the other knowledge forms in this literature review, this category is considered separately in the section which follows. Epistemology is identified in the study as one of the five theoretical perspectives used to guide the study and to provide criteria for evaluating the taxonomy of knowledge forms developed herein.

E. Epistemology and Curricula

Jenkins and Kass (1981, 1983,1986) identify and describe epistemology as a knowledge form to be presented to students. In their original conceptualization, epistemology was a knowledge form created in order to classify knowledge about the nature of science. The nature of scientific knowledge and the limits of scientific ways of knowing, including discussions of alternative ways of knowing, are generally not included in science textbooks. Munby (1982: 40) addresses the integration of epistemology into existing courses and the problem of time in a curriculum ("race course"):

> There is no reason why great strides toward intellectual independence cannot be made through minor adjustments to our present teaching. We must speak of theories as inventions, we must remind learners that scientific constructions are models of reality and not more, and we must be sure that we offer evidence claims and deal with student contributions in a rational manner.

Munby's paper was one of the discussion papers of the Science Council of Canada study of science education. One of the eight major initiatives recommended by this four year study is "presenting a more authentic view of science". Nadeau and Desautels (1984) in addition to Munby (1982) raise the question of the authenticity of the image of scientific activity being presented in classroom and textbook discourse. Nadeau and Desautels (1984: 53) go on to ask further questions:

> Can young high school students really think seriously about the nature of scientific knowledge, and if so, under what conditions? Why should students take time for such reflection, and to what extent will this change the teaching of science?

The Science Council of Canada Report 36 "Science for Every Student" indicates that the Council does not expect students to be trained in the philosophy of science. However, The Author Group seems to indicate otherwise in their textbooks where, in a restricted way, they require students to answer specific questions on the nature of scientific knowledge. Not only do they ask students to classify scientific knowledge and ways of knowing as empirical and theoretical but they require students to identify the characteristics of theories and laws that are accepted by the scientific community. For example, the **STSC Chemistry 10** textbook asks students to list the three characteristics of an acceptable theory as one that explains, predicts and is simple. This is contrasted to acceptable scientific laws and generalizations which describe, predict and are simple. These authors have included specific nature of science content in their textbooks as well as on the tests they have developed to accompany the textbook. In addition they have redefined the categories and content of a student laboratory report to, in their words, more authentically depict the nature of science. This revised report format was an attempt by The Author Group to integrate scientific process skills with concepts from the nature of science. For example, the **STSC Chemistry** laboratory report format includes sections titled evidence (rather than observations) and evaluation (rather than conclusion). The language of science is integrated into the fabric of the textbook discourse and not just into the laboratory work. References to theories, laws and generalizations and to the evidence that supports statements made in the textbook lets the students in on matters affecting the certainty and the origin of knowledge.

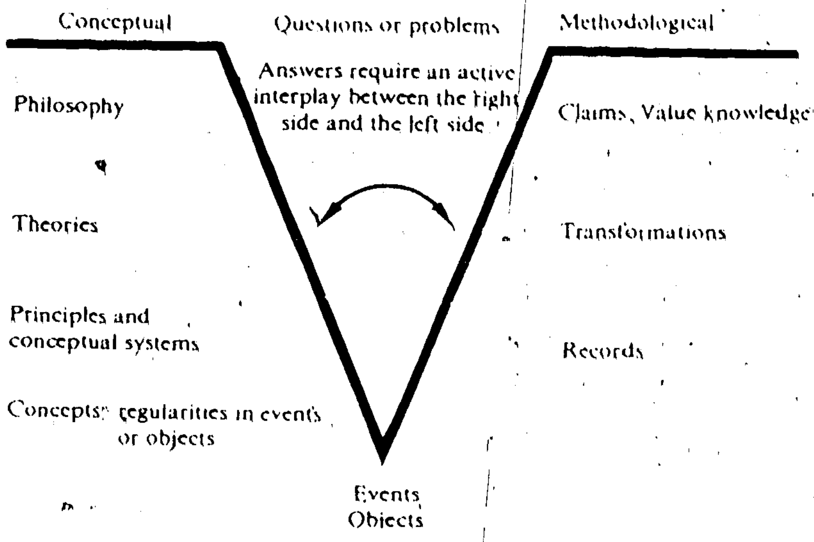
The evaluation section in the **STSC Chemistry** laboratory format directs the students to 1. evaluate the prediction, 2. evaluate the theory, law, or generalization or experience used to make the prediction, and 3. evaluate the experimental design. One significant change is that The Author Group advocates the inclusion of predictions to problems which will not be supported by the evidence. This results in the potential for falsifying the theory, law or generalization used to make the prediction. The **STSC Chemistry** textbook presents "3 R's" to resolve this situation. The student must decide to restrict, revise, or replace the theory, law, or generalization used to make the prediction which was not supported by the evidence. Through this approach the students are introduced to the life-cycle of a theory, law, or generalization and come to appreciate first hand the degrees of certainty associated with scientific knowledge. Classroom evidence gathered by The Author Group indicates this approach works well with high school chemistry students.

Nadeau and Desautels speak to the function of science teaching in the overall context of scientific activity in a manner not unsimilar to Kuhn (1970). They discuss pedagogy and communication as being part of scientific activity in a manner similar to that of the authors of **STSC Chemistry**. The latter group has declared that pedagogy and communication are curricular emphases, and that epistemology is a textbook content item for not only a science emphases, but also for technology, society, communication, and pedagogy emphases.

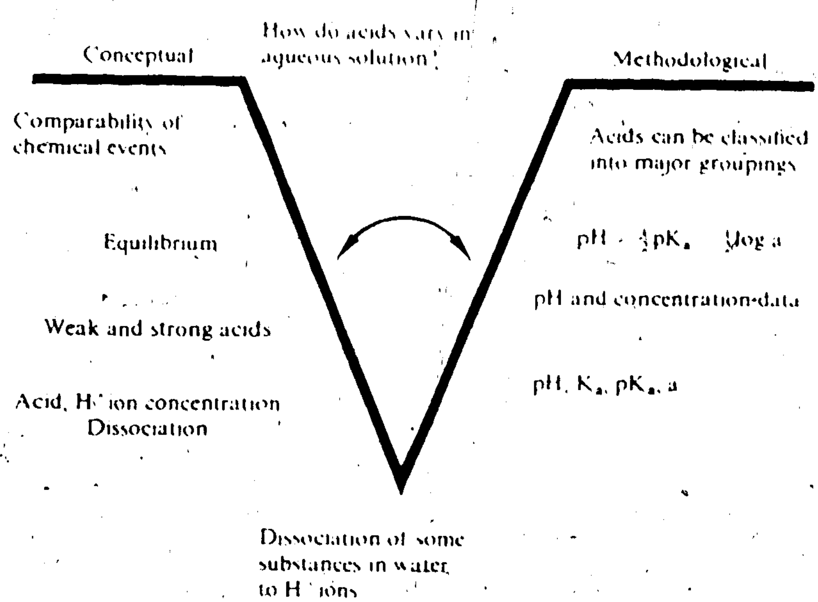
George (1981) lends support to the above view by making the epistemological point for technology and engineering. He indicates that engineering involves knowledge, skills and attitudes different from science. The skills involved in engineering may even be closer to the kinds of skills required by citizens in a technological society than scientific skills are. George also points out that more of our high school science students will go on to become engineers than will become research scientists. Nelson (1981) supports the position taken by George. Nelson indicates that applied science has been misrepresented or neglected in high school chemistry courses. Epistemologically, applied chemistry is largely empirical in nature, and according to Nelson (1981: 5) "the help that 'pure' chemistry can give is relatively limited." Nelson feels that, because of the 'pure' chemistry training of chemistry teachers, changes in curriculum to include more 'applied' chemistry will be very difficult to implement. In Albera The Author Group has been conducting workshops which illustrate through laboratory activities the difference between scientific problem solving and technological problem solving. The systematic manipulation and control of variables is similar to scientific problem solving, but the end product is different. Technology is not interested in describing and explaining a phenomenon. Technology is interested in getting something to work—reliably, economically, and simply.

Epistemology is in part a study of the criteria by which knowledge comes to be accepted or rejected by the relevant community of scholars. To what extent students can be expected to explicitly consider these criteria is a question for classroom research. The Author Group has gathered informal evidence to suggest that such consideration yields positive results with high school chemistry students. They ask students to classify knowledge and procedures as empirical and theoretical. To accomplish this task the students must know the characteristics of empirical and theoretical entities. For consistency The Author Group also refers to operational and conceptual definitions as empirical and theoretical. Any epistemological approach such as this one must be explicit, simple and understandable in order to be successful in the classroom. It seems to this researcher that an epistemological-level classification of concepts and corresponding methodologies presented to students by way of textbook or classroom discourse is fundamental to an understanding of the nature of science and technology.

Gowin (1984) has worked toward the above pedagogic end by creating an "epistemological-V" to conceptualize the relationship among conceptual knowledge, methodological knowledge, events, and questions within an educational context. Gowin's V may be described as a heuristic device to help students learn that concepts are human inventions. Students are given or acquire observations and are asked to list the concepts and methodologies that they would use to make



Gowin's Epistemological V
Figure 2.1



Gowin's V for a Segment of Chemical Knowledge
Figure 2.2

sense of the observations. Figure 2.1 and Figure 2.2 illustrate Gowin's epistemological-V in general form and with an example. Figure 2.1 indicates that "conceptual knowledge" may appear as concepts, principles and conceptual systems, theories, and philosophy. "Methodological knowledge" on the opposite but complementary side of the V includes, respectively, records, transformations, and knowledge claims. Figure 2.2 illustrates the concept mapping of the conceptual and methodological knowledge necessary to answer the problem—"How do acids vary in aqueous solution?" For the current study the classification of knowledge as conceptual and methodological is a useful exercise. However, when analyzing textbook or classroom discourse, the above classification can be shown to be quite restricted. The statements that the number of electrons believed to be in a sodium atom is eleven or that the mass of a particular sample of sodium metal is 5.62 g could not be classified as conceptual knowledge or as methodological knowledge. Gowin's V, therefore, is useful for the purpose for which it was created (i.e., as a heuristic device), but is too restricted to be used for the adequate classification of textbook discourse.

Epistemology as content and as process has been on the fringe of science education for many years. However, the conceptualization has usually been restricted to science as inquiry or critical thinking or scientific attitudes. The broadening of the conceptualization of epistemological content in science education to include modern philosophical ideas about the nature of science and the nature of technology has been advocated by the Science Council of Canada and by others. What remains is to find pedagogic ways of presenting epistemological ideas to high school students, and to find conceptual ways of representing epistemological ideas for researchers and teachers.

F. STS: Science, Technology and Society

Science, technology and society (STS) is a science education movement of the 1980's. STS has been interpreted opportunistically by various interest groups that existed prior to the STS movement. Conceptually, STS has an integrative, synthesizing potential. Many interest groups could be satisfied by curricula and textbooks written with STS components. There is already evidence to suggest that STS is being supported fairly widely for a terminal or general science course (e.g., CHEMCOM) but that academic students are less likely to see STS integrated into their courses. The evidence comes from a perusal of STS publications such as the S—STS Reporter (1986 and 1987), the NSTA Yearbook Science, Technology and Society (1985), the Science, Technology, Society Research Network missives (1986), and the British Council Science Education Newsletter (1986).

Bybee (1985: 82) indicates awareness of the potential misapplication of STS.

> I believe that the new [STS] goals for science and technology education must be for all students, with the single exception of special students. The application of new goals to course materials and instructional strategies must occur for the core science curricula, not just for advanced placement courses or courses for slow learner.

This commitment is different from that of Klopfer (1969) who called for two distinct curricular streams—a Prospective Scientists stream and a Scientific Literacy stream. Roberts (1983: 34) suggests that a balance of curricular emphases is important "for all students". The Science Council of Canada study of science education (1984) also calls for scientific and technological literacy "for every student". An inference that can be drawn from these statements is that there is concern that science curricula with technological and societal components are not being designed for all students. In a democratic and technological society this concern is of particular importance when voters are being asked to make decisions on such science and technology in society (STS) issues as nuclear energy, acid rain, toxic waste, and research funding.

Jenkins (1981) has expressed an additional concern that different kinds of students are both implicitly and explicitly being provided with different kinds of knowledge. "Better" students are studying academic knowledge forms while "poorer" students are studying applied knowledge forms. Besides the concern for the moral and social connotations that such a matching conjures, Jenkins expresses the need for a liberal science education for all students. This same concern has been expressed many times by the scientist and television personality David Suzuki. He has pointed out that lawyers, for example, have come though an academic education stream in school, have taken either academic or no science at the university level, and then many have gone on to become political representatives and leaders in our democratic society. It would seem imperative that these leaders should receive an education which would help them in their service to our democratic way of life. A similar concern has been expressed by

Solomon (1983) through the SISCON materials and by the Association for Science Education (ASE) through the Science in Society readers (1981) and the Science and Technology in Society (SaTiS) mini-modules (1986) used in high schools and universities in Great Britain.

Bybee (1985: 84) also indicates his commitment to STS and the worth of STS knowledge in today's context:

> Science teachers are being called on to answer a contemporary and expanded version of the question philosopher Herbert Spencer asked in 1859: "What knowledge is of most worth?" Spencer's answer was science. So is mine. But what science is of most worth to the citizen today? The knowledge relevant to science, technology and society (STS) issues, for these are the issues the citizens will help resolve.

The problem for science teachers and for departments of education is that technology has been almost ignored (Bybee, 1986) and there is little or nothing of STS in currently available textbooks (Piel, 1981). To assist in the development of STS curricula and textbooks Bybee suggests the following framework for scientific and technological literacy:

Table 2.2
A Conceptual Framework for Scientific and Technological Literacy

Goals	Acquisition of knowledge	Development of learning skills	Development of values and ideas
Themes	Concepts of science and technology	Process of scientific and technological inquiry	Interaction of science, technology, and society
Areas of Emphasis and Activities	Personal matters Civic concerns Cultural perspectives	Information gathering Problem solving Decision making	Local issues Public policies Global problems

The personal, civic and cultural literacy categories in Bybee's conceptual framework are taken from Shen (1975). The first two columns are similar to Gowin's conceptual and methodological sides to the epistemological-V. The "development of values and ideas" is somewhat exemplified by Aikenhead's and The Author Group's multi-perspective classroom approach to science-and-technology-in-society issues. In the present study the knowledge forms that could make up an STS curriculum are viewed as more specific than the categories outlined by Bybee. However, the Bybee framework in being general is also very complete in its description of STS curricula. Curriculum and textbook developers could certainly benefit from using the framework for guidance and comparison.

Aikenhead (1985, 1986) proposes a framework of STS context including, 1. science discipline content, 2. technology discipline content, 3. characteristics and limitations of science and technology, 4. interactions of science and technology with society, and 5. skills of communication and mathematics. Aikenhead's STSC emphases (science, technology, society, and communication) are similar to the STSC Chemistry textbook authors' emphases. The major difference is in the establishment of a separate overall epistemology emphasis by Aikenhead and an integrated epistemology category for each emphasis by the **STSC Chemistry** authors.

The four year Science Council of Canada deliberative inquiry of Canadian science education developed eight recommendations for renewal of Canadian science education (Orpwood and Souque, 1985: 634). Three of these eight could be described outright as STS: 1. presenting a more authentic view of science, 2. introducing technology education, and 3. emphasizing the science—technology—society connection. Two of the other recommendations have societal overtones: 1. increasing the participation of young women in science education, and 2. setting science education in a Canadian context. The last two recommendations deal with science for every student and for all objectives: 1. guaranteeing science education in every elementary school, and 2. ensuring quality in science education (developing and implementing assessment techniques "for all the objectives of science education").

Hurd (1986) lists nine advantages of an STS context for science and technology education. The advantages listed include increased student motivation, a richer framework for the development of intellectual skills, knowledgeable citizens, awareness of the social and personal implications of what is taught, a more authentic view of science and technology, increased connections with other school subjects, and student use of knowledge and skill for planning the future. In summary Hurd describes the STS movement as "holistic" and "ecological" (i.e., STS looks at a combination of relationships between science and society). The researcher through teaching and authoring has come to support the STS movement. This value-laden decision has also led to the establishment of STS as one of the theoretical perspectives within the conceptual analysis research methodology used to guide this study. The next theoretical perspective to be reviewed is the practical perspective.

G. A Practical Perspective

A practical perspective is the fifth theoretical perspective used to guide this study. The other four perspectives reviewed are 1. curriculum emphases, 2. normative perspectives, 3. epistemology, and 4. STS science education. In this study the practical has played a subtle but important role in influencing the questions asked, the procedures used, and the kinds of knowledge forms created for the taxonomy of textbook discourse. The practical perspective is important both as a background methodology and as a criterion for making evaluative decisions on whether to keep certain knowledge form categories in the taxonomy which is being created. The study is set in a research and practice context and was conducted simultaneously with the conceptualization, writing, and piloting of an STS chemistry textbook by a group of authors including the researcher. The literature now reviewed is with reference to this theory-practice dialectic.

Joseph Schwab in a series of four articles entitled "The Practical" (1969, 1971, 1973, 1983) declared that curriculum studies is moribund. A new approach is required. Schwab's interest on behalf of curriculum theorists seems to be to exercise some influence on the attainment of a liberal education for children. Evidence of the lack of application of educational research to educational practice suggested to Schwab that the emphasis on the theoretic in curriculum studies was having little influence on classrooms. Schwab conceptualizes an answer in a language for and an eclectic art of the practical. Schwab may be described as Aristotelian in that he sees significance in the theoretic and practical split in perspectives toward knowledge and advocates a unity of these two perspectives. The unity is seen as a dialectic between the two supposedly opposing perspectives. In a complex fashion that reflects the educational event itself Schwab tries to unify the theoretical and practical perspectives with his underlying liberal education values to create a process of deliberative inquiry. Schwab's conceptualization of deliberative inquiry is useful in describing the background influence of the practical on this study.

Deliberative inquiry is preceived by Schwab (1983) as being a methodology that seeks the unity of theoretical and practical ideas by bringing the agents of these ideas together in a specific problem solving context. Schwab (1974) suggests that the practitioners are the only interest group not to be given special consideration over the years of shifting emphases in education. In "The Practical 4" Schwab (1983: 241) calls on the curriculum professor to lead local groups of curriculum developers in a process of "curriculum reflection". According to Schwab, the most important person to be involved in this reflective process is the teacher. The curriculum reflection would involve a dialectic consideration of ends and means—"a linear movement from ends to means is absurd" (1983: 241).

Jenkins and Kass (1980) have described this kind of process as it has been used by The Author Group in its writing of chemistry textbooks. These authors have over a thirteen year period continually reflected on the goals and activities of chemistry education at the same time as teaching and writing a series of chemistry textbooks. Although the range of "agents" involved in the **STSC Chemistry** project is narrower than Schwab calls for in "The Practical 4", these authors have tried to compensate by actively seeking and discussing alternative perspectives advocated by other interest groups. The **STSC Chemistry** authors have claimed that the active use of the classroom to create STS-type textbook content is responsible for much of their success as authors. Not only do they use deliberative inquiry in their weekly curriculum reflection sessions, they include the most basic practical activity in education—the classroom-in-use (Jenkins and Kass, 1980). The closest that curriculum professors may come to the classroom-in-use may be deliberative inquiry including teachers, students, and parents. However, for teacher-authors the classroom-in-use does not in itself induce curriculum reflection. Regular practical reflection activities as may be exemplified by teachers involved in curriculum development is a perspective not considered by Schwab. These teachers are forced by context into a situation of intense reflection on their everyday activities in the classroom. In a sense they partially integrate the perspectives of the curriculum professor and the classroom teacher. Schwab's perspective is that of a curriculum professor, albeit one who is a teacher advocate.

Reid (1979) and Phillips (1980) are among those who seem to have been converted to the belief that the researchers and the practitioners are going to have to reach some mutually agreeable epistemological approach if maximum benefits are to accrue to the students. Connelly and Clandinin (1982) have simultaneously taken both an empirical and a theoretical approach to studies of teacher interpretive frameworks and restricted their research to teachers' personal practical knowledge.

Lantz and Kass (1987) used Crocker's (1983) concept of teachers' functional paradigms in an implementation study of the ALCHEM high school chemistry textbook. Kuhn's concept of paradigms has been reinterpreted by Crocker to indicate the complex nature of teachers' actions guided by individual beliefs, values, techniques, exemplars, and routines. One of Lantz's major questions is, "What is the nature of teachers' functional paradigms as represented by the way they interpret curriculum materials?" Lantz gathered evidence to show that chemistry teachers place a high value on teaching theoretical chemistry but a low value on teaching the STS connection and the nature of science. According to Lantz, teachers are very concerned about pedagogical efficiency, academic rigor, and student motivation.

Practical concerns as expressed in the conceptualization of a teacher's functional paradigm are particularly important for implementation of curricula. Other than Shipman and Jenkins (1974), Crocker (1983) and Lantz and Kass (1987) there has been little research into the functional paradigms of teacher-authors. This kind of research on the practical has been called for by Jenkins and Kass (1980: 1).

> The theoretical traditions of educational research have to date allowed little place for the conventional wisdom of teachers . . .. Envisaged are practical researchers who engage in an interactive process with the problematic situation—researchers who stress, among other skills, action, judgement, deliberation, and tactics.

In the present study the researcher has sought deliberation not only within a group of textbook authors but also within a classroom context. The taxonomy of knowledge forms has been developed within these interactive contexts. Deliberations have been grounded in and around the researcher's classroom-in-use (Jenkins, 1983). Curriculum reflection requires the dialectic between theoretical and practical perspectives. Schwab (1983) has described deliberative exchange as being among several persons and/or differing selves about concrete alternatives. Much research needs to be completed on the design of deliberative inquiry in a variety of curriculum contexts.

Kuhn (1970), Ravetz (1971), Latour and Woolgar (1979), and Zukav (1979) are examples of authors who have commented on the social construction of scientific facts. As yet a book has not been published on the social construction of pedagogic facts, but many educators and noneducators have commented on the quick acceptance of "fads" in education as being prevalent. Where does the social acceptance of pedagogic facts fit into the academic world and/or the classroom world of educators? In this study, for example, can the taxonomy developed reflect the requirements of the science education community? To build a taxonomy of knowledge forms that would represent the kinds of knowledge preferred by various groups of the science education community requires a practical perspective and an attitude of deliberative inquiry. A practical perspective, for example, would allow for categories to be included in the taxonomy that are not necessarily theoretically justifiable based upon the previously reviewed theoretical perspectives. This kind of flexibility is necessary for building a taxonomy that reflects the kinds of knowledge valued by various segments of the science education community.

In summary, the practical perspective is important to this study in two ways. A methodology of practical inquiry and deliberative inquiry was used to develop a taxonomy of knowledge forms which can be used to describe textbook discourse. A criterion based on a practical perspective was used to make decisions on whether to incorporate categories of knowledge that could not be justified on the basis of the other four theoretical perspectives. The practical perspective completed the pentad of theoretical perspectives used to guide the development of the taxonomy of textbook discourse. The conceptualization of this pentad of perspectives was necessary to the first stage of conceptual analysis—the general methodology of this study. The second stage of conceptual analysis is the development of an analytical framework for analyzing a curriculum or instruction segment. The literature review which follows concentrates on taxonomic frameworks.

H. Taxonomic Frameworks

The dictionary definition of taxonomy refers to "the science, laws or principles of classification", and "the theory, principles and process of classifying [things] into established categories". The etymology of taxonomy reveals that taxis or taxo "indicates order or arrangement", while nomy "indicates the systematization of knowledge about, or laws governing, a specified field" (Houghton Mifflin, 1982). In this study the term taxonomic classification is taken to mean a slightly higher order of classification than the term classification system. Taxonomic classification is used to connote a greater degree of purpose and understanding—a classification guided by organizing concepts and underlying principles. A taxonomic classification in this sense is akin to the "analytical frameworks" which are developed from "theoretical perspectives" in the methodology called "conceptual analysis" by Mahung (1980). In this study an analytical framework called The STSC Taxonomy is developed.

Bloom (1956) differentiates between classification schemes and taxonomies by indicating that the former may be arbitrary elements while the elements of a taxonomy must represent the phenomena in some "real" way. According to Bloom, classification systems are validated by reference to the criteria of communicability, usefulness, and suggestiveness. Taxonomies are validated by demonstrating the consistency of the elements of the taxonomy with theoretical views of order in a particular field of study. A taxonomy can be seen as a method of ordering phenomena in order to reveal significant relationships among the phenomena. The relationship may be hierarchical from simple to complex or level of awareness or consciousness—as in Bloom's Taxonomy—or the relationship may be epistemological, as in the STSC Taxonomy developed herein.

Bloom (1956) indicates that the criteria used to evaluate the Taxonomy of Educational Objectives were communicability, comprehensiveness, thought stimulation, and acceptability to the relevant community of scholars. Communicability was checked by having community members classify a large number of test items and then check for agreement. Comprehensiveness was checked by trying to find written objectives of courses which could not be classified by the existing taxonomy. Thought stimulation was checked by asking various groups to try the taxonomy in a variety problem solving contexts and to report the usefulness of the taxonomy in stimulating the creation of new hypotheses. The acceptance and use of Bloom's Taxonomy by the education community was the final criterion measure that was applied. This criterion required wait-time and could not be judged adequately until years later. The other criteria—communicability, comprehensiveness and stimulation—are employed during the current study to judge the validity of the STSC Taxonomy. Acceptance by the educational community awaits further evidence.

Bloom's Taxonomy of Educational Objectives (1956) is probably the best known taxonomy in the education discipline. The stated major purpose of the taxonomy is to facilitate communication within the education discipline by developing precise definitions and by writing examples of each category of educational objectives. The framework is to be used for viewing and analyzing intended student behaviors. The orgnization for the taxonomy was guided by educational, logical, and psychological principles. The principles could be viewed as the "theoretical perspectives" of conceptual analysis.

Curriculum builders and teachers were to use the taxonomy to plan learning experiences and to prepare evaluation devices. Most educators have used Bloom's Taxonomy at one time or another to prepare tests with a hierarchy of test items ranging from knowledge, comprehension, and application to analysis, synthesis, and evaluation. In science education lesson planning the former group is usually associated with classroom work and the latter with laboratory work.

The major restriction of Bloom's Taxonomy is to intended behavioral outcomes for students. "We are not attempting to classify the particular subject matter or content. What we are classifying is the intended behavior of students" (Bloom, 1956: 12). The major assumption is that the person classifying the objective, for example, of a test item knows the students' prior educational experiences. In the current study, the STSC Taxonomy was restricted to classifying subject matter as expressed in textbook discourse, and this classification, not unlike Bloom's, assumed that the user had knowledge of the students' prior educational experiences. Bloom's Taxonomy operates at a level of generality that allows it to be used in any educational context, while The STSC Taxonomy is restricted to use in a science education context.

Bloom's Taxonomy has received considerable acceptance as a classification scheme for ensuring a hierarchy of test items on a test. For example, Alberta Education currently uses Bloom's Taxonomy to classify diploma examination questions to ensure a range of cognitive complexity within each test. The STSC **Chemistry** authors use Bloom's Taxonomy for writing textbook questions and incorporate analysis, synthesis and evaluation as category headings for student laboratory reports.

Krathwohl, Bloom and Masia (1964) extend the taxonomy of educational objectives into the affective domain. As with the cognitive domain taxonomy, the affective objectives are stated in terms of student behavior that serves as acceptable evidence for the presence or absence of the affective construct. The focus again is on the output from instruction rather than the input. Klopfer (1971) has reinterpreted Bloom's Taxonomy for science education by creating a student behavior versus science content taxonomic matrix. The main "behavior" classes in Klopfer's taxonomy are "knowledge and comprehension", four levels of "processes of scientific inquiry", plus "application of scientific knowledge and methods", "manual skills", "attitudes and interest", and "orientation". The categories could be reclassified within science, technology, society and communication curriculum emphases as done in the current study. Klopfer's taxonomy is useful for classifying objectives that should be part of any science education assessment and it has been used for this purpose by many national and international assessment studies (e.g., the IEA studies). What is not available to curriculum developers, authors, test writers, and teachers is a classification of kinds of knowledge and ways of knowing found in science curricula. In order to facilitate communication, comprehensiveness, and invention of ideas related to the content aspect of science courses, a taxonomy of curriculum emphases and knowledge forms may be useful.

Science subject matter is often classified at the high school level into chemistry, physics, and biology. Another commonly known taxonomic classification used in science education is that of living organisms being classified into a series of nested categories—kingdom, phylum, subphylum, class, order, family, genus, species, and subspecies. In chemistry, substances are classified into pure substances and mixtures, pure substances are classified into elements and compounds, elements are classified into metals and nonmetals, chemical reactions into inorganic and organic, and chemical bonds into intra- and inter-molecular. In the **STSC Chemistry 10** textbook (1986), for example, process skills are classified as scientific and technological with a number of subcategories; technological use is classified as industrial, commercial and consumer; scientific knowledge is classified as theoretical and empirical; and perspectives on an issue are classified into five categories. Classifications such as these are helpful from a scientific perspective to describe the natural and technological world, and from a pedagogic perspective to facilitate communication, teaching, and learning. Classification is one of the basic operations used in all disciplines. The classification systems which result form the basis for organizing and legitimizing knowledge within a discipline.

Harre (1962) indicates that concepts which contain sets of discrete and distinguishable members are taxonomic. Examples of taxonomic chemistry terms used by Fensham (1975) are elements, metals, halogens and transition metals. Harre describes force, surface tension, mass, and density as nontaxonomic. Taxonomic terms describe groups of entities which have two or more properties in common. Nontaxonomic terms describe concepts which involve qualitative or quantitative properties of a single membership. Pedagogically, taxonomic concepts can be distinguished by examples and nonexamples. Nontaxonomic concepts are abstractions learned by "series of concrete experiences of the phenomena" (Fensham, 1975: 208). By this definition curriculum emphases, kinds of knowledge, and ways of knowing would be described as taxonomic. In The STSC Taxonomy presented in this research report two examples are presented for each of the sixty-six categories of the taxonomy.

In the field of educational research, analysis and classification of content has been advocated by Schwab (1964), Finley (1981), Stewart, Finley and Yarroch (1982), and White and Tisher (1986), as an initial requirement for much of the research done in education (e.g., cognitive structure and problem solving research). Once the content variable has been studied, it may then be used as a controlled variable in other research.

Finley (1981) suggests that terms used by philosophers of science to describe types of concepts might be used by educators to build a classification scheme for science education content. An example of the language of science that was used as classificatory words in a study described by Finley is provided below.

> Empirical elements are those which can be observed directly by the senses or measured by relatively simple techniques. Theoretical elements are not directly observable. Concepts, laws and theories provide the knowledge necessary for explaining and predicting events in nature. (emphasis added) (Finley, 1981: 514)

Finley's suggestion and subsequent use of this philosophical analysis technique for establishing controls for his own research are specific to content analysis and classification for the purpose of identifying subordinate concepts. In the present study the researcher is interested in going one step further—to classify textbook concepts, methodologies and questions in general superordinate terms, independent of content topic. The philosphical terms (e.g., empirical and theoretical) suggested by Finley as a tool for classification of content are actual categories in the taxonomy developed in the current study. The **STSC Chemistry** authors are also using the terms empirical and theoretical as epistemological content to be presented directly to students.

Scientific inquiry involves both the input and output of knowledge. Knowledge is what provides meaning to inquiry. Information processing psychologists are interested in the same interaction of pre-and post-knowledge as the philosophers of science are, except that the pre-knowledge is the students' knowledge rather than the science community's knowledge. The methods used for analyzing content include the distribution and co-occurrences of selected words (Clarke 1973; Carss, 1975), paragraph counts (Factor and Kooser, 1981), and message counts (Science Council of Canada study, 1984). By comparison the current study completed a sentence by sentence classification of chemistry textbook discourse in search of knowledge forms. All of these approaches seem to be supported by White and Tisher (1986) who complete their review of developments in current research on the nature of curricula with the following statement.

> Much remains to be learned about the structure of curricula and their textual material. (White and Tisher, 1986:249)

The present study has made an attempt to develop a taxonomy of knowledge forms as a descriptive device for science curricula. The methodology used in this study is a research methodology aimed at uncovering the fine structure of knowledge and ways of knowing found in textbook discourse. The research method of sentence by sentence content analysis might be replaced in the future by computerized word counts or manual paragraph counts. However, the methodology of developing a taxonomy need not be the method of using the taxonomy. Once reseachers have uncovered some of the structural aspects of knowledge, teachers and students should be able to use the results to guide their teaching and learning exeriences.

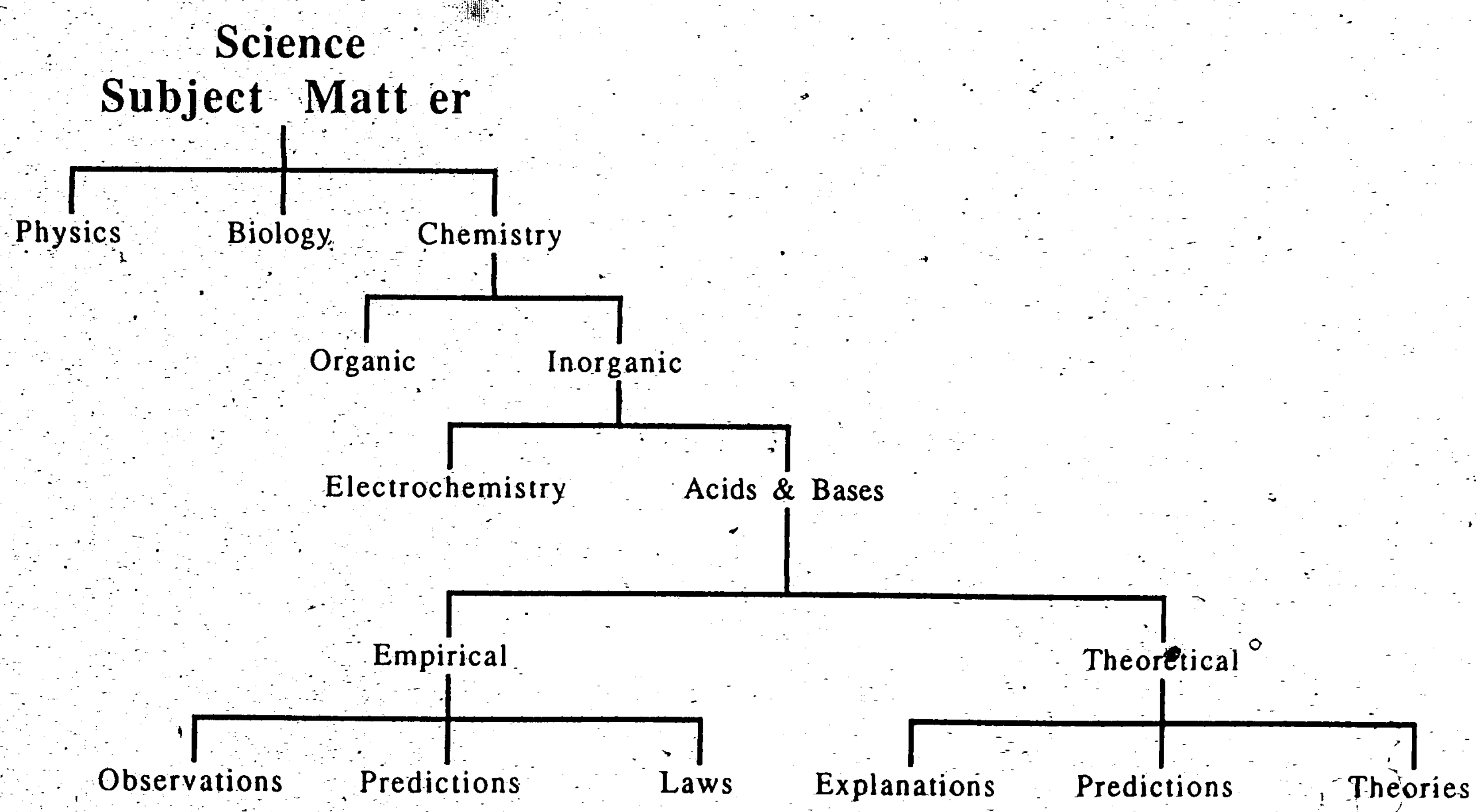
There are different layers of classification of subject matter starting with, for example, nonempirical and empirical; physics, biology and chemistry; organic and inorganic chemistry;

electrochemistry and acid-base chemistry; and theoretical and empirical knowledge. This classification of subject matter is the focus of Figure 2.3. Instead of continuing to subcategorize content into a finer and finer structure, Figure 2.3 illustrates that an alternative exists—a potentially fruitful alternative for describing curricular discourse. The empirical and theoretical categories define epistemological layers which are independent of content and are in this sense different than Finley's conception of content analysis. Identification of underlying epistemologically based categories could allow for a greater degree of generalizability to all subject matter than content analysis of a specific concept or subject area.

According to Walker (1963) models as a way of communicating theoretical knowledge may be further subclassified into conceptual, verbal, postulational, geometric, mathematical, and material categories.

> When a writer refers to the 'Bohr model of the hydrogen atom', [the writer] may have in mind any or all of these aspects; the reader must select the aspects appropriate to the context. (Walker, 1963: 4)

The latter part of Walker's statement is an example of what some educational researchers are investigating. The conceptual framework that pupils bring to their chemistry education context has led to research on the effect of misconceptions, preconceptions, prior knowledge, personal experience, and cultural background on learning (Fensham, 1984: 324). It seems to this researcher that an epistemological-level classification of concepts and of matching



A Classification of Science Subject Matter
Figure 2.3

methodologies given to students by way of textbook or classroom discourse is fundamental to the aforementioned research.

The extent to which the student should be let in on the epistemological classification of concepts and methodologies is being investigated in the classroom by the **STSC Chemistry** authors. They ask students to classify resultant knowledge, definitions, and procedural knowledge as empirical and theoretical. To accomplish this task the students must know the characteristics of empirical and theoretical knowledge entities. The approach must be explicit, simple and understandable. Gowin's epistemological-V has been used with students in a similar way (Fensham, 1984: 322). Students are given observations and asked to list the concepts and methodologies they would use to make sense of the observations (e.g., the concentration and pH of a series of acids).

Another research area that appears ripe for making alternative methodologies (ways of knowing) explicit to students is cognitive preferences. Heath (1964) classifies and describes four cognitive preferences as student preferences for principles, applications, questioning, or memorizing. White and Tisher (1986) have reviewed the ongoing debate over whether cognitive preferences are general or specific over topic and time. This area of research is current and seems relevant to the current study. For example, do students have preferences for certain kinds of knowledge or ways of knowing? The **STSC Chemistry** authors, for example, have experimented in the classroom with explicitly allowing students to choose their way of knowing (e.g., empirical, theoretical, memorized, or referenced). In the present study alternative ways of obtaining the same answer are explicated through the use of a taxonomy of knowledge forms. The idea of a taxonomy which is, in part, useful to students as well as to educators seems to extend the criterion of usefulness beyond taxonomies such as Bloom's. This may be one of the advantages of a taxonomy of knowledge forms over a taxonomy of educational objectives.

In summary, taxonomies have been described in the literature as classification schemes that can facilitate communication and innovation within a particular community. Comprehensive taxonomies can also serve a unifying function and set the overall context for specific areas of research. To qualify as a taxonomy within the realm of education the classification system must be guided by and organized under accepted theoretical views from within the educational community. With these potential benefits and criteria for acceptance in mind, a taxonomy of knowledge forms was developed.

I. Validity and Reliability

The review of selected literature on the validity and reliability of results from educational research which follows is set in a chronological context. Concerns for validity and reliability are not static over the course of a research study. Because of the restrictions placed on this study by the problem statement, the wide range of concerns for validity and reliability in education research is delimited.

Brinberg and McGrath (1982) have reviewed the various classifications of validity and identified three underlying meanings in the concept of validity. According to Brinberg and McGrath validity may be viewed as emphases on "value", "correspondence", and "robustness". These views of validity not only attempt to capture and nest other descriptors of validity but also provide chronological contexts for validity. "Value" to Brinberg and McGrath is primarily a prestudy (preactive) view; "correspondence" is interactive, during the study; and "robustness" is mainly a post-study (postactive) view of validity. Although this classification, like all classifications, oversimplifies the domain, it is useful for portraying in a fairly realistic way of expressing concern for validity over the time span of a study.

II. Preactive Validity

Before starting a study judgements must be made concerning the value of the research in substantive, methodological and conceptual domains. In the present study value judgements were made as to what would constitute a valid research study. From a substantive point of view a value laden decision was made to delimit the study to subject matter displayed in chemistry textbook discourse. A methodology was chosen that could be of value to textbook authors and researchers alike—a research and development methodology. Stake (1978) has pointed out with reference to case studies that a research methodology should be in "epistemological harmony" with the audience's experience. In the current study the methodology valued is one that is potentially compatible with the methodology of textbook writing. The conceptual domain valued and selected was epistemology—the origin and nature of knowledge presented in chemistry textbooks. The meta judgement that must be made in a prestudy context is whether what the researcher values as a research process and research product will also be valued by the relevant community of scholars. The research should, in a Kuhnian sense, fit into or add naturally to existing research paradigms. (This is not to suggest that inquiry aimed at fundamentally altering existing paradigms should not be undertaken, merely that most research in a field is grounded in existing work.)

Dawson (1979) has suggested that valid knowledge is taken to be knowledge which is of value for a specific purpose. The purpose of the current research was to develop a taxonomic classification of kinds of knowledge and ways of knowing found in school science textbooks. From a prestudy value perspective, it would seem that a taxonomy of knowledge forms would be a valuable tool for this purpose in either context—research or development.

The conceptual analysis methodology employed in this study requires a conscious and explicit preactive stage of identifying theoretical perspectives to guide the development of the conceptual framework. The decisions as to what theoretical perspectives to employ and what kind of conceptual framework to develop emphasize what Brinberg and McGrath call "value". Although logical and consistent arguments can be made to justify these decisions, every decision from selection of the substantive domain, to the methodology, and to the conceptual domain is value-laden.

(d) Interactive Validity

Brinberg and McGrath's "correspondence" as validity in an interactive study phase subsumes the Campbell and Stanley (1963) internal validity category. Correspondence between two sets of things is the criterion measure for this type of validity. During the course of a study the forms of validity which are emphasized include construct and predictive validity. In the present study the construct validity of the taxonomy is constantly placed in doubt. The construction of the taxonomy is tested each time it is used. Each textbook sentence has to fit one of the taxonomic categories. In a Popper sense, anomalies are being actively sought with the objective of falsifying the construct. Lindesmith (1968) and Denzin (1970) describe the above process as analytic induction, a research procedure for developing, refining, and accumulating evidence in support of a construct until no negative examples can be found. In the present study a taxonomy of knowledge forms is continually tested against the selected textbook discourse. When anomalies are found, the taxonomy is revised to accept the discourse.

In the interactive phase of this study a fairly continuous application of judgemental criteria characterized the methodology. Thorndike and Hagen (1961) list four attributes of a criterion measure used to establish the validity of a construct. First, the criterion measure should be "relevant". Relevancy is usually determined by professional judgement. In the present study there are several kinds of criterion measures employed—empirical, conceptual and social. Each of these criterion measures is relevant to the ultimate criterion—the adequacy of the description of textbook discourse. Perhaps Stake's term of epistemological harmony or Crocker's functional paradigm are more adequate terms than relevancy. Epistemological harmony and functional paradigm are concepts which help make the term relevancy more explicit, i.e., "Relevant to what"? The case studies of Stake and the implementation studies of Crocker (1983) and Lantz and Kass (1987) suggest that, if a construct such as the STSC Taxonomy is to be judged adequate by teachers, curriculum developers, and/or researchers, then the description must "fit" (to some degree) the existing modes of thought of these people. Their research illustrates the sociological aspects of epistemology. The need for social acceptance of knowledge by the relevant community of scholars can make change slow and difficult.

Relevancy as such has advantages and limitations. Bloom (1956) tried to overcome the limitations of relevancy by making The Taxonomy of Educational Objectives "comprehensive". Comprehensiveness makes Bloom's Taxonomy relevant to some degree to nearly all interest groups or educational movements. A similar attempt at comprehensiveness is made in developing the STSC Taxonomy. The five theoretical perspectives developed in the preactive stage of this study are used to guide the creation of the twenty-two knowledge forms in the interactive stages of the study. This multi-perspective approach is an attempt to increase the chances of epistemological harmony between users and the taxonomy and to develop comprehensiveness in the taxonomy.

The second necessary attribute of the interactive criteria described by Thorndike and Hagan is "freedom from biased". Bloom attempted to overcome the problem of bias and value judgements by claiming to be neutral by virtue of inclusiveness of all educational orientations. In the current study freedom from bias translates into providing an initial opportunity for a wide variety of categories of knowledge to gather empirical support during the classification of discourse. The researcher had to mentally and physically keep the complete taxonomy in a frontal position when classifying each sentence of textbook discourse. As discussed in Chapter 1, the researcher believes that everyone is 100 % biased (Zukav, 1979), but that one way of making bias acceptable is by increasing one's depth and breadth of understanding. Each category of knowledge established has to be understood in depth, and there has to be a continuous openmindedness and willness to change the taxonomy to create even greater breadth to the taxonomy than exists currently.

The third characteristic of criterion measures listed after relevancy and freedom from bias by Thorndike and Hagen is "reliability". To be valid, knowledge must be reliably obtained. In the current study there are three categories of criteria—empirical, conceptual and social-based. Reliability of the empirical criterion relates to the reproductibility of the frequency counts of knowledge forms found in categorized textbook discourse. Reliability of the conceptual criteria is an estimate of the stability and the consistency of application of these criteria (e.g., epistemology, simplicity, and aesthetics) to the structure of the taxonomy. In Chapter 4 a consistent and systematic application of conceptual criteria is outlined. It is difficult to ascribe reliability to the social-based criterion—the social acceptability of the taxonomy. Thorndike and Hagen in 1961 probably did not foresee Kuhnian influences on educational research. There is in this study an attempt to recognize this social criterion by being conscious of the attitudes of both the practical community and the research community.

The fourth Thorndike and Hagen characteristic of a criterion used in criterion-related validity is "convenience and availability". In this study frequency tallies and percentage distributions of tallies are convenient empirical criterion-measures. The conceptual criteria are made public and available to any reader or any researcher interested in replication. The criteria, in this sense, are of the type that do not require sophisticated technological devices or processes. The methodology is more one of philosophical or conceptual analysis than statistical analysis. A methodology was sought that would exhibit epistemological harmony with the relevant audiences—scholars and teachers. The criterion measures chosen are both "convenient and available" to those research audiences.

Construct validity arguments can be used to ascertain the existence of substructure within a test or other instrument. Construct validity is a kind of validity which was important to this study. A construct—an analytical framework in the form of, a taxonomy—is the product of this research study. The overriding purpose of the study is to construct, through a series of eight reconstruction stages, a taxonomy of knowledge forms. The structure of the taxonomy evolves from a complex combination of criteria derived from five theoretical perspectives. Empirical evidence for a postulated factor (category) is not in itself a deciding factor for eliminating or adding categories. The empirical evidence works in dialectic with conceptual criteria for establishing the existence of a knowledge forms within a formal taxonomic structure.

I3. Postactive Validity

Brinberg and McGrath (1982) complete their view of validity by describing postactive validity measures as "robustness". Robustness includes ecological, population and explanatory validity. Campbell and Stanley (1963) use the term external validity to subsume these forms of postactive validity. External validity is concerned with the generalizability of results. This is obviously an important class of validity, but due to the developmental emphasis of this study the researcher concentrated on internal validity. A similar situation existed for ecological validity. For example, can the taxonomic classification developed here be used successfully when the conditions are changed (i.e., in the new contexts of biology and physics textbooks or even in chemistry classroom discourse)? Such questions of generalizability (i.e., ecological validity) are left for further study.

Just as predictions are made early and explanations are made later in a study, predictive validity is a concern early in a study and explanatory validity is a concern later. Explanatory validity is concerned with explaining bodies of data. Interpretations are placed on the data, or the data are analyzed and a formal description arises. Definitions may result. The data may be organized into new constructs. In the classroom an explanation rather than a description is obtained by a series of "Why?" questions. The final chapter, Chapter 6, goes beyond description of textbook discourse to consideration of second and third order constructs that approach an explanatory mode of validity.

Another postactive, external validity determination for the current work is content validity. Although in the present study content validity is concomitant with construct validity considerations in the interactive stages, content and construct validity are externally established in a postactive stage. Authorities were employed to judge the representativeness of the knowledge forms found in each STSCP curriculum emphasis. Each expert was given one or two emphases with its two to seven knowledge forms to judge for completeness of representation. Examples of textbook discourse were included as part of the definitions of each category of knowledge. The experts judged the content of each emphasis for completeness relative to their own experience and background knowledge. The researcher conferred with the judges after their evaluation. The results of this validation were used to revise the content or examples to establish a mutually acceptable taxonomy of knowledge forms.

In summary, concern for validity is central to the study. Empirical, conceptual and social criteria were used in preactive, interactive and postactive contexts. Triangulation (Demain, 1970; Dawson, 1979) is attempted by gathering validation data from a variety of sources. A multiplicity of techniques is employed to ensure the validity of the questions asked (W), the procedures used (KW), and the answers obtained (K). Last but not least valid interpretations are sought.

J. Chapter Summary

The literature considered was organized around the chronological stages of the study and the conceptual analysis methodology used in the study. The complexity of the literature review, like the study, is somewhat alleviated by the use of conceptual analysis and the identification of five theoretical perspectives. Literature on the five guiding perspectives—curriculum emphases, normative perspectives, epistemology, STS science education, and practical inquiry—was reviewed and related to one another. Since the analytical framework created in this conceptual analysis of textbook discourse is a taxonomy, selected literature on taxonomic frameworks was reviewed along with the literature on content analysis of curricular concepts.

In general there is a considerable amount of literature on each of the five individual theoretical perspectives. However, there was no literature found that revealed attempts at integrating a wide range of perspectives to classify textbook discourse. The closest literature found on this topic was that of the STS science educators. In practice, the statements, research, and curriculum outlines of STS educators have often referred to the individual elements of the STSC

Taxonomy of Curricular Discourse, but have not been as specific and/or comprehensive as required within the current work. The combination of purpose, methodology, and product in the current study seems a natural, although fairly unique, outcome of the current state of science education.

Chapter 3: Design and Procedures

A. Introduction

The purpose of this chapter of the research report is to provide an overview of the research design and procedures for the study. However, due to the nature of the research, the specific criteria for decision making are presented in context in Chapter 4. Chapter 4 provides a chronological history of the evolution of The STSC Taxonomy through the first seven stages of the study. The complexity of The STSC Taxonomy (i.e., with criteria from five theoretical perspectives) requires a lengthy description. Since The STSC Taxonomy was the major result of the study, a description of the development and evaluation of the taxonomy is provided as a separate chapter, Chapter 5. In this current chapter the general research design and procedures are presented. In Chapter 4 the specific details of the development of The STSC Taxonomy in stages 1-7 are presented. In Chapter 5 the "final" form of The STSC Taxonomy is described and presented, including the results from Stages 8 and 9 of the study.

The nine stages of the study started with the development of the initial draft of the taxonomy in Stage 1, proceeded through the evaluation of the evolving taxonomy by classifying six units of chemistry textbook discourse in Stages 2-7, and finished with the writing of two examples for each of the sixty-six categories, an external evaluation by judges, and a "final" revision of The STSC Taxonomy in Stages 8 and 9. A description of the specific procedures

Table 3.1
The Stages of the Study

Stage	Purpose	Text	Unit	Content
1	Identify theoretical perspectives Draft first taxonomy	-	-	-
2	Test Draft 1 Revise Draft 1	ALCHEM	L-1982	Energy
3	Test Draft 2 Revise Draft 2	ALCHEM	L-1975	Energy
4	Test Draft 3 Revise Draft 3	STSC	A	Elements
5	Test Draft 4 Revise Draft 4	STSC	B	Compounds
6	Test Draft 5 Revise Draft 5	STSC	C	Reactions
7	Test Draft 6 Revise Draft 6	STSC	D	Stoichi- ometry
8	Write formal rules and definitions Write statements for each category			
9	Prepare evaluation instruments Administer external evaluation Revise Draft 6 of the taxonomy			
X	Intervening stages of practical classroom and author work.			

and evaluation criteria is presented in this chapter, while the specific applications are reported in Chapter 4.

The general design of the study was one of conceptual analysis. The major stages of conceptual analysis as described by Mahung (1980) are 1. the identification and description of theoretical perspectives (or systematic conceptualization) used to guide the formation of an analytical framework, 2. the development and evaluation of the analytical framework, and 3. the application of the analytical framework. In the current study only the first two stages of conceptual analysis were completed. The main purpose of the study was to develop an analytical framework (i.e., The STSC Taxonomy). The "application" of the framework was only for purposes of developing and evaluating the taxonomy. The chronology of the study involved the nine stage development and evaluation of a taxonomy to classify knowledge forms and curriculum emphases found in the discourse of chemistry textbooks.

The early stages of this study accomplished the goal of the first stage of conceptual analysis–the identification of guiding theoretical perspectives. The entire nine stages of the study focussed on the second stage of conceptual analysis–the development and evaluation of an analytical framework (i.e., The STSC Taxonomy). Stage 1 involved the identication of the guiding theoretical perspectives and the conceptualization of the initial draft of The STSC Taxonomy. Stages 2 through 7 involved the continual evaluation and revision of The STSC Taxonomy based upon criteria developed from the five different theoretical perspectives identified in Stage 1. During each of the Stages 2 through 7, a unit (chapter) of discourse from a chemistry textbook was classified sentence by sentence using the then current version of the taxonomy. The eighth stage of the study saw the writing of definitions and examples for each of the sixty-six categories in the taxonomy. The last stage involved the evaluation of the definitions and examples from Stage 8 by external evaluators. The final form of the analytical framework (The STSC Taxonomy) resulted from this nine stage conceptual analysis of chemistry textbook discourse.

B. Stage 1 Procedures

Stage 1 of the study involved the creation of the initial taxonomy of knowledge forms believed to exist in chemistry education discourse, and the identification of the initial set of theoretical perspectives to guide the development and evaluation of the taxonomy. The first set of knowledge forms appeared in a paper written and presented by the researcher as a plenary session at the International Conference for Chemistry Education at the University of Maryland in 1981. This set of knowledge forms was derived from the researcher's reading and experience in the field of science education. This initial taxonomy served as Draft 1 of an analytical framework for classifying chemistry textbook discourse in Stage 2 of the study. The specific details of the initial taxonomy are provided in Chapter 4. The Maryland paper that initialized the study is provided in Appendix A.

The identification of the theoretical perspectives (or systematic conceptualizations) was also initiated during Stage 1. The full impact of the five theoretical perspectives used to develop and evaluate the taxonomy was not felt until after the first couple of trials at classifying textbook discourse. The identification of relevant guiding perspectives and their concomitant criteria for judging the successive taxonomies occurred over a period of time—primarily during Stages 1-3.

The primary ways of knowing employed in developing the initial taxonomy were empirical and referenced. The researcher had been exposed to a wide range of views on science education as a result of being involved in the ALCHEM Chemistry Education Project. In the eight year period previous to the development of the initial taxonomy, the researcher had travelled to conferences in nine of the ten provinces in Canada. The researcher had also presented many inservices within the province of Alberta. The idea of a broader science education for students was the primary message which was being sold by the researcher. This experience had a two fold effect on the taxonomy developed during Stage 1 of this study. Similar to the reports of the evolution of Bloom's Taxonomy (1956), the researcher had to evaluate the internal consistency (including logical fallacies) of the personal presentations being made, as well as, evaluate the presentations against external standards. The science educators who attended the presentations often argued for alternative or additional perspectives on science curriculum and instruction. It was from this background that the creation of a pluralistic taxonomy of science education knowledge forms had its beginnings.

The internal and external evaluation criteria were also established and applied as a result of reading the current literature and being involved with colleagues who were interpreting this literature. The internal consistency of arguments from each singular science education perspective was found to be sound. This was to be expected from established literature in the field. Any logical fallacies should have been discovered by the community of science education scholars prior to this research starting. A primary task of the researcher during Stage 1 was to become aware of the arguments used by the proponents of each perspective. The major task during the rest of the study was to establish a logically defensible multi-perspective view of science education.

The concepts of contexts, normative perspectives, epistemological approaches and curriculum emphases were all usefully intertwined for purposes of creating the classification system. However, the concepts are distinct from one another. Context was used to refer to the situation or location within which textbook discourse was set. The context could be the school laboratory, the science or engineering research laboratory, hundreds of consumer, commercial and industrial applications, political debates or discussions of communication or pedagogic standards. The contexts for the presentation of chemistry textbook discourse are unlimited. The identification of contexts is necessary to use the classification system developed in this study. However, the context can be very narrow or very broad and, therefore, context as a term cannot be used to represent a group of knowledge components such as science or technology. For this reason the term curriculum emphases (Roberts, 1982) has been used in this study to nest component knowledge forms. It was and is not intended that the use of the term curriculum emphases be restricted to those emphases uncovered in this study.

The use of the terms normative perspectives, epistemological approaches, and epistemological preferences has been previously explored conceptually by science educators. In the current study a test is made of the use of epistemological approach as a conceptual organizer of normative knowledge forms in chemistry textbook discourse. Linkages among epistemology, curriculum emphases and normative knowledge forms were sought through the analysis of curricular discourse in chemistry textbooks. The use of a multi-perspective approach to classifying curricular discourse produced some unexpected results in this study.

C. Stage 2-7 Procedures

Stages 2-7 involved the evaluation of the then current taxonomy by using the taxonomy to classify chemistry textbook discourse. If the discourse could not be classified, the taxonomy was revised. The details and results of this process are presented below and in Chapter 4. The first task in Stage 2 was the selection of the chemistry textbook discourse to be classified. The decision was made to classify the 1982 and 1975 editions of the Grade 12 ALCHEM Energy units—33 and 47 pages of discourse, respectively. This classification would be followed by the classification of discourse in the 1984 edition of the Grade 10 **STSC Chemistry** 10 textbook. The reasons for these choices are presented below.

The researcher was the ALCHEM Project Director, was one of the ALCHEM authors, and was a teacher of the ALCHEM materials. As a result of this experience, the Grade 12 Energy unit was chosen from among all of the ALCHEM units for classification. The researcher felt that the Energy unit was appropriate because of its mix of empirical and theoretical content, science-in-society context, and technological applications of chemical knowledge. These selection criteria came from a combination of theoretical perspectives. The Energy unit could be presented in the classroom from a variety of curriculum emphases. Therefore, a variety of curriculum emphases would need to be described by the taxonomy being developed and evaluated. The Energy unit had also caused teaching and learning difficulties for many years. The suspicion that the researcher had was that the mix of empirical and theoretical knowledge (e.g., fact and theory) was presented in a confusing manner. From a practical perspective, the researcher, as author and teacher, was interested in a detailed description of the Energy unit. It was thought that an analysis of this description might lead to a more effective writing of the Energy unit in the new textbook being written. From a research perspective, the decision to describe the 1982 and 1975 ALCHEM 30 Energy units was based on the expectation that these stages (i.e., Stages 2 and 3) were necessary to develop the taxonomy to a point where it could be more extensively tested by the **STSC Chemistry** material.

To describe the knowledge forms in the **STSC Chemistry** 10 textbook was considered a major test for the taxonomy. The objectives and goals of the **STSC Chemistry** Project were similar to the objectives and goals of this research. The Project and the research were seeking to integrate a pluralistic view of science education into a textbook and a taxonomy, respectively. Not coincidental was the fact that the researcher was one of the authors of the **STSC Chemistry** materials.

A dialectic relationship between the research and the STSC **Chemistry** Project was sought. It was believed that there were many mutual benefits that could be derived from this relationship. The intense and extensive debates among the seven authors of the STSC **Chemistry** Project were expected to help evaluate the taxonomy in both an internal and an external sense. Besides being able to argue the logical consistency of the STSC content, the teacher-authors were able to evaluate these constructs in classroom situations. This feedback from the ALCHEM and **STSC Chemistry** authors indirectly and directly assisted the evolution of the taxonomy developed in this research.

Likewise, the **STSC Chemistry** Project benefitted from the relationship with this research. The description of the **STSC Chemistry** 10 textbook was provided to the author group. The authors were able to use the taxonomic description to evaluate and evolve the **STSC Chemistry** 10 materials. Concurrently, the researcher was able to use the taxonomic description to evaluate and evolve the STSC Taxonomy.

D. Procedures for Using the STSC Taxonomy

The procedures for using the STSC Taxonomy evolved quickly during Stage 2—the description of the ALCHEM 30 1982 Energy unit. Some of this Energy unit had to be reclassified as a result of changes in classification rules and categories. The introduction of new categories at other stages resulted in similar action within that particular stage. Changes in classification rules and categories did not result in the reclassification of previously completed units. The purpose of the study was to develop and evaluate a taxonomy that could accurately describe textual discourse, but not necessarily accurately describe discourse classified by an earlier draft of the taxonomy. A full description of the evolution of the STSC Taxonomy is provided, along with criteria for the changes, in Chapter 4. Only the general procedures and criteria for analysis are presented in this chapter. The reader will need to reference the STSC Taxonomy matrix presented at the front of the thesis for a translation of the symbols used in this chapter (e.g., "K The W" translates literally to knowledge of a theoretical way of knowing and refers to using a theory as procedural knowledge to produce resultant knowledge).

D1. Rules for Using the Taxonomy

The following rules for using the STSC Taxonomy were developed from experience and experiment and continue to evolve as the experience broadens. General empirical rules to be followed when using the classification scheme have been listed below. These rules could be changed without affecting the STSC Taxonomy itself—the rules mainly try to establish a consistent use of the taxonomy. Examples of classified discourse appear later in this section of the research report.

1. Each sentence is be classified at least once. Classifying sentence fragments results in classifying some sentences into two or more categories.

2. No mast-heads, headings, or footers are classified.

3. Each line of a table of given knowledge, including the heading, is classified up to a maximum of five entries beyond the heading. If the table requires student input, each line of a table is classified in totality.

4. A large number of simple examples is classified only up to a maximum of five.

The rules other than the first one above are arbitrary and could be changed without much effect on the description of discourse received by using the taxonomy. However, the nature of the full STSC Taxonomy requires that the first rule be followed—classify each sentence at least once. The specificity of the full taxonomy requires a small unit of discourse for analysis. If, however, the taxonomy is collapsed from twenty-two knowledge form categories to the five—STSCP—curriculum emphases, larger units of discourse may be classified (e.g., paragraphs, pages or even chapters of textual material). The purpose for using the taxonomy should dictate the unit of classification. In this research project the sentence or sentence fragment is deemed appropriate. Experience within this research study indicates that the search for kinds of knowledge within textual discourse requires a small unit for classification. The kind of knowledge often changes within a single sentence, or procedural knowledge is presented in the same sentence with produced (resultant) knowledge. Examples are provided later in this section.

As illustrated in the symbols table and in Figure 6.17 at the end of the thesis, the STSC Taxonomy is three dimensional, including:

1. an STSCP curriculum emphases (e.g., science, technology, society, communication, and pedagogy) dimension
2. a knowledge form (e.g., theoretical, empirical, process, and epistemology) dimension that varies from one STSCP curriculum emphasis to another
3. a K-KW-W epistemological triad (kinds of knowledge, knowledge of ways of knowing, and ways of knowing) dimension that is prevalent throughout.

Knowledge forms are nested within curriculum emphases, and epistemological triad is nested within each knowledge form. Following is a description of how each of the dimensions listed above should be used for classifying curricular discourse. A major section with examples follows this section.

D2. The STSCP Emphases Dimension

The STSCP dimension includes science, technology, society, communication, and pedagogy emphases. As this study evolved, the creation of five curriculum emphases on general classes of knowledge and ways of knowing seemed to work best in classifying textbook talk. When classifying textual statements the STSCP emphasis must be classified first before deciding on the knowledge form subcategory. See the STSC Taxonomy on the symbols page and the examples which follow in the next sequence of pages. Presented below are the general initial definitions of the STSCP emphases. More specific definitions evolved during the study. The taxonomic subcategories are eventually used to define each curriculum emphasis.

1. The science (Sci) emphases includes produced knowledge (resultant knowledge, K) about the natural world as gathered by scientists, students and laymen. Ways of knowing (required action, W) and knowledge of these ways of knowing (procedural knowledge, KW) are also included in the science category as in all STSCP categories. In the STSC Taxonomy the definition of science is restricted to the study of natural phenomena and the scientific principles used to explain the workings of a technological device (e.g., the motion of planets and artificial satellites).

2. The technology (Tec) emphasis includes the knowledge and study of manufactured products, processes and skills. This category includes technological process skills and technological problem solving (e.g., operating a balance and manipulating reaction

rates, respectively).

3. The society (Soc) emphasis includes the knowledge and study of social interaction of human beings concerning issues of science, technology and society. The society category is restricted to knowledge and study relating science, technology and society (STS) issues (e.g., acid rain and toxic waste disposal).

4. The communication (Com) emphasis is restricted to including the knowledge and study of scientific and technological communication as practiced by scientists, engineers and technicians. Communication systems used by scientists and engineers are classified into this category (e.g., IUPAC and SI systems).

5. The pedagogy (Ped) emphasis is restricted to the pedagogical statements made in science-education discourse. This category also includes certain knowledge forms that can best be described as pedagogic rather than scientific or technological (e.g., memorized or referenced knowledge).

The STSCP emphases were not created until Phase 4 of the study—the start of the analysis of the **STSC Chemistry** materials. The procedure prior to that was to classify the knowledge form directly, without thought of curricular emphases. The history of the creation of the curriculum emphases, and the criteria for such creations, are presented in Chapter 4.

D3. The Knowledge-Form Dimension

The knowledge form categories vary among STSCP emphases, although an epistemology knowledge form is included in every curriculum emphasis category. In the science emphasis, the knowledge form categories employed were theoretical, empirical, scientific process and epistemological. The empirical, process and epistemology categories are carried over into the emphasis called technology but not into other emphases. Perhaps later work on the STSC Taxonomy may see a greater carry-over of the knowledge form categories into all STSCP emphases. Each knowledge form category is defined and six examples for each are given in Chapter 4. Familiarity with these definitions and examples is necessary to the use of the STSC Taxonomy for classifying curricular discourses. Procedurally, the particular kind of knowledge can be determined by reflecting on the way of knowing that was employed in originally getting that kind of knowledge, and, in some cases, looking at <u>who</u> obtained the knowledge.

D4. The Way of Knowing Triad Dimension

The way of knowing triad dimension has been found by this empirical study to have three components—kinds of knowledge (K), knowledge of a way of knowing (KW), and way of knowing (W). The way of knowing triad may also be called the K-KW-W triad or the epistemological triad. This dimension of the taxonomy may be classified independently of the other dimensions of the taxonomy. For example, the sixty-six category taxonomy could be collapsed to a three category taxonomy—K, KW, and

W.

1. The knowledge, K, subcategory is resultant knowledge presented to students by the authors of the written materials. The knowledge has been produced by someone else and then presented in textbook discourse.

2. The knowledge of a way of knowing, KW, subcategory includes procedural knowledge presented to people concerning how to use a particular way of knowing. This procedural (or methodological) knowledge should be very specific and should allow the person to then adopt that way of knowing.

3. The way of knowing, W, subcategory is usually a question, problem or action required of people. This category requires action from the student; e.g., homework and laboratory work.

The K-KW-W way of knowing triad is used to classify every sentence or sentence fragment. Sometimes sentences will include KW-K and KW-W combinations. Examples are provided over the next few pages and in Chapter 5.

D5. Using the STSC Taxonomy

Using the above rules and definitions, the classification of each sentence or sentence fragment was completed in the margin of the textbook using a set of codes. The codes were standardized to represent the three dimensions of the classification system. Where similar codes were used within the same or different curriculum emphases, subscripts were used to differentiate the classes. The symbols for the complete set of sixty-six categories from the 22 x 3 taxonomic matrix are presented in the Symbols Table. The coding is translated and interpreted below. The translations do not define the categories—complete definitions and examples for the sixty-six categories are provided in Chapter 5. As the STSC Taxonomy is used, a memorized way of knowing the categories and symbols rapidly takes over from a referenced way of knowing. Refer to the Symbols Table as you read the translations below.

Emp K_E - empirical knowledge gained from experience or scientific experiments

Emp K_L - empirical knowledge gained from scientific generalizations or laws

Emp K_T - empirical knowledge gained within a technological context

Reference to the summary of the taxonomy in the Symbols Table indicates that of the three empirical knowledge forms, the first two categories are part of an emphasis on science and one is part of a technology emphasis. Usually subscripts refer to the curriculum emphasis—science (S), technology (T), society (SS), communication (C), or pedagogy (P). For example, the epistemological knowledge form is the only one that repeats through all five curriculum emphases. The symbols used and their translation are provided below.

Epi W_S - an epistemological way of knowing required of people within a science emphasis

Epi W_T - an epistemological way of knowing required of people within a technology emphasis

Epi W_{SS} - an epistemological way of knowing required of people within a science-in-society emphasis

Epi W_C - an epistemological way of knowing required of people within a communication emphasis

Epi W_P - an epistemological way of knowing required of people within a pedagogy emphasis

The K-KW-W triad in the STSC Taxonomy was coded during classification of discourse by using the format K for the kind of knowledge, KW for knowledge of a way of knowing, and W for a way of knowing. Examples of the symbols and their translation are provided below.

Pro K_S - resultant knowledge produced from a scientific process way of knowing and given in a textbook

K Pro W_T - given procedural knowledge about a technological process

Ped W_R - a pedagogically referenced way of knowing required of a person by a question in a textbook (i.e., the answer has to be referenced somewhere)

Using this type of coding system, each sentence or segment thereof was classified in the margin of the textbook. In many cases there was more than one class per sentence or question. Most of these double classifications involved procedural knowledge (i.e., KW) followed by resultant knowledge (i.e., K) or a question (i.e., W). The two codes are separated by a slash as illustrated below.

(1)His K/Nat K/ Emp K_L	(1)In 1864, John Newlands (1838-1908), an English chemist, arranged the elements in increasing order of atomic masses.
(2)Emp K_L	(2)Newland noted that various properties repeated themselves with every eighth element.
(3)Com K	(3)This is the first example of a <u>periodic law</u>.
(4)Emp K_L	(4)When elements are arranged in order of increasing atomic mass, chemical properties repeat themselves at regular intervals.
(5)?/Com K/Epi K_C	(5)Unfortunately, Newlands referred to this observation as the Law of Octaves—an analogy to the octave scale in music.
(6)K Epi W_S/Epi K_S	(6)Since there is no logical connection between music and chemistry, Newlands was ridiculed by many of his peers and his periodic law was not accepted by the scientific community.

In the paragraph of textual discourse classified above the sentences have been numbered for reference. <u>Sentence 1</u> presents two pieces of historical knowledge, "In 1864" and "(1838-1908)", which are coded once as His K. Since the two pieces of knowledge are related, only one coding for His K is made in the margin. Sentence 1 also presents two pieces of national knowledge "John Newlands" and "an English Chemist". Personal names and an indication of nationality are typical examples of what is coded as Nat K. <u>Sentence 2</u> presents a regularity or generalization noted by Newlands. This sentence presents empirical knowledge in the form of a generalization and is therefore coded as Emp K_L. <u>Sentence 3</u> is communicational knowledge (Com K) by giving a name to the relationship presented earlier—the periodic law. <u>Sentence 4</u> is a formal presentation of a periodic law—an <u>emp</u>irical <u>l</u>aw (Emp K_L). <u>Sentence 5</u> begins with the word "Unfortunately" which is difficult by inference to place in the taxonomy and is therefore coded as "?". Naming the observation "The Law of Octaves" is best coded as communicational knowledge (Com K). The phrase "an analogy to the octave scale in music" in Sentence 5 is classified as epistemological knowledge ($Epi\ K_C$) in a communication emphasis because of the word "analogy". Students had learned earlier that scientific knowledge can be communicated by analogies.

Within the context of what the students had learned, the reference to an analogy was knowledge resulting from an epistemological way of knowing about communication. The classification of this phrase illustrates the need for knowing or inferring the context for the presentation of the discourse. As is the case for using Bloom's Taxonomy of Educational Objectives, the context is inferred first from the previous textual discourse and secondly, and only as a last resort, from what students might have learned during past educational experiences. This problem uncovers both a weakness and a strength in the use of the taxonomy. If the previous educational experiences have to be inferred from outside the textual discourse, then maybe the textual discourse should be revised to refer students to the past experiences or past discourse in the textbook (e.g., via parenthetic or margin notes).

Sentence 6 in the above paragraph of textbook discourse is coded as $K\ Epi\ W_S/Epi\ K_S$ to reflect the procedural knowledge ($K\ Epi\ W_S$) plus resultant knowledge ($Epi\ K_S$) content. The first phrase, "Since there is no logical connection between music and chemistry," presents the epistemological procedural knowledge ($K\ Epi\ W_S$) that logical connection is a criterion of judgement for accepting knowledge. The knowledge that Newland "was ridiculed" and his "law not accepted" is resultant knowledge ($Epi\ K_S$) from taking an epistemological view of the situation.

That there might be a different coding of a particular sentence or phrase does not reflect too adversely on the taxonomy. If two people were to argue the classification of the discourse one way or the other, then this lends support to the existence of both knowledge forms for which they are arguing. If a strong conceptual argument for a knowledge form that did not currently exist in the taxonomy was made, then a new knowledge form may have to be created and subsequently tested empirically against textual discourse. The process is open-ended and never ending.

In summary, curricular discourse was classified using a taxonomy which was continually developed and evaluated during the classification of six chapters of textual discourse. Each sentence or fragment was classified using a unique communication system. Several pages of the original classified discourse are presented in Appendix D. Curriculum emphases followed by nested knowledge forms followed by a nested K-KW-W triad were classified in turn for each textual statement encountered. The tallies were used as evidence for the existence of each category in the taxonomy.

E. Criteria and Procedures for Revising the Taxonomy

In Chapter 4 there is a complete history of the changes made in the STSC Taxonomy during Stages 1-7 of the study. Each change made in the taxonomy is documented individually. The criteria for making the changes were derived from the five theoretical perspectives used to guide the conceptual analysis of the textbook discourse. The five theoretical perspectives used were 1. curriculum emphases, 2. normative perspectives, 3. epistemology, 4. STS science education, and 5. practical inquiry. These perspectives are described in Chapter 2. The criteria for revising the taxonomy that were derived from the five perspectives are listed below.

1. From a curriculum emphases perspective, an internal logic within emphases and, if possible, a parallel structure between emphases was sought. For example, the science curriculum emphasis has an internal logic that links theoretical knowledge, two kinds of empirical knowledge, two kinds of theoretical-empirical knowledge combinations, and epistemological knowledge. Knowledge forms were then created within the technology emphasis to parallel the knowledge forms in the science emphasis. Internal logic and parallel structure for curriculum emphases were criteria used to evaluate the taxonomy at each stage development.

2. From an epistemological perspective, the justification for the creation of curriculum emphases (i.e., the five STSCP emphases) was the discovery of epistemological content for such a curriculum emphasis. For example, the communication emphasis is unique to the STSC Taxonomy, and was justified on the basis of discovered epistemological content in textbook discourse. The epistemological content concerned the way in which communication systems come to be accepted by the scientific community.

3. From an epistemological perspective, an epistemological triad was a necessary criterion for the establishment of a knowledge form. For example, some knowledge forms were tentatively identified from K only, KW only or W only statements. A complete K-KW-W epistemological triad needed to be identified before the knowledge form was accepted into the STSC Taxonomy.

4. From an STS science education perspective, a criterion for the STSC Taxonomy was that it should help to define STS science education. Toward this end, STS was adopted as three of five curriculum emphases, and specific knowledge forms within each STS emphasis were identified and defined.

5. From a normative perspective, all knowledge forms widely accepted within the science education community were included in the STSC Taxonomy. Often there was a struggle to find a logical placement of these common knowledge forms within the structure of the taxonomy. For example, psychomotor skills were included as technological skills in the technology emphasis of the taxonomy, and the scientific process knowledge form was redefined as student work only in order to make the logic of the taxonomy consistent.

6. From a practical perspective, the STSC Taxonomy should both guide and reflect practice. For example, the taxonomy should help curriculum developers write curriculum outlines, help authors write science textbooks, and help teachers with classroom discourse.

7. From a research perspective, the relative frequency count of statements classified into each category of the taxonomy is a criterion for accepting knowledge forms into the taxonomy. For example, very high frequency counts resulted in the split of a category into two categories, high frequency counts confirmed a category, and low frequency counts over several units of textual discourse resulted in the dropping of a category. Based upon other criteria, a low frequency count may not be sufficient reason to drop a category from the taxonomy.

All of these criteria were used in as simultaneous a fashion as possible to evaluate the taxonomy. A requirement for the selection of the criteria was that they be pluralistic; i.e., reflect a variety of perspectives from within the science education community.

In some cases problems arose from the perceived deficiencies in the ability of the taxonomy to classify discourse. The design of the study required action when a test of the taxonomy showed deficiencies in the taxonomy. The revision of the classes of textbook discourse involved several alternative procedures. A full chapter of this report—Chapter 4—has been devoted to describing in detail the changes made in the taxonomy at each stage in the study. The criteria and reasoning are presented in Chapter 4, the type of changes and an example for each are presented below.

1. A category was created if there was evidence of a knowledge form which could not be classified within the existing taxonomy (e.g., statements about how communication systems come to be accepted by the scientific community required the creation of the epistemology

of communication (Epi_C) category).

2. The category was split into two categories if it was overloading and/or a logical split was evident (e.g., the heavily loaded empirical knowledge category in science was split into experiential (Emp K_E) and generalizable (Emp K_L) empirical knowledge).

3. The definition of the category was restricted to a more limited context if textual statements in that category appeared too broad in scope (e.g., the epistemology category in science initially included all epistemological statements, but was eventually restricted to just science).

4. A category was renamed if more commonly accepted names became apparent (e.g., the parochial (Par) category became specifically Canadian (Cdn) and then more generally national (Nat)).

5. A category was removed if empirically it received no action and if conceptually it did not fit the logic of the system (e.g., psychological knowledge (Psy K) was removed for a combination of these reasons).

6. A category was moved from one STSCP emphasis to another if the conceptual fit did not seem right (e.g., ecological knowledge (Eco K) was initially moved back and forth between the science and the society emphases before ending up in the society category).

7. A category was split, with one part going to one emphasis and the other part to a different emphasis if a parallel structure between

emphases became apparent (e.g., the process skill category was split into scientific process skills and technological process skills).

8. Terms traditionally used in science education were changed if the internal logic of the taxonomy demanded it (e.g., psychomotor skills were renamed and reconceptualized as technological process skills).

9. Categories were redefined in terms of each other if an overlap of categories resulted in difficulties in the classification of curricular text (e.g., the empirical and process categories in the science and the technology emphases were split by restricting the process skills categories to student laboratory activities).

10. New curriculum emphases were created if there appeared to be an epistemological necessity resulting from the discovery of new categories of epistemological content in curricular discourse (e.g., the communication emphasis was created when espistemological content concerning the criteria for accepting communication system was discovered in the **STSC Chemistry** textbook).

Only singular examples of criterion-based changes in the STSC Taxonomy have been presented above. The detailed reasoning for the specific changes listed plus many more is presented in Chapter 4. The examples presented above were illustrative only at this point in the report.

F. Stage 8 Procedures

Stage 8 in the study involved the development of two example—textbook discourse—statements for each of the sixty-six categories in the "final" version of the STSC Taxonomy. The complexity of the taxonomy required that examples were needed to help define the category. Two examples were considered necessary but sufficient to illustrate the different kinds of statements that might fit into one particular category. The examples are presented, accompanied by a conceptual description and status report for each category, in Chapter 5—The Evolution of the STSC Taxonomy of Curricular Discourse.

The examples developed in Stage 8 of the study were not chosen from the textbooks discourse classified. The one hundred and thirty-two examples are written with primarily a high school chemistry education context. An attempt was made to narrow the chemistry context to examples involving water. Previous in-service presentations had been made by the researcher using water as the context for presenting perspectives (e.g., aesthetic, ecological, legal, political and scientific statements concerning water.) This experience led the researcher to an attempt at the same approach to developing example statements to illustrate the STSC Taxonomy categories. It was felt that a common context, employing perhaps the most important chemical on our planet, might help when comparing different kinds of knowledge and ways of knowing. Some sample statements within a water-context from STSCP emphases, respectively, are provided below.

The K: The oxygen atom in the water molecule is surrounded by two lone pairs of electrons and two bonding electrons.

K Tec W: Water may be used to mine sodium sulfate from the bottom of lakes.

His W: Discuss how the water wheel may have influenced the development of the cottage industries in Britain during the industrial revolution.

K Com W: Instead of calling $H_2O_{(l)}$, hydrogen oxide, the scientific community prefers to call this substance "water".

Ped Kp: The purpose of this laboratory work is to gain a better appreciation of the importance of water as a solvent.

The water-context for all of the 132 example statements provided in Chapter 5 was not followed. For example, the researcher did not provide a water-context for a sociological way of knowing question within the science-in-society emphasis.

Soc W: Try to stand back from your society and interpret the effect of removing technology from your everyday life pattern.

The procedure that was followed to write the two example statements for the sixty-six categories involved several rewrites. One or two examples for each category were written during draft one. The initial examples were revised and the remaining examples were written during the completion of several more drafts.

Some of the cells in the 22 x 3 taxonomic matrix had produced zero tallies during the classification of statements in six units of textbook discourse. These categories were created for logical and/or philosophical reasons. For example, no statements representing the K Emp W_E-K The W category were found in any of the six units of textual discourse analyzed. The writing of example statements allowed the researcher, and will allow future users of The STSC Taxonomy, to judge the validity of this taxonomic category. If an example statement could not be written or if the example statement appeared to repeat a statement in another category, then the category would be omitted. For example, context categories were eventually eliminated due to the fact that all example statements written could be classified within other categories.

The reinterpretation or refinement of a taxonomic category was another potential goal for the writing of examples. Relatively loose definitions supported by recalled and re-examined discourse were used during Stages 2-7 to classify textbook discourse. It was not until formal definitions and examples were written during Stage 8 that some long-term and some alternate interpretations were solidified. For example, the researcher had trouble with the difference between Pro K_S (process knowledge) and K Pro W_S (knowledge of a process way of knowing) until the formal definitions and examples were written. The realization that K Pro W_S was textual, while Pro K_S had to, by definition, be produced by students. This is now obvious but caused many difficulties during the study. Although over 500 statements in the six units of discourse analyzed were categorized as a scientific process knowledge form (Pro_S), some of the statements classified Pro K_S were misclassified according to the definitions established during Stage 8. The tallies made during Stages 2-7 were not changed as a result of these reconceptualizations of certain knowledge forms. The knowledge forms had been established empirically during Stages 2-7.

The fine structure of the triads within each knowledge form was developed, evaluated and redeveloped during Stage 8.

In summary, Stage 8 served to consolidate and define the sixty-six categories of the STSC Taxonomy. Evidence for twenty-two knowledge forms was found during the classification of six chapters of textual discourse in Stages 2-7. In many cases an incomplete K-KW-W triad within each knowledge form was found in the textual discourse. The formal definitions and examples served to test the logical existence of these incomplete triads. An accommodation of the triad into the taxonomy by the researcher required that several criteria be met.

1. The triad must describe an observed or created set of statements.
2. The triad must be internally consistent and must exhibit a logically-fit within the structure of the taxonomy.
3. The triad must add to the elegance, economy, and parsimony of the taxonomy.

At the conclusion of Stage 8 of the study the STSC Taxonomy was in relatively final form. Rules for use, conceptual definitions, and example statements had been written by the researcher. In the final stage of the study, Stage 9, external experts in curriculum discourse were asked to judge the content validity and general fruitfulness of the taxonomy.

G. Stage 9 Procedures

A limited amount of external evaluation was completed on the STSC Taxonomy by a panel of judges during Stage 9 of the study. During the development of the taxonomy of knowledge forms through Stages 2-7 the taxonomic categories were tested externally against six chapters of textual discourse. Stage 8 of the study concentrated on an internal evaluation of the taxonomy in terms of the internal logic of the curriculum emphases and the knowledge form triads. During Stage 9 six judges were asked to critique the descriptive structure of the taxonomy, the definitions and example statements for each of the sixty-six categories, and the fruitfulness of the taxonomy.

The six judges were assigned to two groups. Each group classified sixty-six of the examples created in Stage 8. The examples were presented in random order as determined by numbers generated from a computer program that eliminates DOS interference from the RND command in the Apple computer. This computer program is presented in Appendix C. The two instruments containing the examples are also presented in Appendix C. Many of the examples have now been reworded and are presented in Chapter 5 in the "final" descriptive form of the STSC Taxonomy of Curricular Discourse. The assignment of judges and odd and even numbered examples is summarized in Table 3.2.

From a practical inquiry perspective the researcher decided to involve six authors of the ALCHEM and the STSC Chemistry materials in the content validation process. It was felt that this relationship would be mutually beneficial to the authors and to the research. The authors had demonstrated an expertise in and a long-term commitment to a pluralistic approach to science education. Their criticisms of the analytical framework created in Stage 1-7 and of the definitions and examples created in Stage 8 were deemed necessary at this point in the development of the taxonomy. Before the taxonomic structure could be communicated to the general science education community, the descriptions and examples for each category had to be judged pedagogical sound. These descriptions and examples were communication devices necessary to convince the education community of the worth of the STSC Taxonomy of Curricular Discourse. The authors were also interesting in what they might learn to assist in their practical activities of authoring and teaching. A dialectic between the conceptual concerns of the research and the practical concerns of the classroom was promoted at many stages in this study, including Stage 9.

The judges were also asked to edit the example statements as they classified the sixty-six textbook statements assigned to them. The four instruments described in Table 3.2 are presented in Appendix C. Editing was done on the basis of factual content and clarity, as well as on the ambiguity of classification. If the evaluators felt that the classification of an example statement as S, T, S, C or P (or as K, KW or W) was hampered by the wording, they were asked to record their concern for future discussion. A post-classification interview was held with each judge to confirm their answers and obtain verbal explanations of their recommendations.

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education communities as criteria for taxonomic descriptions (Bloom, 1956). Complete copies of the two questionnaires are provided in Appendix C. The results from the evaluations are presented in Chapter 5. The inteviews with the judges assisted in the writing of the status reports presented in Chapter 5 for each of the twenty-two knowledge forms and five curriculum emphases.

H. Chapter Summary

In summary the experimental design for this study involved a nine-stage process to develop and evaluate a taxonomy of curricular discourse. The first stage of the study saw the development of the first draft of the taxonomy of normative knowledge forms and the identification of five theoretical perspectives to guide the development and evaluation procedures. The second through the seventh stages involved tests of the content validity of the taxonomy by classifying six chapters of chemistry textbook discourse. The taxonomy was continually evaluated and revised during these six stages of the study. During Stage 8, formal definitions and examples were written for each of the sixty-six categories in the STSC Taxonomy. In the last stage of the study, judges were asked to evaluate the taxonomy for content validity and utility, and a "final" revision of the definitions and examples was completed.

The experimental design was one of conceptual analysis—the identification of guiding theoretical perspectives followed by the development and evaluation of a conceptual framework. The conceptual framework in this case was a taxonomy of curricular discourse. The taxonomy was developed and evaluated by classifying textual discourse. However, it was assumed that the taxonomy would eventually have much wider utility. The taxonomy was to become conceptual knowledge generally useful to the science education community in both an understanding and in a practical sense. For as Kaplan (1964) states, "concepts mark the path by which we move most freely in logical space." The success of this research will be eventually judged by that criterion.

Chapter 4: The Evolution of the STSC Taxonomy

A. Introduction

This study has two basic sets of results. Evidence was collected in the form of classification tallies that either supported or refuted the ability of the then current taxonomy to describe chemistry textbook discourse. The second set of results was the classification system itself as a product of the research. The former evidence is presented in this chapter as background to the evolution of the taxonomy. The taxonomy as product is described in Chapter 5 along with the results of the external evaluation of the taxonomy.

The reader is provided with a fairly detailed, chronological account of the research. Many of the difficulties encountered are related to the complexity of the research paradigm. Some aspects of the practice-theory (research and development) dialectic that define the context of the research are messy and are hard to relate to each other. But in order to relate the type of criteria that were used in making decisions, the researcher feels that a detailed account of the progression of the research is necessary. Each decision about the retention or rejection of a category in the taxonomy was based on a plurality of criteria. Since the relevant criteria varied from one decision to another, each decision is presented separately and in sequence of occurrence.

The reconstructed account of the development of the taxonomy includes both quantitative and qualitative—empirical and conceptual—evidence. The report of this evidence is organized into the nine stages outlined in earlier chapters and repeated here. The stages of the research can be tied directly to the textbook discourse classified, as communicated in Table 4.1.

The nature of the interplay between the conceptual and the empirical aspects of the study could be described as dialectic. An overall view of the study may be achieved by thinking of the study as a cyclic progression from the conceptualization of the taxonomy through a series of empirical tests to the final (for the current study) reconceptualization of the taxonomy. The series of development and evaluation cycles that the taxonomy was put through is reported below.

B. Stage 1: The Initial Conceptualization of the Taxonomy.

Historically, the conceptualization of the STSC Taxonomy can be traced backward in time by examining the researcher's vita in Appendix D and the Personal Ground section of Chapter 1. The vita and personal ground statement reveal dual commitments to the practical world of the classroom and to the conceptual world of science education research. These documents also reveal a strong commitment to integrating alternative viewpoints into curriculum practice. The researcher's involvement as an author and director of the ALCHEM chemistry education project contributed to the eventual conceptualization of the STSC Taxonomy in several ways. First, the authors of the ALCHEM chemistry materials integrated senior-level chemistry content with

Table 4.1
The Stages of the Research Study

Stage	Development and Evaluation Activity
Stage 1.	identifying the theoretical perspectives for guiding the development of the analytical framework, and conceptualizing the first draft of the taxonomy
Stage 2.	evaluating the initial taxonomy by classifying the discourse in the 1982 edition of ALCHEM Unit L (Grade 12 thermochemistry)
Stage 3.	evaluating Draft 2 of the taxonomy by classifying the discourse in the 1975 edition of ALCHEM Unit M (Grade 12, thermochemistry)
Stage 4.	evaluating Draft 3 of the taxonomy by classifying the discourse in the 1984 edition of **STSC Chemistry** Unit A (Grade 10, periodic laws and atomic theories)
Stage 5.	evaluating Draft 4 of the taxonomy by classifying the discourse in the 1984 edition of **STSC Chemistry** Unit B (Grade 10, communicating and predicting chemical formulas)
Stage 6.	evaluating Draft 5 of the taxonomy by classifying the discourse in the 1984 edition of **STSC Chemistry** Unit C (Grade 10, communicating and predicting chemical reactions)
Stage 7.	evaluating Draft 6 of the taxonomy by classifying the discourse in the 1984 edition of **STSC Chemistry** Unit D (Grade 10, communicating and predicting stoichiometric reactions)
Stage 8.	conceptualizing the categories of the 22 x 3 taxonomy by writing definitions and examples for each of the 66 categories
Stage 9.	gathering evidence of the validity of the STSC Taxonomy in an attempt to refine the conceptual and operational definitions of the curricular emphases and knowledge forms identified over the course of the research

applied and descriptive chemistry contexts and with a distinctively pedagogic textual format. The classification and integration of different knowledge forms during the ALCHEM project foreshadowed the more formal operationalization of this methodology during the current study.

The second influence that the ALCHEM project involvement had on this research study was the opportunity that the project provided to be involved in intensive discussions with educators offering differing points of view. Regardless of the rating or priority assigned by this researcher to the points of view expressed by others, a recognition and tolerance for such views was developed. The ability to classify the points of view of the hundreds of people met during and after inservice presentations was an asset not only in that context but also during the development of the STSC Taxonomy.

Another context that influenced the researcher's interest and skills in classifying conceptual positions taken by science educators was the years of writing textbooks with a team of authors. The intellectual arguments that were part of the team-authoring approach fostered the ability to find alternative points of view with which to enter the discussions. This process involved not only an identification and expression of personal points of view but also a perceived necessity to express points of view not highly valued by the author group.

The use of classification systems with students in the classroom also developed an appreciation for the descriptive power of such devices. In the classroom context students of the researcher were asked to use a modified version of Aikenhead's (1975) classification of "ways of knowing". The students were assigned the task of classifying "perspectives" taken on science in society issues within videos and films, magazine and newspaper articles, and textual material. The students and the researcher modified the list of perspectives to more completely and simply describe the variety of perspectives taken on issues. The research lesson learned from this practice was that a classification system of conceptual positions can be created and/or evolved by the empirical procedure of classifying discourse—verbal or written. The issue-perspectives classification system was continually revised through classroom use until a list of twelve categories were agreed upon. The list is presented in the form of a wheel in Appendix B. Pilot work was also done with students analyzing the evidence gathered from classifying discourse for patterns of issue perspectives presented within the media. For example, students were able to identify perspectives favored or ignored by the media, and were able to identify the favored perspectives in different newspapers in a city.

Another classroom research context that developed the researcher's interest and skill in classifying discourse was that of having students identify scientific language in scientific articles. Students were asked to underline phrases in written discourse which identified the scientific appeal to evidence, appeal to the nature of science, and appeal to theories, laws and generalizations. The methodology was similar, although restricted, to that used in the current study. Teacher workshops were presented by the researcher on this approach to teaching about the nature of science.

Still another context for learning about classification was the researcher's experience as an graduate student. The writings of Kuhn (1970), Capra (1982) and Zukav (1979) stressed alternative perspectives about the nature of science. People such as Apple (1974), Aoki (1979) and Kilbourne (1980) were writing about alternative world views. Scientific process skills and scientific attitudes were being classified by Nay (1971) and Kozlow and Nay (1976). Aikenhead (1975) was classifying ways of knowing; Roberts (1980) was classifying curriculum emphases; and many education researchers (e.g., Rist (1981)) were classifying alternative research methodologies.

From within this variety of contexts, the interest of the researcher in classifying knowledge forms within curricular discourse emerged. The most important lesson learned from these classificatory experiences was that classification systems can be developed by classifying curricular discourse. Secondly, these systems had been found useful for organizing one's knowledge about a subject and developing an awareness of the pluralistic character of human endeavors. However, the weaknesses of such systems also emerged; e.g., the use of discourse to classify people rather than ideas and opinions. A positive aspect of classification systems is their ability to make people aware of the alternative actions or points of view available to them, and of the priority or weighting placed on these alternatives.

The third lesson learned through experience about classification systems is that they are far from perfect. The usefulness of the systems is not necessarily proportional to the ability of the system to classify each and every example encountered "correctly" without argument. The usefulness of most classification systems is in their general definition of new concepts to lead a discipline "forward" in its search for new knowledge and new ways of thinking about a topic.

In a more formal sense the conceptualization of the first draft of a taxonomy of curricular discourse involved the writing of several exploratory papers and an investigation of the relevant literature. The exploratory papers began with the writing of a paper, "The Potential of a Teacher-Generated Frame of Reference as a Curriculum Research and Development Perspective" (Jenkins and Kass, 1980) presented at the CSSE Annual Meeting in Montreal. (This paper is reprinted in Appendix A.) The important product of this paper was the establishment of a methodology for the research undertaken in this study. A commitment to a Schwabian (practical and deliberative) research study was made.

The researcher had, at that time, been involved in the ALCHEM curriculum project for nine years. This involvement led to an attitude that a practice-theory dialectic involving a research study and a curriculum project could be mutually beneficial. As a result an informal concomitant research and development dialectic was established involving the current research study parallel with the development of the **STSC Chemistry 10** textbook. This "frame of reference" paper also helped to define the practical perspective which was used as one of the guiding theoretical perspectives for the conceptual analysis of curricular discourse in the current study. From a practical perspective the prevailing criterion for evolving the taxonomy was the recognition and valuing of the attitude that educational research should be grounded in classroom life. An elaboration of this practical perspective is presented in context in the report on Stages 2-7 below. The practical criterion was invoked often in making decisions about the evolution of the STSC Taxonomy.

A second paper that helped to conceptualize this study during Stage 1 was "Contexts and Contextual Dimensions for Science Education in Canadian High Schools" (Jenkins, 1980). This paper set the groundwork for classifying textual discourse on the basis of context. One of the statements, "A Canadian context for science education is just one of many contexts in which science education can be embedded," foreshadowed the introduction of scientific, technological, social and pedagogic contexts incorporated into curriculum emphases in the STSC Taxonomy. The idea of a Canadian context as advocated by Page (1979), begged the question as to what other kinds of contexts there were. This question is answered to a degree by the current study. As the present study progressed the idea of context changed considerably as documented later in this chapter.

Another statement made in the 1980 paper on context was that identical knowledge can be given to students and identical ways of knowing can be used by students in contextual or acontextual textual discourse. Keeping the content the same and changing the context was sorted out conceptually in this "context" paper. Not only was the context classified differently in these cases but the standard context of the sentence came to be classified differently, based on the particular pedagogic context. This result is documented, with examples, later in this chapter. The idea that theoretical and technological knowledge can be integrated in academic science curricula was stressed, and the co-existence of different knowledge forms in textual discourse was described and advocated. There were no systematic relationships developed between the knowledge forms described, but this paper on context did open the question and express confidence that an answer would be found. It was also suggested that the intertwining of scientific ways of knowing, and other ways of knowing which reveal our underlying assumptions, values and beliefs concerning the role and effects of science in our society, is essential to the process of knowing ourselves. A strong web of science, epistemology, values, and science in society was deemed desirable in any curriculum. The structure of that web was not discussed in any detail in this Stage 1 paper on context, and certainly not to the point that it is in this research report.

A review of Kuhn's book, "The Structure of Scientific Revolutions", in Stage 1 stimulated the researcher's appetite in the area of epistemology of knowledge and led, in part, to the central position of epistemology in this research study. Instead of focussing on the structure of scientific revolutions, this researcher focussed on the structure of scientific knowledge and the structure of curricular discourse. Secondly, the book review opened methodological questions. The whole idea of a reconstructed view of a process-in-use is an important methodological concept in many research areas, educational research included. One result is the attempt in this chapter to describe the practice-theory interface as part of history of the evolution of the taxonomy. The re-examination of the process-in-use during this research study, in part, reflects the methods used by Kuhn in reconstructing scientific revolutions.

A major step in the conceptualization of a taxonomy of knowledge forms during Stage 1 of this research was the writing of the paper, "Custom Tailoring the Chemistry Curriculum to the Culture: A Classification of Chemistry Education Subcultures" (Jenkins, 1981). This paper was prepared for a plenary session of international chemistry educators at the sixth ICCE conference in Maryland and is presented in Appendix A. From the researcher's reading and experience in the field of chemistry education, a classification system of nine chemistry education subcultures (normative perspectives) was conceptualized. These normative perspectives, as they were later called (Kass and Jenkins, 1982 and 1986), were operationally defined with examples from the ALCHEM curriculum project in which the researcher was involved. This was the first of a series of classification systems which eventually led to the final product of this research. At that point the focus was on value positions or normative perspectives; i.e., What kind of knowledge is most valued by particular chemistry education subcultures? A particular important advance at this stage was the conceptualization of the epistemology category.

> Chemistry curricula have always been tailored to the culture and always will be. Chemistry curricula like all forms of knowledge are socially constructed . . .. The particular subcultures to which each of us belongs will depend upon our general cultural heritage, our personal chemistry education experiences, and our stage of conscious growth as chemistry educators . . .. Too often our experiences have been restricted to theoretical knowledge only . . .. Although in theory it should be possible to teach every chemistry topic with any one of the emphases mentioned, in practice this is difficult to accomplish . . .. Although such a reconstruction [i.e., the classification system] can never truly claim to reflect actual ideas and positions, it can be useful in dialectic exchanges, and should also help chemistry educators who use it to evolve new perspectives from those held by them now. (Jenkins, 1981: 105)

The influence of this Maryland paper on the current research study was three fold. First, the paper provided Draft 1 of a taxonomy of knowledge forms and helped in this way to conceptualize the possibility of such a taxonomy. Second, the paper explored the concept of normative perspectives which led to the presentation of two other papers on the topic (Kass and Jenkins, 1982 and 1986). The literature research into alternate perspectives on what constitutes important curricular knowledge had an important influence on future work. A familiarity with these alternate perspectives was indispensible for building a taxonomy of alternate knowledge forms. The third influence of the paper on the current research was the philospophical and practical position taken by the researcher concerning a pluralistic approach to science education. The philosophical position taken was that a pluralistic approach should be sought, and the practical position was that a pluralistic approach would work in the classroom. The confidence that such a solution existed was a necessary motivating factor in seeing this research through to a conclusion.

The next paper by this researcher that helped to conceptualize the initial draft of a taxonomy of knowledge forms during Stage 1 was "Espistemological Approaches and Issue Perspectives as Influences on Science Education Curriculum Design" (Jenkins, 1983, a PhD proposal). The intent of this proposed research was to look for evidence of epistemological approaches and issue perspectives within the curriculum documents and textual discourse of the ALCHEM project. An important statement made in the proposal indicated that there were various ways of knowing and concomitant knowledge forms available to textbook authors. The decision as to what emphasis to put on various ways of knowing and the resultant kinds of knowledge is cited as becoming increasingly more complex and more difficult to make. The link between ways of knowing and resultant knowledge forms was established as a dyad and opened the door for the conceptualization of the knowledge-form triad in Stage 2. A basic question asked in the 1983 research proposal was, what patterns of coherence between the epistemological approaches displayed by the curriculum materials and the epistemological approaches intended by the teacher-authors can be discerned? The reference to congruence between actual textbook discourse and statements of intent raised a difficulty in establishing the normative perspectives and/or epistemological approaches of authors. In order to establish the preferred epistemological approaches of authors, textbook discourse had to be analyzed. This requirement led to the necessity for a set of rules for classifying textbook discourse, sentence by sentence. Instead of inferring the normative perspectives and epistemological approaches of authors, the new research problem became the epistemological analysis of textbook discourse to uncover curriculum emphases and knowledge forms. From this point on epistemology remained a central tenet throughout the research.

A conceptual criterion for judging the construct validity of a knowledge form introduced in the classification sytem was epistemological. When a pilot classification of textual discourse was conducted as a transition from the conceptualization of the initial taxonomy in Stage 1 to the empirical test of the taxonomy in Stage 2, a K-KW-W triad was discovered. Until the triad was recognized there was a considerable amount of conceptual discord encountered by the researcher during the classification procedure. Things were not working right. There seemed to be two general kinds of knowledge being presented in textual discourse—resultant-knowledge and procedural knowledge. Once this breakthrough was made, the espistemological criteria for the establishment of a knowledge form included the necessity of a resultant—knowledge (K), procedural knowledge (KW), and way of knowing (W) triad (i.e., a K-KW-W triad). Resultant knowledge (K) could be obtained by procedures given by a knowledge of a way of knowing (KW). The actual action component (i.e., in a classroom or laboratory exercise in textual discourse) required using a way of knowing (W). The presentation of this K-KW-W triad in textual discourse or the student response was visualized as in Figure 4.1 and Figure 4.2.

Resultant Knowledge (K) (Statements)	--> <--	Procedural Knowledge (KW) (Statements)	-->	Required Action (W) (Questions)

The K-KW-W Triad in Textbook Discourse
(Reading a Texbook)
Figure 4.1

Although the sequencing of the K-KW-W triad in textbook discourse was not to be analyzed in this study, the sequencing was important to the process of classifying discourse. The relationship among the components of the triad was used to decide in what knowledge-form category a statement belonged. The kind of knowledge produced depends upon the way of knowing used. The details of such decisions are provided in Chapter 3 and again later in this chapter. The central position of procedural knowledge in these decisions is illustrated in Figure 4.2.

Required Action (W) (Questions)	-->	Procedural Knowledge (KW) (Procedures)	-->	Resultant Knowledge (Answer)

The W-KW-K Triad Used by Students
(Answering a Question in a Textbook)
Figure 4.2

This study has been restricted to the conceptualization of the K-KW-W triad as found in textbook discourse. The application of the triad to curricular discourse, in general, and to student responses in particular remains to be tested by further research. The evidence to support the existence of the K-KW-W triad in textbook discourse is presented throughout this chapter.

The initial efforts at classifying textual discourse during Stage 1 not only forced the creation of the K-KW-W triad, but also forced the realization that the triad should not and could not cross between knowledge forms. For example, a K-KW-W sequence in textual or classroom discourse which crosses over from one knowledge form to another could unknowingly be:

A. The K — K The W — Emp W
B. Emp K — K Ped W — Ped W
C. Emp K — K The W — Emp W

(The symbols used in the above communication are part of the thirty categories defined below in Table 4.2. The three categories referred to above are, The—theoretical, Emp—empirical, and Ped—pedagogic.)

It might be argued that students could become very confused if classroom or textbook discourse were to flip back and forth among a variety of knowledge forms. A question might be asked in general terms, for example, and answered by using an empirical, a theoretical or a pedagogic way of knowing, without making the way of knowing explicit. On another occasion the teacher might identify two or three different ways of knowing how to answer the question. Perhaps the ideal situation would be to have students classify the way of knowing used by the teacher in providing an answer.

The teacher-authors of The Author Group have been using the latter two techniques of identifying alternate ways of knowing for several years in their classrooms, and have now incorporated these techniques into their **STSC Chemistry** textbook. However, before extensive research can be done on the K-KW-W triad in an interrelational way among knowledge forms, the knowledge forms themselves have to be explicated. When this discovery was made during Stage 1 of this research study, the decision was made to restrict the research to classifying the knowledge forms presented in chemistry textbooks. As mentioned earlier, the knowledge forms may also be nested into curricular emphases or epistemological approaches. Going into Stage 2 of the research, the K-KW-W triad concept had been established, and ten knowledge forms had been conceptualized and nested into four curriculum emphases. The results of Stage 1 are summarized in Table 4.2.

Table 4.2 represents Draft 1 of the STSC Taxonomy of Curricular Discourse. The epistemological triad was spread over ten knowledge forms for a total of thirty categories in which to classify textual discourse. These knowledge forms were derived from the list of normative perspectives created by Jenkins (1981), and Kass and Jenkins (1982 and 1986). A rationale for and a description of each initial knowledge form is provided in the 1981 and 1986 papers presented in Appendix A.

C. Stage 2: Classification of Discourse in the ALCHEM Energy Unit L (1982)

The classification of discourse in the 1982 ALCHEM 30 Energy unit was the first empirical test of the STSC Taxonomy. In a Popper sense, the researcher predicted that the textbook discourse could be classified according to the 10 x 3 taxonomic matrix developed in State 1. The researcher established a research methodology to falsify this

Table 4.2
Initial Taxonomy of Science Textbook Discourse

Emphasis and Knowledge Form	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
	The Epistemological (K-KW-W) Triad		
Academic			
1. Theoretical	The K	K The W	The W
2. Empirical	Emp K	K Emp W	Emp W
3. Process	Pro K	K Pro W	Pro W
Applicational			
4. Applicational	App K	K App W	App W
5. Parochial	Par K	K Par W	Par W
6. Ecological	Eco K	K Eco W	Eco W
Pedagogical			
7. Pedagogical	Ped K	K Ped W	Ped W
8. Psychological	Psy K	K Psy W	Psy W
Implicit			
9. Epistemological	Epi K	K Epi W	Epi W
10. Reconstructional	Rec K	K Rec W	Rec W

prediction. The procedures used to test the prediction are described in Chapter 3. The evidence, and the analysis and evaluation of this evidence, are presented in this chapter. The evidence gathered during the classification of the 1982 ALCHEM 30 thermochemistry unit in Stage 2 is communicated in Table 4.3 and in Figure 4.3.

Table 4.3 summarizes the evidence gathered to test the existence of the categories in the 10 x 3 taxonomic matrix depicted in Table 4.2. The total tallies and percentages of the grand total (701 tallies) are presented for each postulated category. Figure 4.3 graphically communicates the proportion of knowledge forms discovered in the discourse classified. This evidence was further analyzed to produce Table 4.4.

Table 4.4 expresses the classification of the textbook discourse in ranked order. The ranking was done to provide an indication to the researcher which knowledge forms were supported by the evidence, and to provide to the authors an indication of the knowledge forms emphasized in the textbook discourse. The number of tallies for each of the thirty categories was converted into a percentage of the 701 total tallies of discourse classified. An analysis of the evidence was then completed by ranking the thirty categories from greatest number of tallies (greatest percentage of tallies) to least. In Column 1 of Table 4.4, the top ten of the thirty categories are listed in rank order. Column 2 ranks all ten resultant knowledge (K) categories, Column 3 ranks six of the ten procedural knowledge (KW) categories, and Column 4 ranks five of the ten required action (W) categories. The

Table 4.3
A Classification of Discourse in the ALCHEM (1982) Energy Unit

Emphasis and Knowledge Form	Resultant Knowledge (K) (#)	(%)	Procedural Knowledge (KW) (#)	(%)	Action Required (W) (#)	(%)	Total Tallies (#)	(%)
			The Epistemological (K-KW-W) Triad					
Academic								
1. Theoretical	67	10	2	0	9	1	78	11
2. Empirical	114	16	57	8	65	9	236	34
3. Process	37	5	30	4	25	4	92	13
Applicational								
4. Applicational	69	10	1	0	0	0	70	10
5. Parochial	0	0	0	0	0	0	0	0
6. Ecological	21	3	0	0	0	0	21	3
Pedagogical								
7. Pedagogical	125	18	7	1	22	3	154	22
8. Psychological	15	2	0	0	1	0	16	2
Implicit								
9. Epistemological	26	4	3	0	0	0	29	4
10. Reconstructional	5	1	0	0	0	0	5	1
Total Tallies	479	68	100	14	122	17	701	100

Table 4.4

Ranking of Categories in the ALCHEM (1982) Energy Discourse

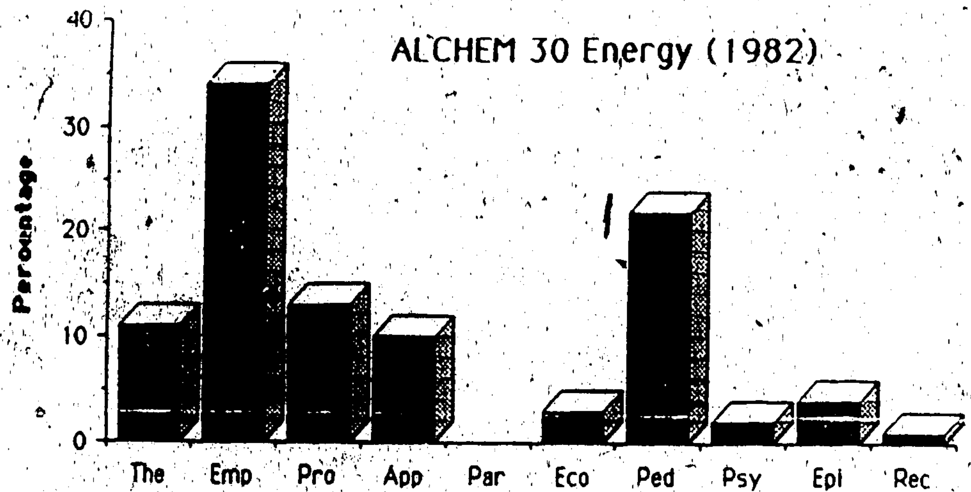
Ranking Overall (K,KW or W)	Ranking of Resultant Knowledge (K)	Ranking of Procedural Knowledge (KW)	Ranking of Required Action (W)	Ranking of Knowledge Form (K-KW-W) Triad
1. Pedagogical K	1. Pedagogical K (1)	1. K Empirical W (6)	1. Empirical W (5)	1. Empirical (34 %)
2. Empirical K	2. Empirical K (2)	2. K Process W (8)	2. Process W (10)	2. Pedagogical (22 %)
3. Applicational K	3. Applicational K (3)	3. K Pedagogical W	3. Pedagogical W	3. Process (13 %)
4. Theoretical K	4. Theoretical K (4)	4. K Epistemological W	4. Theoretical W	4. Theoretical (11 %)
5. Empirical W	5. Process K (7)	5. K Theoretical W	5. Psychological W	5. Applicational (10 %)
6. K Empirical W	6. Epistemological K (9)	6. K Applicational W	6. —	6. Ecological (3 %)
7. Process K	7. Ecological K	7. —	7. —	7. Psychological (2 %)
8. K Process W	8. Psychological K	8. —	8. —	8. Epistemological (< 1 %)
9. Epistemological K	9. Reconstructional K	9. —	9. —	9. Reconstructional (<< 1 %)
10. Process W	10. Parochial K	10. —	10. —	10. Parochial (0 %)
Total Tallies (%)	K — 479 (68 %)	KW — 100 (14 %)	W — 122 (17 %)	K-KW-W — 701 (100 %)

( ) Overall ranking if in the top ten out of thirty categories

categories not listed in Column 3 and Column 4 received no action at all during the classification process. The last column ranks the knowledge forms from one to ten and presents the percentage values. The bottom row of the table indicates that in total 68 % of the statements were classified as resultant knowledge (K), 14 % were classified as procedural knowledge (KW), and 17 % were classified as requiring action (W). The evaluation of the STSC Taxonomy employed this analysis to make decisions about the evolution of the taxonomy, as illustrated below.

A surprise from this analysis of evidence for knowledge forms (as communicated in Figure 4.3) was the high frequency of pedagogical knowledge found in the textbook discourse. ALCHEM was a chemistry education textbook to be used in schools, but the Ped—22 % result was still unexpected by the researcher even though pedagogy was one of four curriculum emphases postulated. The result did, however, confirm the declared emphasis of the ALCHEM authors on pedagogy. The emphases declared by the authors were academic, applied and descriptive chemistry with a strong pedagogic approach (ALCHEM 30, 1982: Introduction).

The large tally as evidence of a pedagogy emphasis (22 %) ran somewhat contrary to previous lists of curricular emphases in the literature (e.g., Eisner and Vallance, 1974; Factor and Kooser, 1981; Roberts, 1982); and showed strong support for the inclusion of pedagogy as an actual knowledge form in textual discourse (e.g., Jenkins, 1981; and Kass and Jenkins, 1982). Most important to this study was the empirical definition provided for the pedagogy category



Proportions of Knowledge Forms Discovered
in the ALCHEM 30 (1982) Energy Discourse
Figure 4.3

by the 154 examples found in the textual discourse classified. The discourse encountered during the classification process forced the evolution of the taxonomy in the direction described below.

After a couple of false starts and the establishment of some rules, the classification went well. Each sentence was classified in a fairly confident, although very time consuming, manner. The false starts involved problems encountered with the pedagogy category in particular. During the classification of discourse in this first chapter of textbook discourse the pedagogy class of knowledge was coded into three subcategories—pedagogical purpose, pedagogical reference, and pedagogical communication. The pedagogical purpose category (Ped K_P) included statements such as:

> Ped K_P: "A primary objective of this unit will be to give . . . an understanding of the relative amounts of energy that can be obtained from the three types of energy changes . . . ." (ALCHEM 30, 1982: L1)

The statement of objectives in textbooks is pedagogic and the classification of the pedagogic statement as purpose oriented (Ped K_P) was done with a high degree of certainty. The doubt that was present centered around whether from a student's perspective this knowledge was resultant (Ped K_p) or procedural (K Ped W_p). This question remained unresolved at that point.

The pedagogical reference (Ped_R) category was operationally defined by examples such as:

> K Ped W_R: "(These molar values are provided on the ALCHEM data sheet for future reference.)" (ALCHEM 30, 1983: L9)

Teaching a student how to reference knowledge qualified as procedural knowledge. Logically, this kind of procedural knowledge did not fit anywhere else in the taxonomy. The question begged by this classification was, "Is pedagogic knowledge a result of this referencing procedure?" For example, if a person references the chemical formula for water, then is the knowledge gained in this context pedagogic knowledge or scientifc knowledge? This question is raised again in Chapter 5 and Chapter 6.

The pedagogical communication (Ped_C) knowledge form was operationally defined by examples dealing with definitional knowledge such as:

K Ped W_C: "Molar heats of reaction for exothermic reactions are arbitrarily assigned a negative value." (ALCHEM 30, 1983: L16)

Ped W_C: "Identify the various changes by their proper name." (ALCHEM, 1982: L9)

The emphasis in these textual statements is on how knowledge is communicated. The most obvious place to classify this kind of knowledge at that point in the study was as a subcategory of pedagogy. At that point the researcher did not create entirely separate knowledge forms for pedagogical purpose, reference and communication. However, the empirical evidence was recorded separately for only the resultant knowledge (K) components of the three subcategories of the pedagogical knowledge form. The criteria that were used to make the decision not to create three separate knowledge forms were three fold.

1. The first criterion used was <u>empirically</u> based. Representative textbook discourse was classified to determine whether the categories in the proposed taxonomy of curricular discourse could be demonstrated to exist in "real" discourse. In the case of the pedagogical knowledge form, the total frequency count for two of the three subcategories of pedagogical knowledge was relatively high. Pedagogical purpose (Ped K_P) accumulated a total tally of 48 (7 %), pedagogical reference was 6 (1 %), and pedagogical communication was 71 (10 %). However, there was a lack of direct empirical evidence to support the existence of complete K-KW-W triads in each of the three pedagogy subcategories. The frequency counts in total for the KW + W dimension of the three subcategories was only 29 (4 %).

2. Another criterion used was the existence of a <u>logical conceptualization</u> by the researcher of a complete K-KW-W triad for each knowledge form. In this case in addition to the lack of empirical support for splitting the pedagogy category, the full <u>conceptualization</u> of the K-KW-W triads was still incomplete. For example, the difference between Ped K_C and K Ped W_C was not clear at that time. From a later perspective much of what was classified as Ped K_C should have been classified as K Ped W_C. An example of misclassification from the ALCHEM discourse classified is:

   Ped K_C: "The energy change that accompanies a phase change, chemical reaction or nuclear reaction <u>can be represented</u> in one of two ways." (ALCHEM, 1982: L20)

This statement, in retrospect, should have been classified as procedural knowledge (K Ped W_C) telling the student how to represent energy changes. The knowledge resulting from this procedural knowledge would be Ped K_C telling the student how to represent energy changes. This classification problem plagued the early use of the taxonomy. Although the "correct" classification is fairly obvious now to an experienced classifier, the early conceptual problems with the Ped K versus K Ped W categories are difficult to describe in retrospect (as la Kuhn).

3. Simplicity was the third criterion for not creating complete pedagogy subcategories at that time. Pedagogy was not a curriculum emphasis or an epistemological approach at that point and therefore subcategories of pedagogy would have introduced an unwarranted complexity to the classification. Secondary subcategories were not wanted. Simplicity is a criterion for acceptance of empirical and theoretical constructs by a community of scholars. An immediate resolution of the anomaly created by the evidence was not apparent. Since the other categories of knowledge seemed to be working fairly well without creating subcategories, a decision was made to restrict rather than revise the classification system. At this point the pedagogy category was an exception to be noted and to be considered for future action.

At the practice-theory interface of this study, the authors who wrote both the ALCHEM and the **STSC Chemistry** materials were operationalizing pedagogical reference ways of knowing in their classrooms. Students were being taught that, besides theoretical and empirical ways of knowing in science, there were "other" ways of knowing, namely, given, referenced and memorized ways of knowing. These were not called pedagogical-reference ways of knowing (Ped W_R) to the students, but in research terms that seems to be the most appropriate description of this particular K-KW-W triad.

In summary Stage 2 provided an initial test of the taxonomy of knowledge forms and a test of the experimental design including research procedures. The existence of five out of the ten predicted knowledge forms was supported by the evidence (i.e., the theoretical, empirical, process, applicational, and pedagogical knowledge forms all tallied ten percent or greater of the total discourse classified). The statements classified for all ten categories of knowledge now stood as examples to help operationally define each category. The epistemological (K-KW-W) triad was also given support by the evidence. Although a large proportion 68 % of the statements classified were resultant knowledge (K), 14 % and 17 % of the statements were classified as procedural knowledge (KW) and requiring action (W), respectively. The results from Stage 2 provided the researcher with confidence that the taxonomy and the research design was potentially fruitful.

D. Stage 3: The Classification of Discourse in the ALCHEM Energy Unit M (1975)

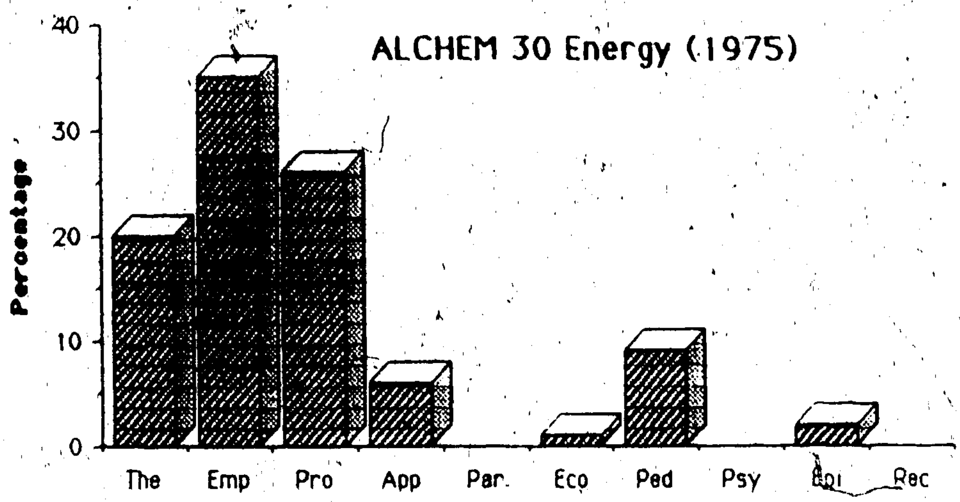
The test of the initial draft of the taxonomy of curricular discourse was followed by another test in Stage 2. The statements in the 1975 edition of the ALCHEM 30 Energy unit were classified sentence by sentence. The procedures described in Chapter 3 were followed to complete the classification. The classification of the discourse provided a total of 534 tallies—35 % Empirical, 26 % Process, 20 % Theoretical, and 9 % Pedagogical. The remainder of the evidence for knowledge forms and K-KW-W triads is provided in Table 4.5 and is communicated graphically in Figure 4.4.

For the second consecutive unit, half of the categories (the same half) tallied three percent or less each; i.e., ecological, psychological, epistemological, reconstructional and parochial. The comparison of proportions of discourse in each knowledge form is presented in Figure 4.5. The five high and the five low filling categories are illustrated by the bar graph analysis. However, a decision was made at that time to retain the five categories with the lowest support from the discourse classified. The criteria used to make this decision were two-fold. First, there was no cost in research efficiency (i.e., time and effort) to retain these low scoring categories. Secondly, the units of textbook discourse classified in Stage 2 and Stage 3 were on the same topic—thermochemistry. Stages 4-7 involved classifying the discourse in four units in the **STSC Chemistry 10** textbook each with a different STSC emphasis. The researcher felt that at this time the five knowledge forms that did not get any action should be retained until a more adequate test of their existence could be performed.

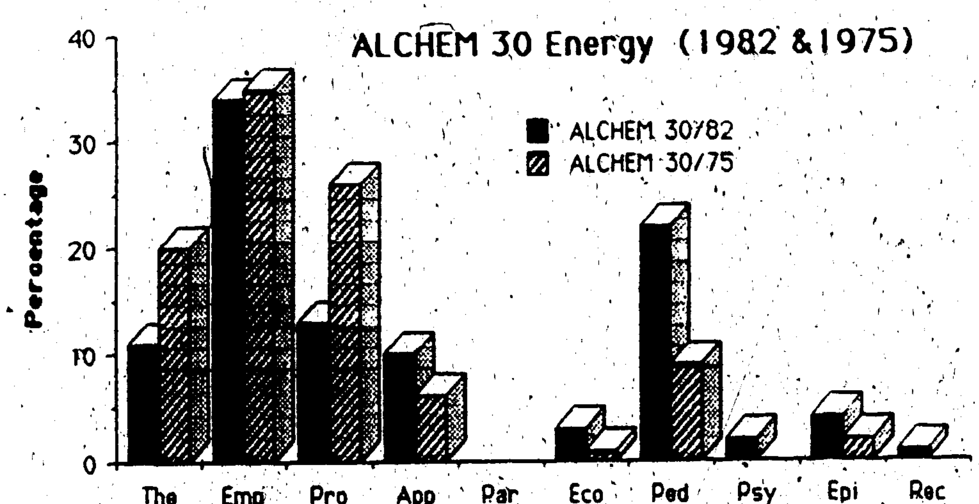
The evidence gathered by the classification of discourse in the 1975 Energy unit revealed some new problems with the taxonomy. Again

Table 4.5
Initial Classification of Discourse in ALCHEM (1975) Energy Unit

Emphasis and Knowledge Form	Resultant Knowledge (K) (#)	(%)	Procedural Knowledge (KW) (#)	(%)	Action Required (W) (#)	(%)	Total Tallies (#)	(%)
	The Epistemological (K-KW-W) Triad							
Academic								
1. Theoretical	92	17	1	0	14	3	107	20
2. Empirical	107	20	24	4	56	10	113	21
3. Process	69	13	1	0	68	13	138	26
Applicational								
4. Applicational	30	6	0	0	2	0	32	6
5. Parochial	0	0	0	0	0	0	0	0
6. Ecological	7	1	0	0	1	0	8	1
Pedagogical								
7. Pedagogical	34	6	1	0	13	2	48	9
8. Psychological	0	0	0	0	0	0	0	0
Implicit								
9. Epistemological	11	2	0	0	2	0	13	2
10. Reconstructional	0	0	0	0	1	0	1	0
Total Tallies	350	66	27	5	157	29	534	100



Proportions of Knowledge Forms Discovered
in the ALCHEM 30 (1975) Energy Discourse
Figure 4.4



Proportions of Knowledge Forms Discovered
in the ALCHEM 30 (1982 and 1975) Energy Discourse
Figure 4.5

the conflicting evidence was used to produce minor revisions of the classification system. The two areas of revision were definitions and empirical knowledge found in the textbook discourse. Definitions within textual discourse were classified in Stage 2 as communicational knowledge (Com K), theoretical knowledge (The K), or empirical knowledge (Emp K). However, early in Stage 3 definitions were classified as theoretical or empirical or conventional (convenient). This conceptualization was contrary to the community standard of referring to definitions as conceptual or operational. Ironically, a communicational device such as a definition was redefined. The criteria for making the decision to rename the categories of definitions were multifold.

1. The internal consistency of the taxonomy required that empirical knowledge in the form of definitions be called empirical definitions and likewise with theoretical knowledge and theoretical definitions. The fit was conceptually more pleasing. Definitions could be classified and named just like any other statement classified by the taxonomy.

2. For reasons of pedagogical efficiency, the teacher-authors of The Author Group felt that the change should be made. The epistemological teachings of The Author Group, including the researcher, required their students to classify scientific knowledge as theoretical or empirical. The parallel between theoretical and empirical knowledge and definitions worked well in the classroom with students. To STSC Chemistry students and teachers it did not make sense to classify knowledge as empirical

and theoretical and then to classify definitional knowledge as operational and conceptual. This practical classroom criterion was not officially part of the research design, but was included in many decisions. The practice-research interface will appear many times below as a context for providing criteria for decision making on revising the classification system.

3. Students, who epistemologically classified theoretical and empirical knowledge and ways of knowing, could further their epistemological understanding of the underpinnings of scientific and technological knowledge by the logical consistency of referring to theoretical and empirical definitions. For example, **STSC Chemistry** students were regularly asked to classify the way of knowing that they were or had been employing to create knowledge. This epistemological activity was enhanced by the renaming of classes of definitional knowledge.

4. Another relevant criterion introduced formally in the **STSC Chemistry** textbook involved the criteria for having a system of communication accepted by the scientific community. These criteria for an acceptable communication system were listed as 1) international, 2) precise, and 3) simple. The use of the terms theoretical and empirical were judged to be more general, if not more international, precise, and simple than the use of the terms conceptual and operational within the science education context. In this case the epistemological content concerning the nature of scientific communication in the **STSC Chemistry** textbook itself was

providing epistemological criteria for use in the research. The benefits from the dialectic were mutualistic.

The dialectic relationship between this research and the development of the **STSC Chemistry** materials by The Author Group is illustrated by the conceptualization of empirical and theoretical definitions. Empirical and theoretical definitions became one of the ways of communicating empirical and theoretical knowledge. For example, empirical knowledge may be communicated by statements, tables, graphs, empirical definitions, generalizations, and laws. Theoretical knowledge may be communicated as statements, theoretical definitions, analogies, models, and theories. A complete list of STSC **Chemistry** ways of communicating empirical and theoretical knowledge is provided in Appendix B.

A second revision of the STSC Taxonomy during Stage 3 involved the splitting of the empirical knowledge category. Classifying textbook discourse forced the conceptualization that <u>empirical knowledge can be described as being a duality</u> of either knowledge gained by employing empirical definitions, generalizations and laws (Emp K_L) <u>or</u> knowledge gained by observation through experience or experiment (Emp K_E). The empirical and conceptual criteria used in making this separation are listed below.

1. <u>Empirically</u>, as illustrated in Figure 4.5, the filling of the empirical knowledge cell in the classification matrix was high—187 of a total of 534 tallies for 35 % of all discourse. Out of ten categories, the empirical category tallied over one-third of the

textbook discourse in this unit. The high frequency count in the empirical category was evidence of significant subcategories.

2. Conceptually, there is a significant difference between straight observational (experiential) knowledge (Emp K_E) and generalized (law-based) knowledge (Emp K_L). Some examples from the ALCHEM 30 Energy unit (1975) classified during this stage of the study are provided below. The example discourse illustrates complete triads of both the Emp_E and the Emp_L knowledge forms. (The emphasis has been added.)

Emp K_E: "During boiling the temperature stays constant until all the water is boiled away." (ALCHEM 30, 1975: M9)

K Emp W_E: "Methane . . . is very difficult to liquify . . . . Methane can be oxidized to methanol . . . ." (ALCHEM 30, 1975: M27)

Emp W_E: "Describe what happens to the potential energy of two oppositely charged pith balls as they are separated." (ALCHEM 30, 1975: M2) [poor]

The context for the Emp_E triad above is experiential or experimental. The resultant knowledge (Emp K_E), the procedural knowledge (K Emp W_E), and the action required (Emp W_E) are all contextually embedded within experience. The phrase "the temperature stays constant" is empirical resultant knowledge generated by a third person. The knowledge communicated is a specific observation and is not generalizable (i.e., Emp K_L below). Empirical knowledge about how-to oxidize methane to methanol in nonindustrial context is K Emp W_E. A poor example of an empirical way of knowing being required of students is presented in the third example above. The example presented involves theoretical and/or empirical conceptual knowledge to answer the question and not experiential or experimental knowledge. A better example of Emp W_E might be: "Describe from your experience what happens when two like charged pith balls are brought together." In contrast the Emp_L triad below is embedded within empirical definitions, generalizations and laws. The laws and generalizations themselves are Emp K_E, a resultant knowledge of experiments (Emp W_E). Within the context of use, the laws are procedural knowledge (K Emp W_L) and action required (Emp W_L) statements. The resultant knowledge (i.e., the answer in problem solving that uses laws) is classified as Emp K_L.

Emp K_L: "$\Delta H = \Delta E_K = ms\Delta t$" (ALCHEM 30, 1975: M10) [poor]

K Emp W_L: "The change in heat (ΔH) <u>is found by</u> $\Delta H = \Delta E_T = \Delta E_P + \Delta E_K$." (ALCHEM 30, 1975: M10)

Emp W_L: "<u>Find</u> the gain in kinetic energy when 150 L of water is heated from 20.0°C to 65.0°C in a hot water tank." (ALCHEM 30, 1975: M10)

All of these statements are law-based. <u>How to use</u> a law or other empirical construct to produce knowledge, as in the second example, is classified as procedural knowledge (K Emp W_L). A question requiring the use of a law, as in the third example, is classified as Emp W_L and resultant knowledge from using this procedure is classified as Emp K_L. From a current perspective many of the classification tallies made during Stage 3 were in error; i.e., the laws themselves, as in Example 1 marked "poor", were originally classified as Emp K_L rather than Emp K_E or K Emp W_L. The laws are products of experimental work (Emp W_E and K Emp W_E) and therefore should be classified as resultant Emp K_E

rather than Emp K_L. The common tendency is to classify laws as Emp K_L. Also in many cases the classification of a single sentence as Emp K_E or Emp K_L was difficult without the context set within the paragraph or without inferring the context from the rest of the unit, textbook, course outline, or classroom experience. This difficulty with using the classification system was viewed positively in the following ways.

1. The classification was revealing potential weaknesses in the sequencing of textual discourse and in the communication of context. Although the evaluation of triadic sequencing in textbook discourse was not the immediate purpose of this research, this was assumed to be a fruitful use for the product of this research, the STSC Taxonomy. For example, does the textbook reveal to the reader whether given knowledge is empirically obtained directly from experience (Emp K_E) or indirectly predicted from laws or generalizations (Emp K_L)? It seems that the epistemological context of knowledge is an important part of what is communicated by textual discourse. Without the epistemological context, knowledge would have to be memorized only and alternate ways of knowing would be unavailable to the student.

The second positive perspective on the classification difficulties encountered was that the use of the classification system was epistemological. Forms of knowledge and ways of knowing were being revealed and brought into question that would have otherwise remained implicit. For example, was the statement of the calorimetric equivalent of kinetic energy ($E_K = ms\Delta t$) resultant knowledge or procedural knowledge? The researcher was forced by the classification exercise to define the statement as either form of knowledge, depending on the context. As a scientific law it was a result of empirical research, but in a different context it was a procedure for predicting more empirical knowledge.

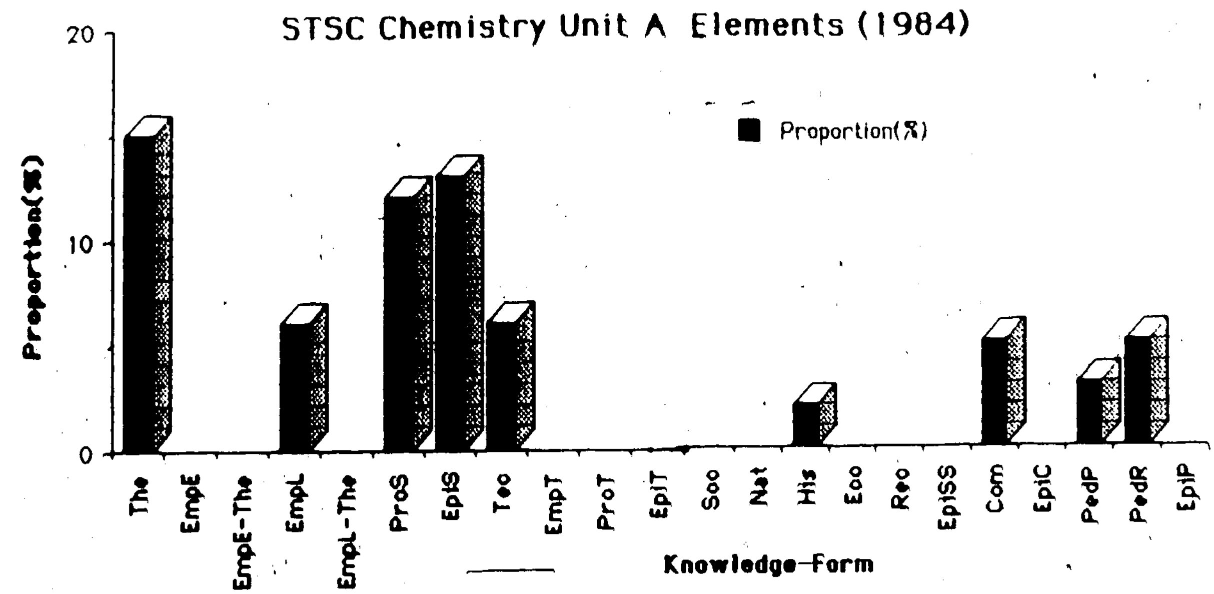
3. In another sense this split in the empirical knowledge form also allows for the reconceptualization of inductive and deductive reasoning, respectively, as Emp W_E and Emp W_L. The specificity of knowledge forms and ways of knowing could potentially provide a simpler and more precise meaning to reasoning. These potentials have not been explored in this research study, although on the surface the logical consistency of teaching inductive and deductive reasons as two forms of procedural knowledge (i.e., K Emp W_E and K Emp W_K) seems pedagogically sound.

The completion of the classification of discourse in the two editions of the ALCHEM thermochemistry units achieved their purpose as initial tests of the STSC Taxonomy. As expected a great deal of effort was spent during the process on finding exemplars to define categories. The technical rules for using the classification system were more firmly established, and the research procedures were in place to start the descriptive classification of the **STSC Chemistry 10** (1984) textbook.

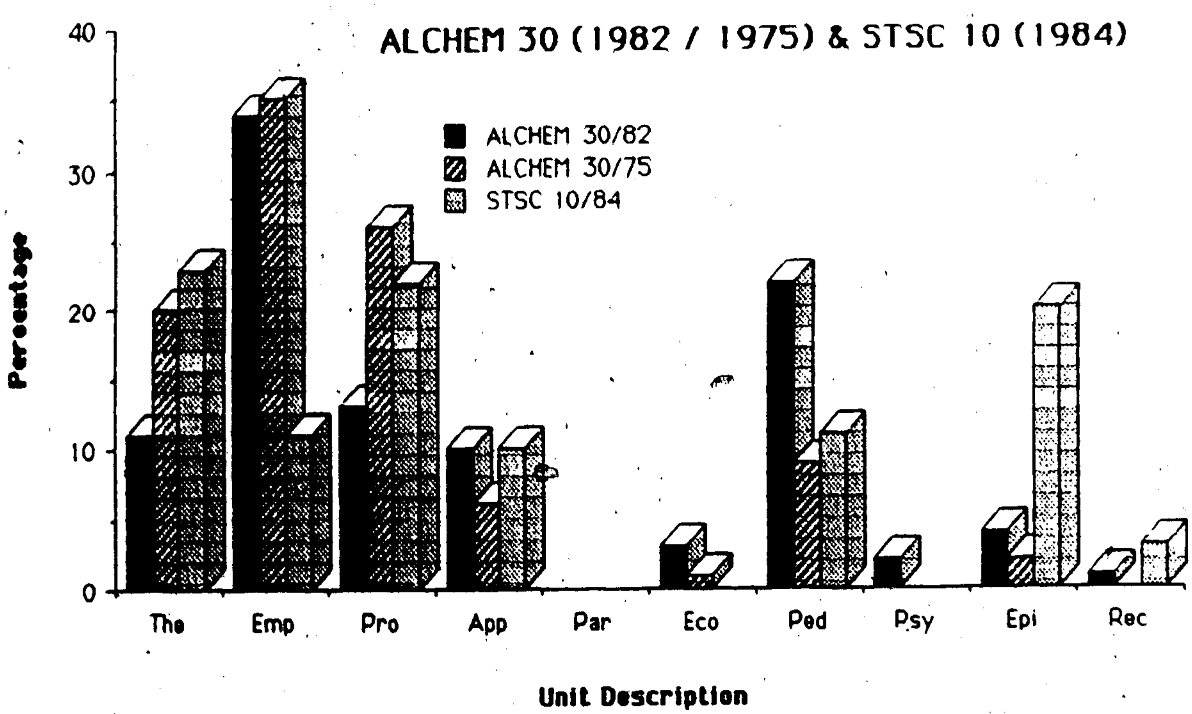
E. Stage 4: The Classification of Discourse in STSC Chemistry 10 Unit A (1984)

Stage 4 of the research involved the classification of the textual discourse in Unit A (Elements, Periodic Laws, and Atomic Theories) from the 1984 edition of **STSC Chemistry** 10. The Venn diagram on the front cover of Unit A indicated a nature of science emphasis integrated with chemistry content on periodic laws and atomic theories. This unit was projected to provide an extensive test of the theoretical (The), empirical (Emp), and epistemological (Epi) knowledge form categories. The evidence gathered supported this prediction.

As communicated in Figure 4.6 the six top categories in terms of frequency count (minus context tallies) were theoretical (The—23 %), process (Pro—22 %), epistemological (Epi—20 %), empirical (Emp—11 %), pedagogical (Ped—11 %), and technological (Tec—10 %). The bottom four knowledge forms remained the same as the previous two tests: reconstructional (Rec—3 %), psychological (Psy—0 %), ecological (Eco—0 %), and parochial (national) (Par—0 %). This analysis is represented graphically in Figure 4.7. The evidence for all ten knowledge forms and their triadic components is superimposed on the "final" STSC Taxonomy matrix in Table 4.6. The percentages expressed in Table 4.6 are from the grand total of tallies including context statements. An analysis and evaluation of this evidence, including the synthesis of a revised STSC Taxonomy appears below.



Proportions of Knowledge Forms Discovered
in the STSC Chemistry 10 (1984) Elements Discourse
Figure 4.6



Proportions of Knowledge Forms Discovered
in the First Three Chapters of Discourse Classified
Figure 4.7

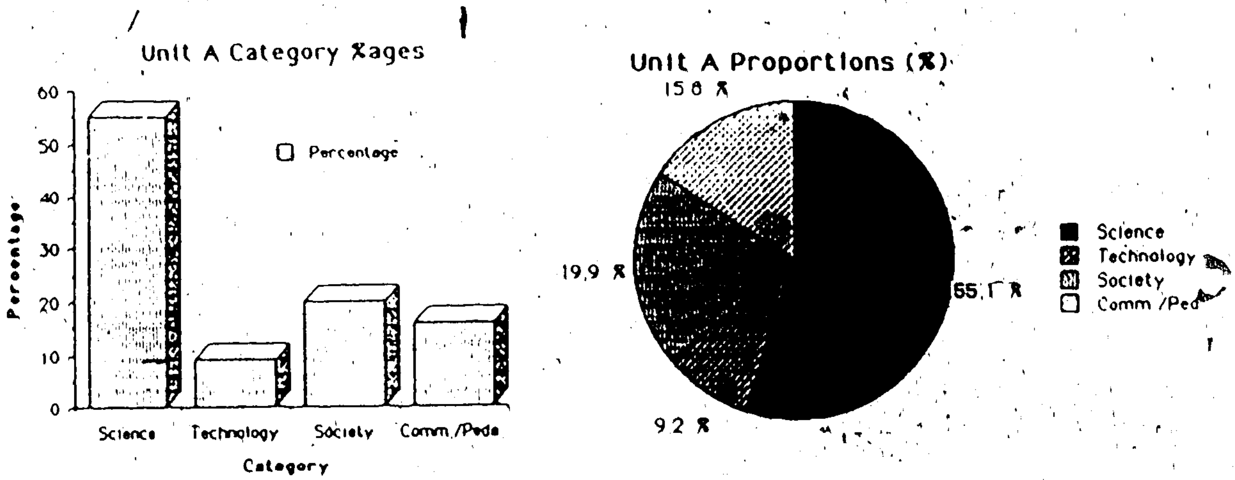
Table 4.6
Stage 4: The Classification of Discourse in Unit A—
"Elements, the Periodic Law and Atomic Theories"

Emphasis and Knowledge Form	Resultant Knowledge (K) (#)	(%)	Procedural Knowledge (KW) (#)	(%)	Action Required (W) (#)	(%)	Total (#)	(%)
Science								
1. Theoretical	133	9	14	1	65	4	212	15
2. Empirical$_E$ (experiential)	14	1	1	0	1	0	16	0
3. Empirical$_E$—Theoretical	–	–	–	–	–	–	–	–
4. Empirical$_L$ (laws) (E & L)	60	4	13	1	10	1	83	6
5. Empirical$_L$—Theoretical	–	–	–	–	–	–	–	–
6. Process	6	0	92	6	80	5	178	12
7. Epistemological (General)	149	10	10	1	27	2	186	13
Context (Sci C)							130	9
Totals	Sci K 362	25	K Sci W 130	9	Sci W 183	13	805	55
Technology								
8. Technological (Applic.)	54	4	16	1	20	1	90	6
9. Empirical	–	–	–	–	–	–	–	–
10. Process	–	–	–	–	–	–	–	–
11. Epistemological	–	–	–	–	–	–	–	–
Context (Tec C)							45	3
Totals	Tec K 54	4	K Tec W 16	1	Tec W 20	1	135	7
Society								
12. Societal	3	0	1	0	0	0	4	0
13. [illegible]onal	–	–	–	–	–	–	–	–
14. H[illegible]ical	22	2	–	–	–	–	22	2
15. Ec[illegible]gical	1	0	0	0	1	0	2	0
16. Reconstructional	0	0	2	0	5	0	7	0
17. Epistemological	–	–	–	–	–	–	–	–
Context (Sci C)							256	18
Totals	Soc K 26	2	K Soc W 3	0	Soc W 6	0	291	20
Communication								
18. Communication	35	2	33	2	6	0	74	5
19. Epistemological	–	–	–	–	–	–	–	–
Context (Com C)							21	1
Totals	Com K 35	2	K Com W 33	2	Com W 6	0	95	6
Pedagogy								
20. Pedagogical Purpose	50	3	–	–	–	–	50	3
21. Pedagogical Reference	–	–	26	2	44	3	70	5
22. Epistemological	–	–	–	–	–	–	–	–
Context (Ped C)							16	1
Totals	Ped K 50	3	K Ped W 26	2	Ped W 44	3	136	9
Total Contexts							468	32
Grand Totals	529	36	208	14	259	18	1462	100

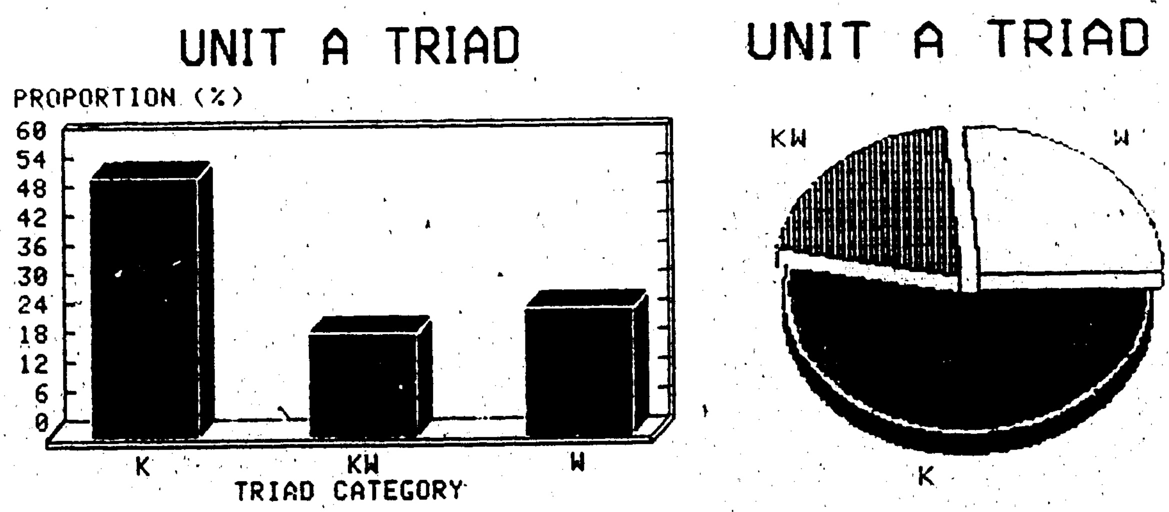
The most significant changes from the two previous classification stages were recorded in the empirical (Emp) and epistemology (Epi) knowledge form categories. See Figure 4.7 for a comparison of all knowledge form categories over the first three stages of classifying discourse. The change in the empirical knowledge category from about 35 % previously to 11 % in this unit was, however, not unexpected. The previous thermochemistry units were empirically oriented while the current atomic theory unit was, as expected, theory laden. The epistemology (Epi) category went from a eighth (< 1 %) and sixth (2 %) ranking previously to a third (20 %) position in overall ranking of the ten knowledge form categories. In fact, the epistemological knowledge (Epi K) category ranked Number 1 (16 %) of the thirty K-KW-W subcategories in the 10 x 3 taxonomic matrix.

The Author Group had obviously set out to write a unit (chapter) with a nature of science emphasis. A content area (periodic laws and atomic theories) had been chosen by the authors to make the task easier, but the 55 % Sci and 13 % Epi findings were still surprising to the researcher and the teacher-authors of the **STSC Chemistry** textbook. The proportions of discourse in each STSC/P emphasis in Unit A are communicated graphically in Figure 4.8. A sampling of some epistemological discourse from Page A11 of the 1984 edition is presented below.

Laws and Theories
Chemistry is often described as a body of scientific laws and theories. A scientific law is a statement which is accepted by the scientific community and is based only on observations (called experimental knowledge or empirical knowledge). A law can be used to predict but cannot be used to explain why something happens. A theory is an explanation



Proportions of STSC/P Discourse in Unit A
Figure 4.8



Proportions of K-KW-W Discourse in Unit A
Figure 4.9

> of why something happens, usually in terms of things which cannot be seen (e.g. atoms or molecules). Laws and theories can never be proven but empirical results will either lend support to or conflict with the law or theory. (Emphasis added)

The epistemological content in the above paragraph informs the reader about the attributes of scientific laws and theories (i.e., about the origin, nature and limitations of knowledge). Regardless whether the user of the taxonomy agrees with the definitions provided in the textual discourse, the discourse should be classified as epistemological (Epi).

The epistemological (K-KW-W) triad was completed later in the textbook by discourse that necessitated classification as an epistemological way of knowing (Epi W). Some sample questions classified for the **STSC Chemistry** discourse as epistemological (Epi W) are presented below. (Emphasis has been added.)

Epi W: "Why can't a theory or law ever be proven?" (Page A12)

Epi W: "Are theories always accepted or rejected solely on the basis of their ability to accurately explain natural phenomena?" (Page A12)

Epi W: "Do the results of the calculations in Question 1 support Doebereiner's classification?" (Page A24)

Epi W: "Why is Mendeleyev's knowledge of combining capacities considered to be empirical?" (Page A24)

The above questions from the **STSC Chemistry** (1984) Grade 10 unit on periodic laws and atomic theories illustrate the type of action-required statements discovered that required the students to employ an epistemological way of knowing about how scientific knowledge comes to be accepted by the scientific community. The students' responses which were not classified in the current study could, however, be classified as Emp K_S.

In retrospect the epistemology category was still unidimensional at that time. Epistemological statements within technological or communication knowledge forms were not recognized or not differentiated. The establishment of epistemological categories within each curriculum emphasis was to come later. For example, the following statements from Unit A would have been classified in later stages of this research as indicated below, rather than as general Epi K. Note the subscripts indicating technological (T) and communication (C) categories of epistemological statements.

Epi K_T: ". . . technologies can arise from following laws, without the need to explain why the procedure works (i.e., without theories)." (Page A11)

Epi K_C: "One very important principle of communication is that of shared meaning. . . . Scientific communication is a specialized form of communication. Some parts are international (symbols, ideas and laws) although the expression and general discussion is usually in the local language like English." (Page A14)

Statements relating to the nature of technology (Epi_T) and the nature of scientific communication (Epi_C) were not characterized by a multitude of exemplars until the discourse in the unit with that particular curriculum emphasis was classified (e.g., Unit D and Unit B, respectively). Often, due to the nature of the discourse, only particular sections of the taxonomy were tested and revised in each stage of the study. This was the primary reason that the research design for the research required the classification of discourse in all four STSC **Chemistry** 10 units.

El. Contexts

Two other explorations were initiated during the Stage 4 classification of the STSC **Chemistry** Unit A discourse. Context subcategories (e.g., Tec C and Ped C) were created to complement each of the ten original categories. In addition an historical context (His C—163 tallies), a nature of science context (NSC—77 tallies), and a nature of technology context (NTC—14 tallies) were created to help handle textbook discourse that did not otherwise classify well into a particular knowledge form. A total of 468 tallies of contexts were classified for 32 % of the 1462 tallies for the unit. This evidence is presented in Table 4.5. Some examples of the classification of context are presented below. The underlined discourse corresponds to the underlined category symbol.

His C/Emp K_E:	"By the year 1800 about thirty-five elements had been discovered." (Page A23)
Par K/His C/Cdn C:	"Ernest Rutherford was born in New Zealand, but did most of his work at Cambridge University in England as well as spending several years at McGill University in Montreal." (Page A30)

Key words or phrases were often focused on in order to make the classification process more efficient and consistent. The historical (His C) and Canadian (Cdn C) context categories were particularly suited to this approach. However, as explained below this efficiency criterion may have delayed needed revisions to the taxonomy.

The revisions to the taxonomy stopped short of creating an historical knowledge category. In this sense the creation of context categories was a stop-gap measure—an attempt, in retrospect, to forestall major revisions until forcefully required. This conservatisms is reminiscent of Kuhn's description of resistance to change within the science discipline—"fix, fix, fix" until a full reconceptualization is available. These historical and Canadian context tallies would later (i.e., in Stage 6) be classified as historical knowledge and national knowledge, respectively.

There was also a tendency at that time to categorize empirical definitions as Emp K/Com C, where later these would be classified as Emp K/Com K. There appeared to be some hesitation in classifying some statements into two categories. The criterion used later recognized that the taxonomy was a reconstruction of real discourse and, therefore, the reconstruction had to recognize complexities and not over simplify the classification. Multiple classifications become more and more frequent due to the experience with classifying discourse in Unit A.

E2. Epistemology

The scientific language of expressing uncertainity and of referencing theory and evidence was also apparent in the **STSC Chemistry** textbook discourse. This epistemological language was in evidence throughout Unit A as part of sentences containing knowledge components. The authors had intentionally used what they called "scientific language" in their textbook writing. The researcher initially held back from classifying the scientific language phrases as epistemological knowledge (either resultant or procedural). Some examples from Unit A, with the scientific language underlined, are presented below.

Epi K: "J. J. Thomson provided evidence for the existence of . . .." (Page A29)

Epi K: ". . . the discovery of X-rays and radioactivity had prepared the scientific community to accept . . . .." (Page A29)

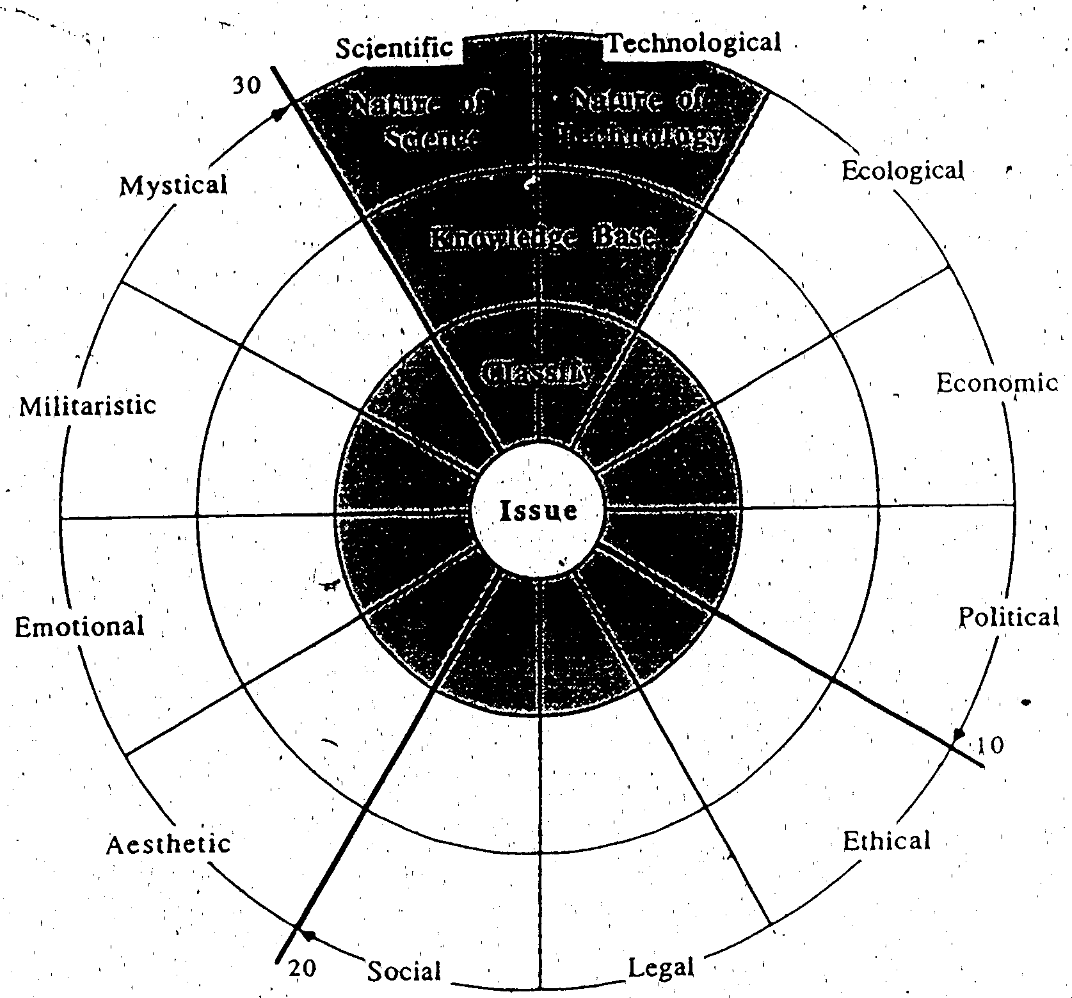
Epi K: "Thomson proposed that . . . .."
"The model . . . suggests that . . . .."
". . . an image which agreed with the empirical evidence." (Page A29)

The phrases underlined above were evidence of an emphasis on epistemology that permeated the writing of Unit A. The appeal to evidence in the first and third examples, the reference to how the scientific community comes to accept knowledge in the second example, and the approach of indicating the origin of knowledge in the third example conveys an implicit epistemological message to students. The conceptualization of epistemology as content rather than epistemology as an author's approach or preference in writing textbooks was raised to a higher level of consciousness in the study. The epistemology was not implicit it was very explicit. The students were not only given epistemological statements and questions, the regular science content knowledge statements and questions were also steeped in epistemological language. The assumptions, appeals to evidence, reference to theories, laws and generalization, and declarations of uncertainty were part of the regular textbook discourse. As a science educator the researcher also developed an impression of epistemology as pedagogy while reading the unit. If students were to use an epistemological way of knowing (Epi W) to classify, for example, the ways of knowing the chemical formula for water that they were employing at a particular point in their chemistry education, then is this epistemology as pedagogy? This question is raised again in Chapter 6.

E3. Perspectives

Another revision of the taxonomy during Stage 4 attempted parallel to the introduction of context categories, was the use of perspectives categories. The perspectives were derived from a list that The Author Group had been using in their classrooms for about three years. The list of perspectives was revised from Aikenhead's (1975) Science: A Way of Knowing textbook. The list of twelve perspectives developed by the author group and their students included aesthetic, ecological, economic, emotional, ethical, legal, militaristic, mystical, political, scientific, social, and technological. See the issue perspectives wheel in Figure 4.10.

Although the use of this classification of perspectives had worked well in the classroom context for classifying perspectives taken on science-in-society issues, it did not work well in this research context. The classification of perspectives in newspaper and magazine articles, films, videos, and political speaches produced significant frequency counts for student analysts. The classification of perspectives within the **STSC Chemistry** textbook discourse did not provide evidence of being useful. The criteria used for discontinuing



Science and Technology In Society Issue Perspective— STSC Chemistry 10, 20 and 30 Scope and Sequence
Figure 4.10

the use of these perspectives as categories of textual discourse were multifold.

1. The frequency counts for each perspective category were low—zero to six out of 1462 total tallies. This empirical result was a necessary but not sufficient reason for dropping the classification of perspectives. Combined with the other criteria discussed below, the frequency count was important to the decision.

2. Some of the perspective categories repeated current knowledge form categories (i.e., science, technology, and ecological) and the societal knowledge form that was added later. The repetition indicated that the perspectives and knowledge form taxonomies may provide alternate ways of classifying but that the context for their use may be quite different.

3. The perspectives categories were too broad for the type of classification being done. The classification of perspectives in general literature such as newspapers worked well for The Author Group's students, and the classification of knowledge forms in textual discourse worked well for the researcher in this study. The classification of perspectives in the context of this research did not work well. However, their breadth was an advantage when defining the broad field from which science, technology and society (STS) are derived. The perspectives wheel in Figure 4.10 hints at the relationship between perspectives and knowledge forms by indicating a progression from classifying <u>public discourse</u> to

identifying a knowledge base and on to identifying the nature of each knowledge base. This figure is used by the **STSC Chemistry** authors at teacher inservices to illustrate that science curriculum to date has been primarily restricted to one cell—the scientific knowledge base cell.

In summary, Stage 4—the classification of discourse in the STSC **Chemistry 10** Unit A—saw the solidification of new knowledge forms (i.e., Emp_E, Emp_L and Com), the creation of context categories, and the creation and deletion of perspectives categories. More importantly the epistemological knowledge category (Epi K) was ranked first out of 33 taxonomic categories. This foreshadowed the splitting of the epistemology knowledge form in future stages of the study, which, in retrospect was a major breakthrough for the STSC Taxonomy and for the STSC **Chemistry** textbook and its authors. Evidence for epistemology as extensive, explicit content in textual discourse was the most important result of Stage 4 in this study.

F. Stage 5: The Classification of Discourse in STSC **Chemistry** 10 Unit B (1984)

The **STSC Chemistry** Unit B (1984)—"Communicating and Predicting Chemical Formulas"—was written purposefully by the authors with a communication emphasis (i.e., the C in STSC). The evidence gathered from the classification of discourse in Unit B (the fourth of six units of discourse classified) was congruent with the goal established by the authors. The single communication (Com) knowledge form tallied

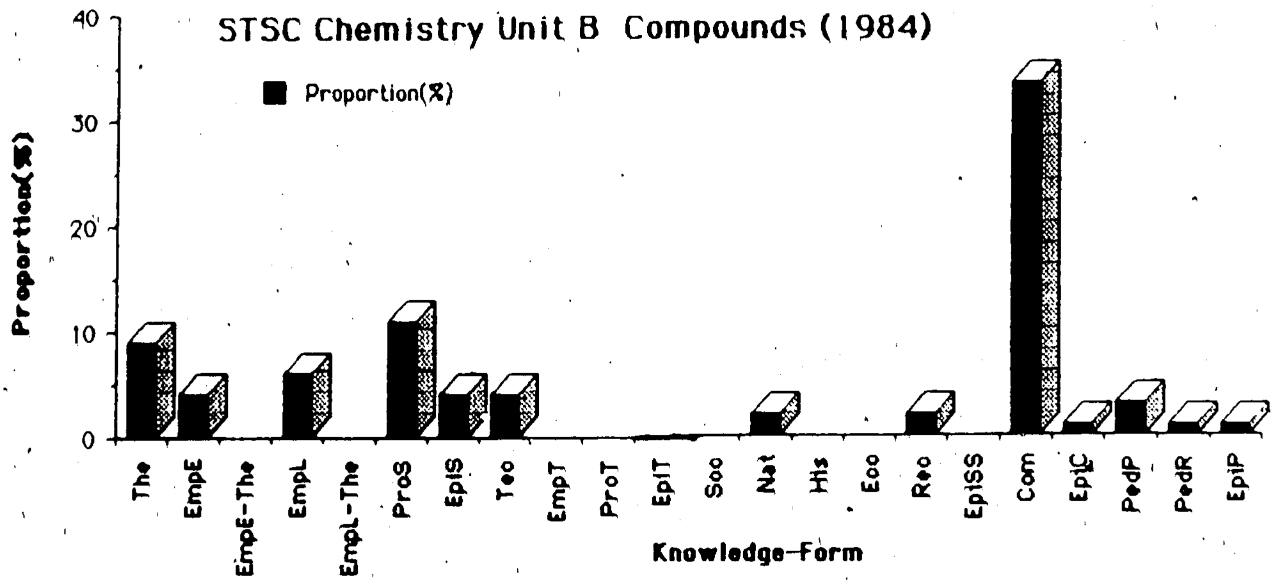
33 % (469 out of 1414 total tallies). As communicated in Figure 4.11 the Com knowledge form was the highest single knowledge form, with distant second and third places going to the scientific process skills (Pro—11 %) and theoretical (The—9 %). The total communication emphasis including only two knowledge forms (Com and Epi_C) tallied 34 %, while the total science emphasis, including five knowledge form (The, Emp_E, Emp_L, Pro, and Epi_S) tallied 38 %. The proportions of Unit B discourse classified into STSC/P emphases is summarized in Figure 4.12. The complete evidence is presented in Table 4.7. What follows in this section is an analysis, evaluation and synthesis of this evidence for knowledge forms in textual discourse.

Stage 5 was the first real test of the communication knowledge form created as a complete K-KW-W triad during Stage 4. The distribution within this K-KW-W knowledge form triad was significant for its relative balance—11 %, 7 % and 15 %, respectively. Some evidence from Unit B of resultant (K) and procedural (KW) knowledge are presented below along with an action-required (W) statement. The underlining has been added to assist the reader with the classification process.

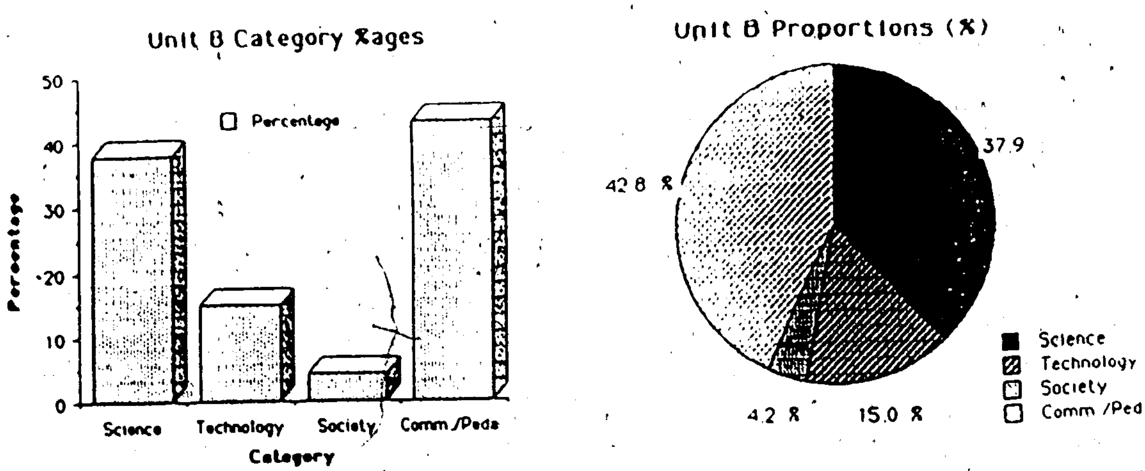
Com K: "The mineral name for lead(II) sulfide is galena." (Page B7)

K Com W: "The kind of atoms or ions present is given by the accepted chemical symbols . . .. The specific number or simplest ratio of atoms or ions is given by the subscripts in the balanced formula." (Page B30)

Com W/The W: "Predict the ionic formula for each of the following substances . . .." (Page B4)



Proportions of Knowledge Forms Discovered in Unit B Discourse
Figure 4.11



Proportions of STSC/P Discourse in Unit B
Figure 4.12

Table 4.7
Stage 5: The Classification of Discourse in Unit B—
"Communicating and Predicting Chemical Formulas"

Emphases and Knowledge Form	Resultant Knowledge (K) (#)	(%)	Procedural Knowledge (KW) (#)	(%)	Action Required (W) (#)	(%)	Total (#)	(%)
Science								
1. Theoretical	37	3	22	2	71	5	130	9
2. $Empirical_E$ (experiential)	42	3	2	0	12	1	56	4
3. $Empirical_E$—Theoretical	–	–	–	–	–	–	–	–
4. $Empirical_L$ (laws) (E & L)	7	0	11	1	70	5	88	6
5. $Empirical_L$—Theoretical	–	–	–	–	–	–	–	–
6. Process	1	0	72	5	89	6	162	11
7. Epistemological (General)	16	1	23	2	12	1	51	4
Context (Sci C)							50	4
Totals	Sci K 103	7	K Sci W 130	9	Sci W 254	18	535	38
Technology								
8. Technological (Applic.)	20	1	1	0	37	3	58	4
9. Empirical	–	–	–	–	–	–	–	–
10. Process	–	–	–	–	–	–	–	–
11. Epistemological	–	–	–	–	–	–	–	–
Context (Tec C)							154	11
Totals	Tec K 20	1	K Tec W 1	0	Tec W 37	3	212	15
Society								
12. Societal	–	–	–	–	–	–	–	–
13. National	24	2	–	–	–	–	24	2
14. Historical	3	0	–	–	–	–	3	0
15. Ecological	–	–	–	–	–	–	–	–
16. Reconstructional	11	1	1	0	20	1	32	2
17. Epistemological	–	–	–	–	–	–	–	–
Context (Sci C)							1	0
Totals	Soc K 38	3	K Soc W 1	0	Soc W 20	1	60	4
Communication								
18. Communication	155	11	104	7	210	15	469	33
19. Epistemological	11	1	–	–	–	–	11	1
Context (Com C)							–	–
Totals	Com K 166	12	K Com W 104	7	Com W 210	15	480	34
Pedagogy								
20. Pedagogical Purpose	25	2	17	1	2	0	44	3
21. Pedagogical Reference	1	0	7	0	–	–	8	1
22. Epistemological	10	1	4	0	2	0	16	1
Context (Ped C)							57	4
Totals	Ped K 36	3	K Ped W 28	1	Ped W 4	0	125	9
Total Contexts							262	19
Grand Totals	363	26	264	17	525	39	1414	100

In the first example resultant communicational knowledge—"The mineral name is . . ."—is followed by an example of some procedural knowledge on how to communicate a chemical formula, and finally by a required action statement that requires the use of procedural knowledge in a communication knowledge form.

Part of the reason for the high frequency count on the part of communicative knowledge was the explicit nature of the curricular emphasis on communication in the **STSC Chemistry** textbook. The integration of the theoretical and communication knowledge forms was explicit. The ionic chemical formula was both a "theoretical" formula (predicted from or explained by ion theory) and an "internationally accepted" formula (using international rules of communication). The way of knowing was simultaneously scientific and communicative (i.e., The W and Com W).

An epistemological triad, Epi K_C—K Epi W_C—Epi W_C, for tallying nature of communication statements was created during this stage of the research study. The initial classification process did not find evidence for all parts of the Epi_C triad, but in retrospect some exemplars were not recognized. Some examples of epistemology in communication, that helped to describe this category, are presented below.

Epi K_C: "Our ability to understand is limited by our language, as a representation . . .. The representation is never complete compared to the real object or event." (Page B14)

Com W/Epi W_C: "What information is directly given by the chemical formula, $H_2O_{(l)}$? . . . What else do you know about this substance that is not given by the chemical representation (formula)?" (Page B14)

In the first example above the statements about the limitations of communication are epistemological. The limitations in the nature of communication are spoken to. The epistemological aspect of the Epi W_C in the latter example is implicit. The question could have been followed up in the textual discourse by a question explicitly asking about the nature and limits of symbolic communications such as $H_2O_{(l)}$.

Epi W_C: "What does the limit of what can be communicated by a chemical formula, such as $H_2O_{(l)}$, indicate about the nature of communication?"

This kind of question focuses directly on epistemological aspects of communication and requires epistemological procedure to obtain an answer such as, "A communication is always a restricted representation of the 'real' thing." In later editions of the **STSC Chemistry 10** textbook (e.g., 1986), the following epistemological (Epi K_C) information is provided.

> "There are many communication systems in use within the scientific community. Systems acceptable to the scientific community share certain common characteristics. These systems are international (in meaning and symbols), social (commonly accepted agreement), precise (restricted to specific situations), and simple (easily understood)." (Page B24)

The above discourse illustrates the direction in which the 1984 edition of **STSC Chemistry 10** was headed. The epistemological underpinnings of other than scientific knowledge were being attended to in an explicit manner (e.g., the identification of the characteristics of a communication system acceptable to the scientific community). More importantly, for this research, the STSC Taxonomy was also undergoing significant structural changes. Strong evidence for the existence of an epistemology category in communication was deemed sufficient grounds for the reorganization of the structure of the taxonomy. The idea for the restructuring also had its origin in the complex dialectic relationship that existed between the reseacher's simultaneous involvements in this research and in the **STSC Chemistry** curriculum project.

F1. STSCP Curriculum Emphases

The most significant aspect of the epistemology in communication category was that an epistemology category was created outside of the science emphasis. For subsequent classification of textbook discourse the taxonomy was revised to include epistemology categories in all curriculum emphasis areas. Simultaneously, there was a complete reorganizing of the classification system into STSP (science, technology, society and pedagogy) emphases. Categories were also created at this time for which there was no evidence for in the textual discourse to that point. The criteria for the reorganization were primarily conceptual— 1. congruence with the STS science movement, 2. congruence with the **STSC Chemistry** project, and 3. congruence with the search for epistemological content in textbook discourse. The conceptual criteria were derived from the five theoretical perspectives used to guide the study. The conceptual analysis design of the research was most in need of these guiding perspectives during this period of rapid evolution for the taxonomy.

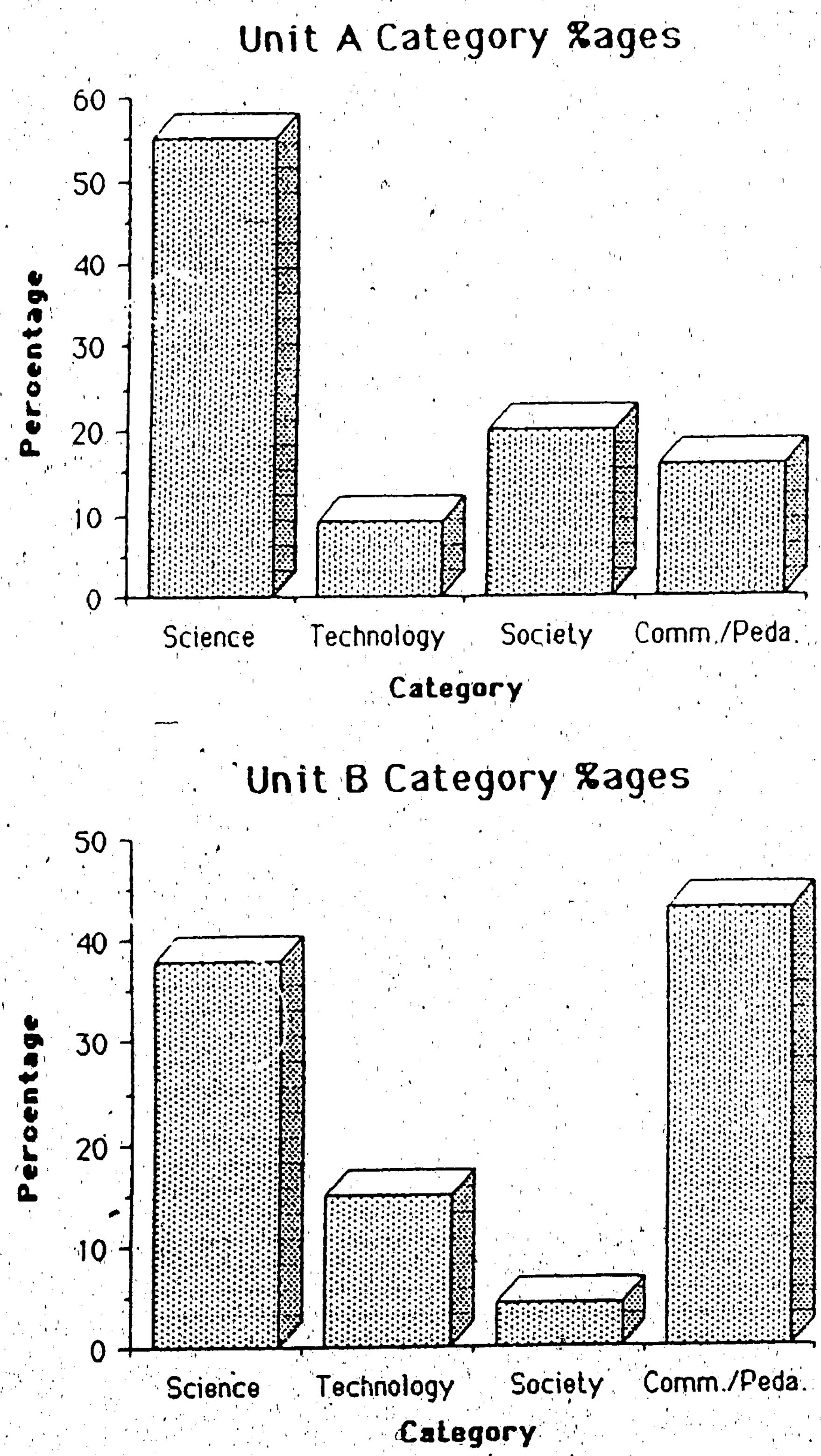
From STS science education and curriculum emphases perspectives, the researcher felt that the knowledge forms identified to that point could best be classified with STS curriculum emphases. To that point curriculum emphases had played a minor role in developing and evaluating a taxonomy of curricular discourse. The initial curricular emphases conceptualized in Stage 1 had been 1. academic (including theoretical, empirical and process knowledge forms), 2. applicational (including applicational, parochial, and ecological knowledge forms), 3. pedagogical (with pedagogical and psychological subcategories), and 4. implicit (with epistemological and reconstructional knowledge forms). As textbook discourse was classified, evidence and logic mounted to support the reconceptualization of academic as science, applicational as technology, and pedagogical as pedagogy and communication. The implicit emphases (epistemological and reconstructional) initially formulated did not translate well into an STS emphasis. The implicit epistemology knowledge form became an explicit category in each of the STS emphases, and the implicit reconstructional knowledge form was reimbedded in the society emphasis as a knowledge form. These changes were tentatively made in an attempt to integrate the community accepted concepts of curriculum emphases and STS science education with the fledgling STSC Taxonomy of knowledge forms. This type of "bigger-picture" criterion is common to many endeavors in science and science education. Further empirical and conceptual tests of this new STS structure for curriculum emphases were to follow in Stages 6-9.

From a practical perspective, the researcher felt that it was time to revise the taxonomy to reflect the curriculum emphases professed by The Author Group in their **STSC Chemistry** 10 textbook. The authors had recently changed the name of their textbook from STS Chemistry: Chemistry in Context to the current **STSC Chemistry**. This change reflected the explicit pursuit of writing science, technology, society, and communication emphases into designated units of the textbook. The authors had found that STS was too restrictive in describing the plurality of curricular emphases they wished to pursue. In the context of this parallel textbook development project, these STSC emphases translated into four emphases on the nature of science, technology, society, and pedagogy/communication.

From an epistemological perspective, the specific reference to the nature of science in the previous reading by and writing of the researcher was generalized to the other curricular emphases—technology, society, and pedagogy/communication. There was a conceptual imperative when defining a nature of communication emphasis, for example, to explicate the nature and origin of communicative knowledge (i.e., the epistemology of communicative knowledge). The decision was made by the researcher to search and research for epistemological textbook content in each of the STSCP emphases. Without textbook evidence for the existence of, and without a definition of, for example, the nature of technology, the authors and the researcher believed that the category would eventually be found and defined. At this point the reseacher no longer saw technology as applied science and for this epistemological reason the "applicational" emphasis label in the taxonomy was renamed (and reconceptualized) as "technological". The realization had occurred that many technological advances were not "applied science". For example, batteries and electrolytic cells were invented long before the "science" was available to explain how these technologies worked. The conceptualization of the technology emphasis in terms of knowledge forms and epistemological content was not complete. This explication had to wait until Stage 7, the classification of discourse in the STSC **Chemistry** 10 stoichiometry unit with a technology emphasis. This deliberative inquiry involving the parallel research study and the curriculum development project often exuded a confidence and openminded-willingness to change current constructs and test new ones in and around the classroom-in-use (Jenkins and Kass, 1980).

In summary, the above analysis and evaluation of the then current version of the taxonomy is based upon the evidence gathered during Stage 5 of the research. A synthesis is also alluded to from a number of research perspectives. When this synthesis or reconceptualization of the taxonomy was completed, a reanalysis of the evidence into STSC emphases provided outputs for Unit A (Periodic Laws and Atomic Theories) and Unit B (Communicating and Predicting Chemical Formulas) as represented in Figure 4.13.

The display of STSC/P curriculum emphases in Figure 4.13 indicates that about 55 % of all discourse classified in Unit A was from within a science emphasis. In Unit B the major emphasis indicated is the communication/pedagogy combination. This was good early news to



A Comparison of STSC/P Discourse
in STSC Chemistry Unit A (Elements) and Unit B (Compounds)
Figure 4.13

the authors of the STSC **Chemistry** textbook and provided a positive example of the fruitfulness of the taxonomic framework to the researcher. The discourse classified was from Draft 1 of the textbook. Although the implementation of the taxonomy for providing feedback to authors or textbook selectors was not part of this research and development study, the output of STSC/P emphases as a percentage of the discourse classified provided a degree of satisfaction to the authors and researcher. The actual comments of the authors are presented in Chapter 5 of this report. From this point on in the research, the analysis of the evidence groups the knowledge forms into STSCP emphasis for display and discussion.

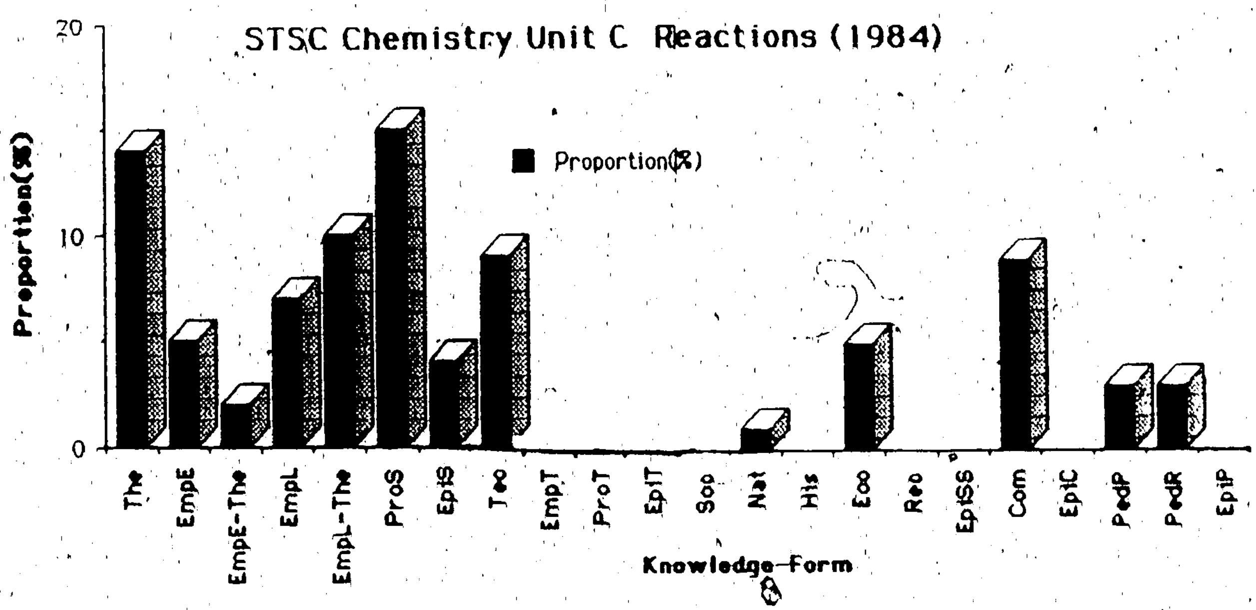
G. Stage 6: The Classification of Discourse in STSC Chemistry 10 Unit C (1984)

The classification of discourse in Unit C—"Communicating and Predicting Chemical Reactions"—involved the first use of the STSCP emphases as conceptual organizers of the knowledge forms. Table 4.8 presents the overall evidence gathered from the classification of discourse in Unit C. Figure 4.14 displays the distribution of knowledge forms in the Unit C discourse. A further analysis of the evidence showed that the distribution of STSCP curricular emphases from a total of 1286 tallies was science (Sci)—63 %, technology (Tec—9) %, society (Soc)—10 %, communication (Com)—9 %, and pedagogy (Ped)—10 %. The textbook authors' declared curricular emphasis for Unit C was science and technology in society. The evidence did not support this declaration—only 10 % of the discourse was societal. This analysis is graphically displayed in Figure 4.15.

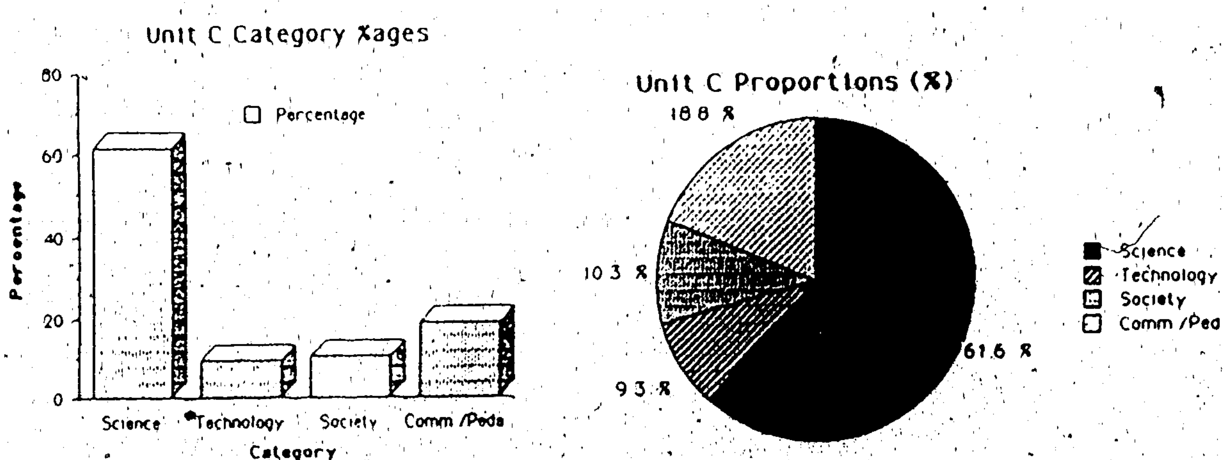
Table 4.8
Stage 6: The Classification of Discourse in Unit C—
"Communicating and Predicting Chemical Reactions"

Emphases and Knowledge Form	Resultant Knowledge (K) (#)	(%)	Procedural Knowledge (KW) (#)	(%)	Action Required (W) (#)	(%)	Total (#)	(%)
Science								
1. Theoretical	91	7	32	3	60	5	183	14
2. Empirical$_E$ (experiential)	49	4	3	0	14	1	66	5
3. Empirical$_E$—Theoretical	21	2	0	0	5	0	26	2
4. Empirical$_L$ (laws) (E & L)	21	2	15	1	60	5	96	7
5. Empirical$_L$—Theoretical	7	1	4	0	113	9	124	10
6. Process	13	1	*87	7	95	7	195	15
7. Epistemological (General)	36	3	4	0	8	1	48	4
Context (Sci C)							54	4
Totals	Sci K 238	19	K Sci W 145	12	Sci W 355	28	792	63
Technology								
8. Technological (Applic.)	80	6	14	1	18	1	112	9
9. Empirical	–	–	–	–	–	–	–	–
10. Process	0	0	0	0	1	0	1	0
11. Epistemological	0	0	2	0	0	0	2	0
Context (Tec C)							4	0
Totals	Tec K 80	6	K Tec W 16	1	Tec W 19	1	119	9
Society								
12. Societal	–	–	–	–	–	–	–	–
13. National	6	0	0	0	1	0	7	1
14. Historical	3	0	0	0	0	0	3	0
15. Ecological	61	5	4	0	4	0	69	5
16. Reconstructional	5	0	0	0	3	0	8	0
17. Epistemological	0	0	0	0	0	0	0	0
Context (Sci C)							46	4
Totals	Soc K 75	6	K Soc W 4	0	Soc W 8	1	133	10
Communication								
18. Communication	33	3	36	3	52	4	121	9
19. Epistemological	4	0	1	0	0	0	5	0
Context (Com C)							–	–
Totals	Com K 37	3	K Com W 37	3	Com W 52	4	126	9
Pedagogy								
20. Pedagogical Purpose	25	2	11	1	1	0	37	3
21. Pedagogical Reference	8	1	16	1	8	1	32	3
22. Epistemological	–	–	–	–	–	–	–	–
Context (Ped C)							47	4
Totals	Ped K 33	3	K Ped W 27	2	Ped W 9	1	116	10
Total Contexts							151	12
Grand Totals	463	36	229	18	443	34	1286	100

* K Pro W_S plus K Pro W_S — Pro V_S



The Distribution of Knowledge Forms in the Unit C Discourse
Figure 4.14



The Distribution of STSCP Discourse in Unit C
Figure 4.15

Although the analysis of the evidence from the classification of discourse in Unit A (atomic theories) and Unit B (chemical formulas) had supported the proclaimed curriculum emphases of the STSC Chemistry authors, this was not true for Unit C. Science scored about 60 % while the other four (TSCP) emphases tallied about 10 % each as illustrated in Figure 4.15. This analysis was presented to the authors and discussions immediately began on how to increase the declared science-in-society emphasis in this first draft of Unit C. The positive part of the analysis was that the authors now knew without reservation that Unit C had to be revised—the prediction of a science-in-society emphasis had been falsified. The negative part for the research study was that the internal structure of the society emphasis in the taxonomy had not been tested sufficiently. Fortunately, the large number of tallies in the science emphasis provided an additional major test of the science knowledge form structure as described below.

From a practical perspective, an important author use for the taxonomy was the conceptual framework of emphases, knowledge forms, K-KW-W triads, contexts, and epistemological approaches provided. The terms "emphases", "contexts", "ways of knowing", "empirical knowledge", "theoretical knowledge", and "nature of . . . " were now commonly used by the authors. The theoretical-practical dialectic was used by the authors to conceptualize and operationalize a description of STSC chemistry that could appear as content in a high school chemistry textbook. In an interactive sense the authors used the interim results of this research to affect changes in their textual materials.

From a research perspective, the major changes to the classification system during Stage 6 came in the definition of the nature of science emphasis. As communicated in Table 4.8 and Figure 4.14, the 63 % science rating was distributed as 14 % The, 5 % Emp_E, 2 % Emp_E—The, 7 % Emp_L, 10 % Emp_L—The, 15 % Pro_S, 4 % Epi_S, and 4 % Sci C. Two categories were created early in the analysis of Unit C—the linked categories of experiential empirical-theoretical (Emp_E—The) and generalizable empirical—theoretical (Emp_L—The). The content of Unit C made the revision obvious. Chemical equations presented in the discourse included both theoretical and empirical knowledge. The atoms, ions, and molecules communicated symbolically in a chemical equation are theoretical entities (The K). The states of matter of the chemicals communicated as subscripted information is empirical knowledge (Emp K). A chemical equation, translated as a sentence, therefore communicates both theoretical and empirical knowledge.

The K—Emp K_L: $Cu_{(s)} + 2\ AgNO_{3(aq)} \rightarrow 2\ Ag_{(s)} + Cu(NO_3)_{2(aq)}$

Furthermore, when students are asked to predict and communicate a balanced chemical equation for a given reaction the ways of knowing employed are both theoretical (The W) and empirical (Emp W_L). Chemical formulas for ionic compounds are predicted from a theory of ions and ionic compounds (The W). Balancing the equation is predicted from a theory of conservation of atoms (The W). The state of matter, of ionic compounds, for example, are predicted from generalizations (Emp W_L)

about the pure or water environment states of these compounds.

Where theoretical and empirical knowledge is linked closely within one sentence (a chemical equation is a sentence) of textbook discourse, a description of the discourse should include this information. The information as to how often students are given linked knowledge forms or are required to use linked ways of knowing may be important information to researchers and textbook developers alike. For example, the **STSC Chemistry** authors have plans to move from explicitly treating empirical and theoretical knowledge epistemologically to the same type of treatment for linked empirical and theoretical knowledge. In the **STSC Chemistry** 10 textbook empirical and theoretical knowledge are epistemologically separated. Plans are that in the **STSC Chemistry** 30 textbook empirical and theoretical knowledge will be epistemologically reunited to illustrate the complexity of scientific work. The criterion for establishing these new dialectic categories was in the above sense epistemologically driven. The criterion for establishing these two new (The—Emp_E and The—Emp_L) knowledge forms was epistemology. The feeling was that the complexity of scientific work and discourse could not be reduced to separate ~~and seemingly~~ unrelated empirical and theoretical knowledge forms. The addition of these new linked knowledge forms reflected an empirical criterion (i.e., the evidence for these knowledge forms in textual discourse) and a conceptual criterion (i.e., the logical presentation of current views on the nature of science).

In summary, Stage 6 was successful in an unexpected direction. Instead of providing a major test of a society curriculum emphasis, the discourse in Unit C of **STSC Chemistry 10** provided a test of the previously established science emphasis. Instead of forcing revisions to the society knowledge forms. A large number (12 %) of statements classified in Stage 6 were placed in one of two knowledge forms which linked empirical and theoretical knowledge or ways of knowing. Creating these linked knowledge forms provided a greater sophistication to the **STSC Taxonomy** and a greater ability to describe complex curricular discourse.

H. Stage 7: The Classification of Discourse in STSC Chemistry 10 Unit D (1984)

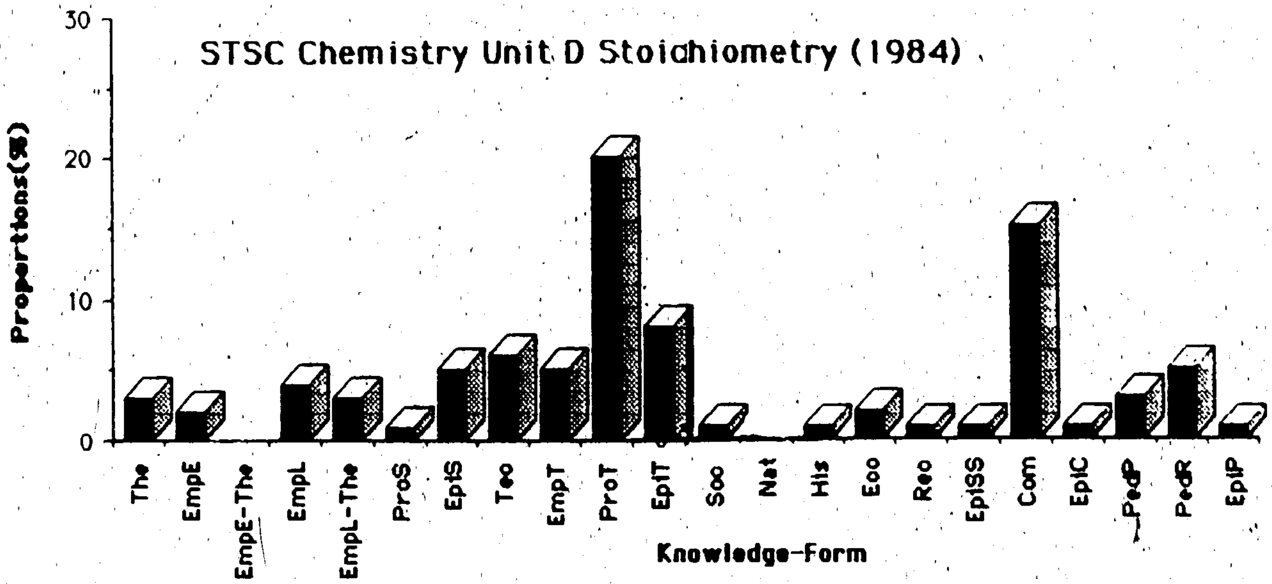
The final unit of discourse to be classified in this research study was the **STSC Chemistry 10** textbook Unit D—"Quantitative Predictions in Chemistry". The intended curricular emphasis for Unit D was technology. The evidence gathered by the classification of the textual discourse and presented in Table 4.9 and Figure 4.16 support this claim. The technology knowledge forms tallied 41 % of 1360 total classifications. Science at 20 %, communication at 16 %, pedagogy at 14 %, and society at 9 % followed the technology lead. This analysis in search of STSCP curriculum emphases is presented graphically in Figure 4.16.

The analysis of the evidence for Unit D confirmed the claim of the **STSC Chemistry** authors of a technology emphasis. This was particularly important since chemistry is classified in school as a

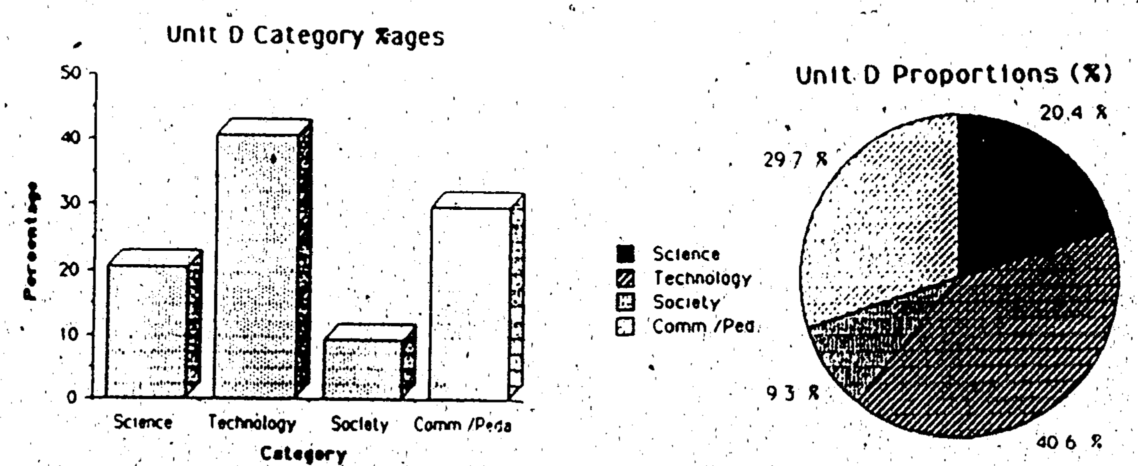
Table 4.9
Stage 7: The Classification of Discourse in Unit D—
"Quantitative Predictions in Chemistry"

Emphases and Knowledge Form		Resultant Knowledge (K) (#)	(%)		Procedural Knowledge (KW) (#)	(%)		Action Required (W) (#)	(%)	Total (#)	(%)
Science											
1. Theoretical		33	2		3	0		3	0	39	3
2. $Empirical_E$ (experiential)		28	2		1	0		3	0	32	2
3. $Empirical_E$—Theoretical		5	0		0	0		0	0	5	0
4. $Empirical_L$ (laws) (E & L)		20	1		19	1		14	1	53	4
5. $Empirical_L$—Theoretical		9	1		3	0		30	2	42	3
6. Process		2	0		5	0		13	1	20	1
7. Epistemological (General)		51	4		2	0		21	1	74	5
Context (Sci C)										12	1
Totals	Sci K	148	11	K Sci W	33	2	Sci W	84	6	277	20
Technology											
8. Technological (Applic.)		72	5		3	0		5	0	80	6
9. Empirical		19	1		23	2		29	2	71	5
10. Process		83	6		90	7		94	9	267	20
11. Epistemological		69	5		7	1		29	2	105	8
Context (Tec C)										29	2
Totals	Tec K	243	18	K Tec W	123	9	Tec W	157	12	552	41
Society											
12. Societal		14	1		0	0		0	0	14	1
13. National		4	0		0	0		0	0	4	0
14. Historical		17	1		0	0		1	0	18	1
15. Ecological		21	1		0	0		4	0	25	2
16. Reconstructional		16	1		1	1		1	1	18	1
17. Epistemological		3	0		0	0		13	1	16	1
Context (Sci C)										31	2
Totals	Soc K	76	6	K Soc W	1	0	Soc W	19	1	127	9
Communication											
18. Communication		33	3		36	3		52	4	121	9
19. Epistemological		4	0		1	0		0	0	5	0
Context (Com C)										–	–
Totals	Com K	37	3	K Com W	37	3	Com W	52	4	126	9
Pedagogy											
20. Pedagogical Purpose		25	2		11	1		1	0	37	3
21. Pedagogical Reference		8	1		16	1		8	1	32	3
22. Epistemological		–	–		–	–		–	–	–	–
Context (Ped C)										47	4
Totals	Ped K	33	3	K Ped W	27	2	Ped W	9	1	116	10
Total Contexts										151	12
Grand Totals		463	36		229	18		443	34	1286	100

* K Pro W_S plus K Pro W_S — Pro V_S



The Proportions of Knowledge Forms in Unit D Discourse
Figure 4.16



The Distribution of Curriculum Emphases in Unit D Discourse
Figure 4.17

science, not a technology, course. At that point none of the other emphases had outperformed the science emphasis on previous units. The two-to-one margin of technology statements over science statements was a major finding which pleased both the authors and the researcher. The authors felt confident that they were on the right track for creating textual material with a technology emphasis. The researcher knew that the technology emphasis in the STSC Taxonomy had been given a significant test (i.e., 552 tallies for 41.% of the total tallies). The significant emphasis on technology in Unit D increased the confidence in the completeness of the technology knowledge forms. If additional knowledge forms existed in a technology emphasis, 552 technology related statements should have forced an undercovering of them. The revisions that were made during the process of classifying discourse in Unit D are discussed below.

During the test of the taxonomy against the Unit D discourse, two of the STSCP emphases were revised—technology and society. A societal knowledge form category was created even though the K-KW-W societal triad did not receive much empirical support. The distribution of tallies for the societal K-KW-W triad was a low 14, 0 and 0. An additional few tallies (31) were placed in the societal context category. However, the societal category was retained. The criteria for inventing and retaining the societal category are presented below.

1. Just on the basis of name the category seems like it should reasonably fit into the society emphasis. Every other curriculum emphasis contains a knowledge form namesake except the society emphasis. In the science discipline this criterion for acceptance

might be described as aesthetics.

2. The Unit C discourse did not prove to be a very good test of the curricular emphasis of science-and-technology-in-society. As it turned out Unit D did equally well in exemplifying textbook discourse with a societal emphasis. Even though there was little empirical evidence for the societal knowledge form, it was retained until a more extensive empirical test could be arranged.

3. The **STSC Chemistry** author group had discussed revisions to Unit C to increase the societal component. The majority of the discussion centered on the use of a list of twelve perspectives that may be taken on a science-and-technology-in-society issue. These perspectives were a revision of Aikenhead's (1975) list of alternate ways of knowing. The twelve perspectives identified by the author group were aesthetic, ecological, economic, emotional, ethical, legal, militaristic, mystical, political, scientific, social, and technological. Considerable classroom pilot work had been done by the **STSC Chemistry** teacher-authors in having Grade 12 students use all twelve perspectives to classify discourse in newspaper and magazine articles, films and videos. However, no piloting had been done with Grade 10 and Grade 11 students. The decision, that was made and was subsequently piloted, was to have Grade 10 students classify given science-in-society issue statements restricted to five of the twelve perspectives. The five perspectives chosen were ecological, economic, political, scientific, and technological. Through piloting done after the

current research data base was collected, it was found that Grade 10 students could handle this skill well. As to what taxonomic way of knowing was displayed by doing this type of classifying, a societal way of knowing seemed to fit best. Some examples of a societal way of knowin (Soc W) for classifying perspective statements are provided below from Page C35 of **STSC Chemistry 10** (1986). The students were expected to provide the coded answer (Soc K) given in front of the statement.

Pol: "MP's in Ontario need to be knowledgeable about acid rain in order to get elected."

Tec: "Solvents are now being used to remove sulfur from coal."

Sci: "Acid has been purposely added to a research lake in Ontario."

Econ: "Srubbers to control sulfur emissions are expensive (megadollar) items."

Ecol: "In acid lakes, fish die from the toxicity of aqueous metal ions."

4. A fourth reason for creating the societal knowledge category was to decrease the entries in the societal context category. Experience with the evolution of the classification system indicated that, if the researcher did not know how to classify a statement or phrase, the item was classified as contextual in one of the STSCP emphases. Experience also indicated that, as the appropriate knowledge categories were created, the percentage of context tallies decreased.

5. The empirical evidence indicated that societal knowledge was present in the Unit D discourse—14 tallies. The lack of the K-KW-

W triad (i.e., a 14, 0, 0 tally) was not sufficient evidence to eliminate the category. Most new categories start with knowledge only tallies. Science textbook authors may even decide not to complete the triad. They might feel that procedural knowledge and questions are inappropriate to the pedagogical purpose of their science textbook.

For these reasons the societal category was retained. The degree of certainty associated with this decision is lower than for decisions of retention on other knowledge forms. Earlier decisions were given a more rigourous test. More tests on the societal category are still necessary using science-in-society textual discourse.

The second area of revision of the classification system during Stage 7 was in the technology emphasis. Previous to Unit D, the technology emphasis only had two knowledge forms—technological (Tec) and epistemological (Epi_T). During the classification of textbook discourse in Unit D two new technology knowledge forms were added and tested—empirical (Emp_T) and process (Pro_T). The criteria for adding and retaining these two new technology based knowledge forms are outlined below.

1. The science and technology emphases were made <u>more parallel</u> by the creation of the empirical (Emp_T) and process (Pro_T) knowledge forms. Including epistemology (Epi_T), this meant that the parallel was extended to three categories. This move made the whole system "neat and tidy"; i.e., aesthetic. This is a criterion used in the science and engineering disciplines and seemed appropriate here.

2. The revision was also epistemologically driven. Without the two new categories the production of technological knowledge and manufactured products could not be classified. The whole question of how technology operates was missing. The concept of technology being applied science needed to be replaced in general vocabulary by terms which more accurately reflected the nature of technology (George 1981).

3. The empirical technology (Emp_T) category was created to reflect the empirical character of engineering. Technology was seen as employing more of an empirical way of knowing than science. The resultant knowledge and way of knowing employed by an engineer or technician were classified as Emp K_T and Emp W_T, respectively.

4. The technological process (Pro_T) category was created to cover textbook discourse describing technological work done by students. This definition parallels the definition of the scientific process (Pro_S) category. The empirical (Emp) category in both cases involves a third person or professional context. The process categories (Pro_S and Pro_T) require a student context. These are not definitions which are generally accepted in the science education community but were found to be necessary definitions when using the STSC Taxonomy. From a practical perspective, evidence for the extent of student work could be obtained without this type of definition. Time will test the general acceptability of this definition in the science education community.

5. There was a need to differentiate between scientific process skills (such as students stating problems, making predictions, and

designing experiments) and technological process skills (such as student manipulating technological devices (e.g., bunsen burners and pipets) and carrying out technological processes (e.g., filtrations and titrations)). Technological process skills are often referred to as psychomotor skills. However, terms such as psychomotor skills or scientific process skills are not specific enough to be used in classifying STS textbook discourse.

6. The invention of the term technological process skill (derived from the term technological skill) helps to define STS within an academic science course context. A language was needed to express the concept. This invention helps in a normal science way to complete the conceptualization of STS science education.

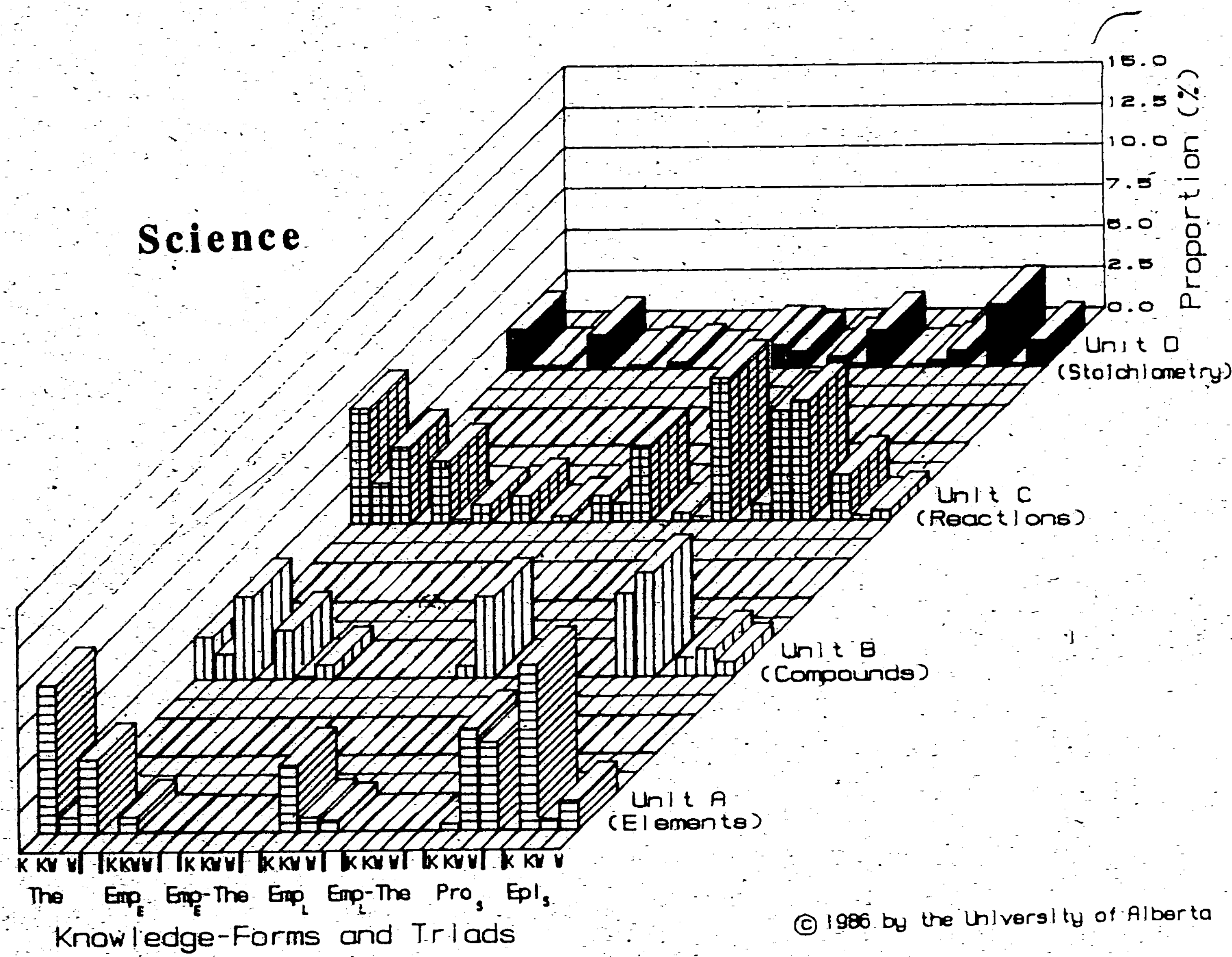
7. From a practical perspective the 1986 edition of the **STSC Chemistry** 10 has a Reference Section with two descriptive lists of scientific process skills and technological process skills. The Author Group has also listed eight "categories of technological understanding [which] a comprehensive science curriculum should include." One of these categories of technological understanding is technological skills (**STSC Chemistry 10**, Teachers' Edition, 1986: TDiv). The STSC Taxonomy was made consistent with this classroom use.

As usual the criteria for inclusion or exclusion of curriculum emphases and knowledge forms in the STSC Taxonomy were the appropriateness of the category in defining STS science education, epistemologically justifying STSCP emphases in science education, describing chemistry textbook discourse, making epistemological content more clear and explicit to the student, guiding practice in chemistry textbook writing, guiding practice in the chemistry classroom. Further tests of the STSC Taxonomy, using these criteria and others, need to continue in order to provide for greater acceptability of the system by the science education community.

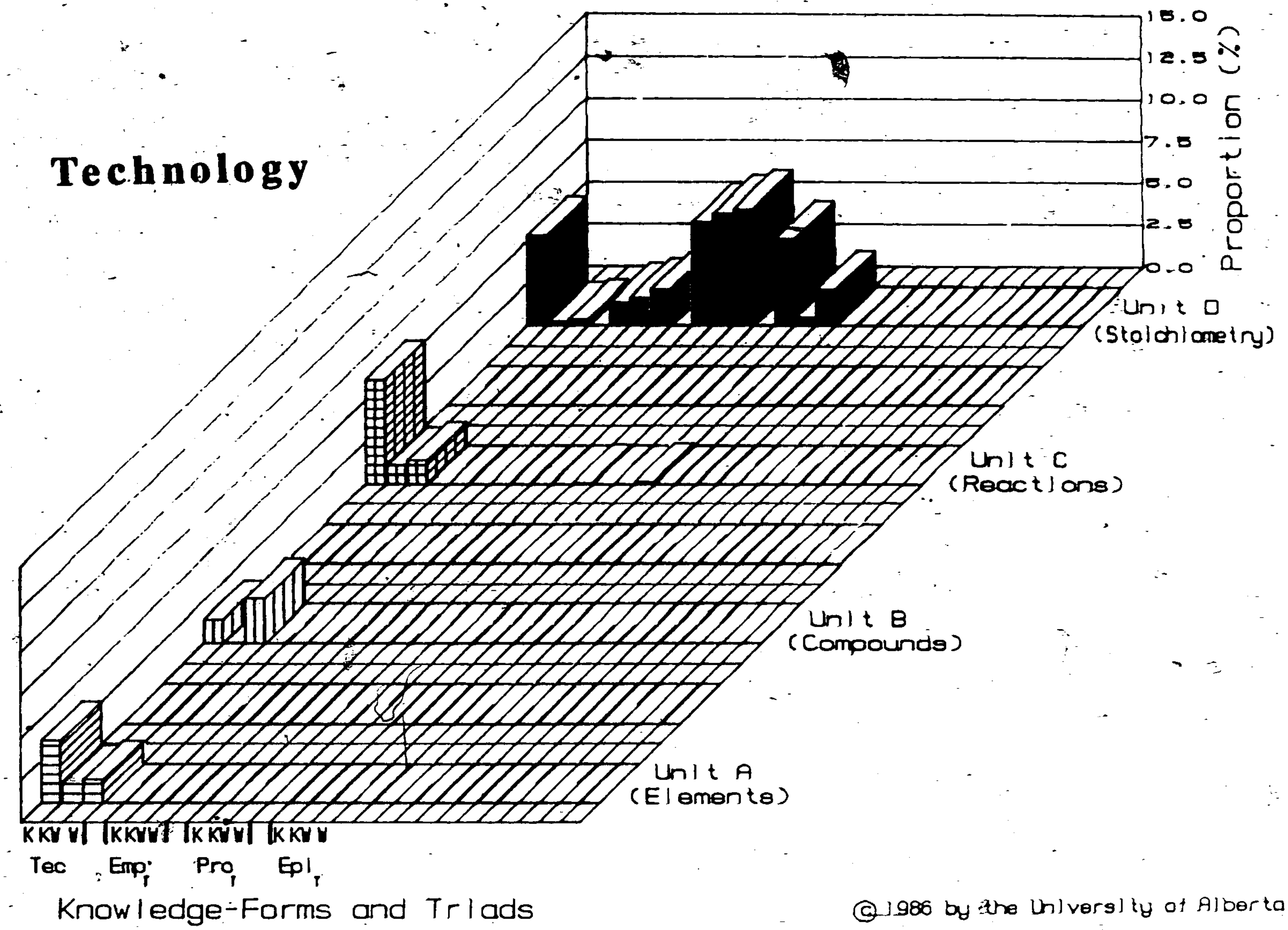
I. Chapter Summary

The evolution of the STSC classification system through the seven reconstruction stages described above was in itself an epistemological adventure. The nature and origin of knowledge found in chemistry textbook discourse was classified based upon empirical evidence and conceptual arguments. The STS science education concept and epistemology were used as conceptual organizers to group knowledge forms into curriculum emphases within a taxonomic framework. The evolution of the taxonomy generated considerable empirical data some of which has been presented unit by unit earlier in this chapter. A summary of the amount of discourse within each category within STSC/P curriculum emphases for **STSC Chemistry** Units A-D are presented in Figure 4.18 through Figure 4.21. These figures also graphically depict the percentage of tallies for each of the sixty-six categories in each unit of textual discourse analyzed.

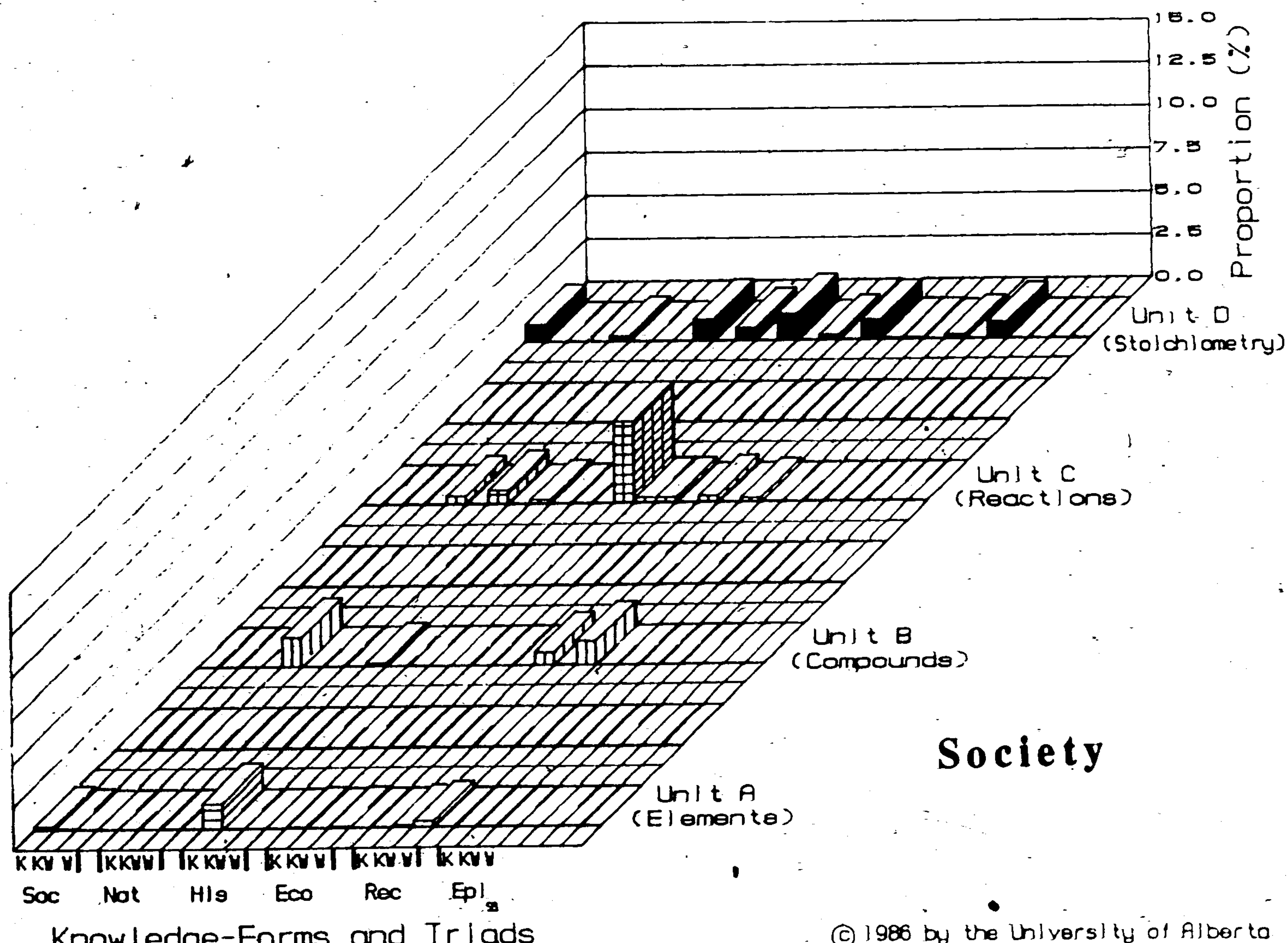
The trends from Unit A through Unit D can be ascertained within each curriculum emphasis. For example the science emphasis in Unit A and Unit C is fairly clear. The differences from Unit A to Unit C are



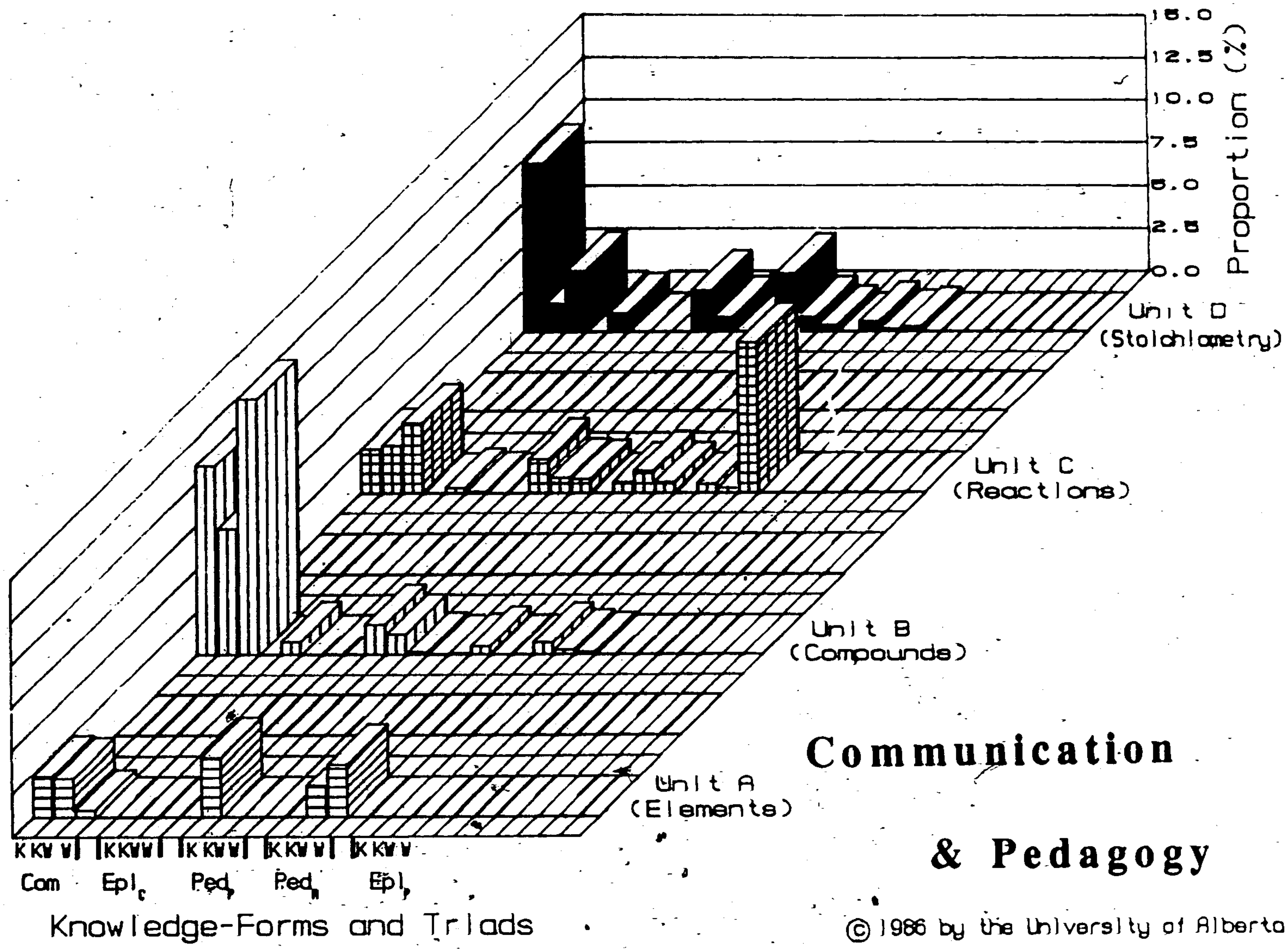
The Proportions of Knowledge Forms and Triads
in a Science Emphasis
Figure 4.18



The Proportions of Knowledge Forms and Triads
in a Technology Emphasis
Figure 4.19



The Proportions of Knowledge Forms and Triads
in a Society Emphasis
Figure 4.20

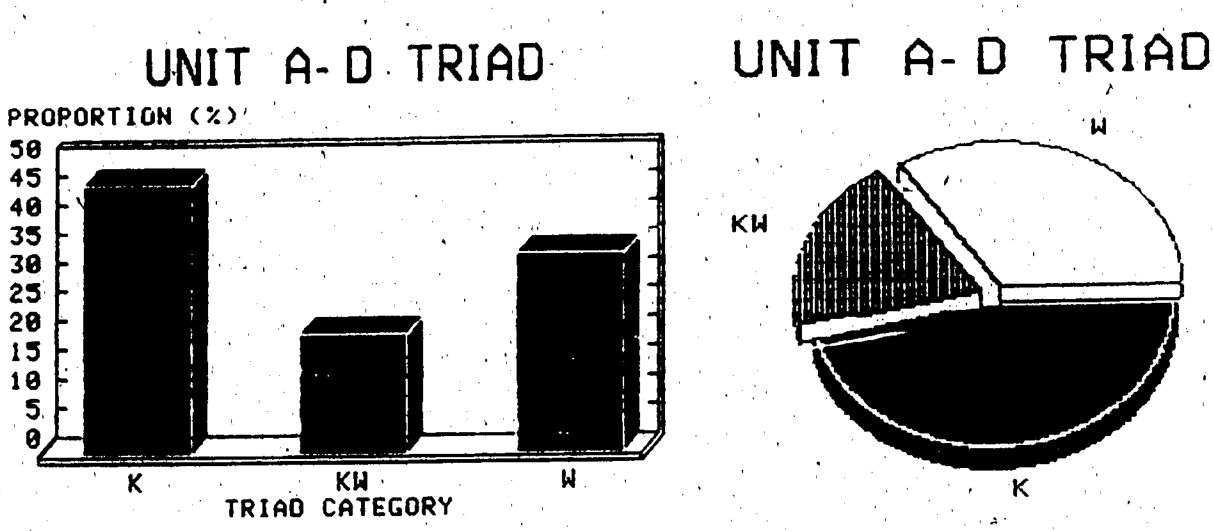


The Proportions of Knowledge Forms and Triads
in Communication and Pedagogy Emphases
Figure 4.21

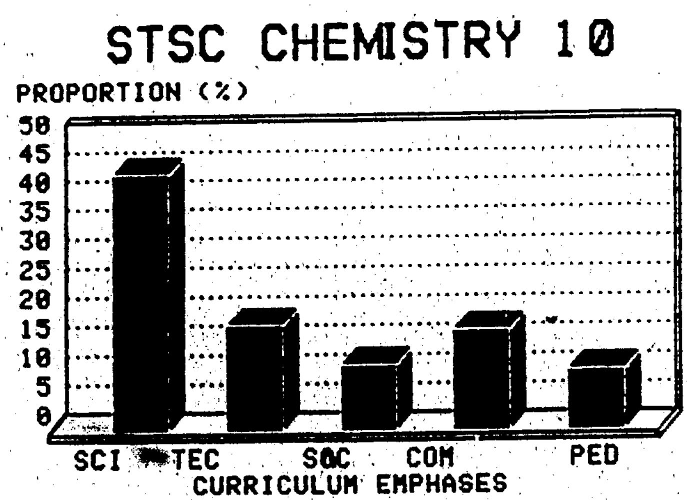
in the knowledge forms. Unit A is higher in epistemological discourse, while Unit C is higher in empirically conceptual knowledge (Emp_L). Similar analyses can be completed for each curriculum emphases in each unit of discourse but for the current study the wide range of significant kinds of discourse is the most telling feature of the graphical display. The lack of evidence for discourse in certain knowledge forms is an important message about balanced discourse to authors, but leaves the researcher uncertain about the conceptualization and future of these forms in a taxonomy.

Figure 4.22 communicates the percentage of discourse classified within each category of the K-KW-W epistemological triad. The classification of the Unit A-D discourse yielded 46 % resultant knowledge (K), 20 % procedural knowledge (KW), and 34 % action required statements. This analysis of the evidence presents strong support for the existence of the epistemological triad within textual discourse. The epistemological triad could be considered one of the major findings of the study. A concept and language has seen developed through the concept of this triad to describe textual discourse in terms of three relatively simple categories.

A further analysis as in Figure 4.23 shows that the Unit A-D STSCP grand totals calculate to science at 44 %, technology at 18 %, society at 11 %, communication at 17 %, and pedagogy at 10 %. None of the STSCP emphases rated out at less than 10 %. These values can be used cautiously to tell us something about the **STSC Chemistry 10** course (i.e., that there is evidence of STSCP emphases and their nested knowledge forms and K- KW-W way of knowing triads), but this



Discourse Classified in the Epistemological Triad
for Unit A-D in STSC Chemistry 10 (1984)
Figure 4.22



Discourse Classified in the STSCP Emphases
for Unit A-D in STSC Chemistry 10 (1984)
Figure 4.23

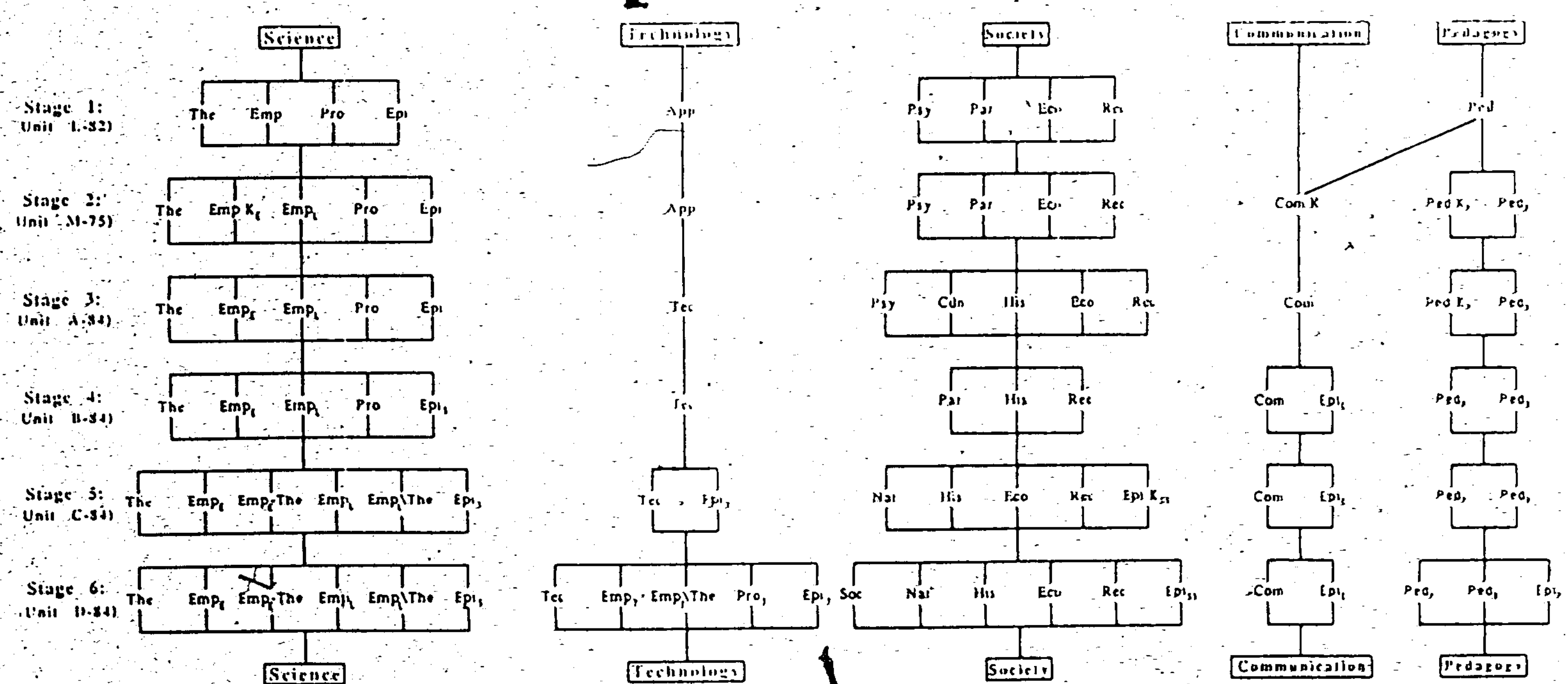
study was not designed to evaluate a textbook. In fact the textbook discourse was one of the ways used to evaluate an evolving taxonomy of knowledge forms. For example, the technology emphasis in the classification system was not substantially revised until the last chapter of textbook discourse was classified. The technology component of the previous units classified would have increased, perhaps significantly, due to the splitting of scientific and technological process skills in Unit D.

The STSC classification system was tested both empirically and conceptually in a series of seven stages, including six stages of classifying textual discourse in the ALCHEM Unit L (1982) and Unit M (1975), and the STSC Chemistry 10 Units A-D (1984). The evolution of the STSC Taxonomy through the six stages has been analyzed and displayed in three ways.

1. Table 4.10 uses the 22 x 3 classification matrix and numbers 2-7 to communicate which of the 66 categories were introduced at which stage in the research. For example, "5. Pro K_T" in Table 4.10 indicates that technological process skills was introduced as a knowledge form during Stage 6 of this research study. The advantage of this display is that all sixty-six categories of the STSC Taxonomy can be shown on one page.
2. Figure 4.24 shows the evolution of the five STSCP emphases from Stage 2 through Stage 7. The ten original categories shown in Stage 2 are shown as if they were nested in STSCP emphases—they were not until Stage 5 of the study. Stage 2 versus Stage 7 is the most important comparison to make. The criteria for making the

Table 4.10
Stages 2-7: The Evolution of the STSC Taxonomy

Emphases and Knowledge Form	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
Science			
1. Theoretical	1. The K	1. K The W	1. The W
2. Empirical$_E$ (experiential)	1. Emp K_E	3. K Emp W_E	2. Emp W_E
3. Empirical$_E$—Theoretical	5. Emp K_E—The K	5. K Emp W_E—K The W	5. Emp W_E—The W
4. Empirical$_L$ (laws)	1. Emp K_L	1. K Emp W_L	1. Emp W_L
5. Empirical$_L$—Theoretical	5. Emp K_L—The K	5. K Emp W_E—K The W	5. Emp W_L—The W
6. Process	1. Pro K_S	1. K Pro W_S	1. Pro W_S
7. Epistemological Context (3. Sci C)	1. Epi K_S	1. K Epi W_S	1. Epi W_S
Technology			
8. Technological	1. Tec K	1. K Tec W	1. Tec W
9. Empirical	6. Emp K_T	6. K Emp W_T	6. Emp W_T
10. Process	5. Pro K_T	5. K Pro W_T	5. Pro W_T
11. Epistemological Context (3. Tec C)	5. Epi K_T	5. K Epi W_T	5. Epi W_T
Society			
12. Societal	6. Soc K	6. K Soc W	6. Soc W
13. National	1. Nat K	1. K Nat W	1. Nat W
14. Historical	3. His K	3. K His W	3. His W
15. Ecological	1. Eco K	1. K Eco W	1. Eco W
16. Reconstructional	1. Rec K	1. K Rec W	1. Rec W
17. Epistemological Context (3. Soc C)	5. Epi K_{SS}	6. K Epi W_{SS}	6. Epi W_{SS}
Communication			
18. Communication	1. Com K	3. K Com W	3. Com W
19. Epistemological Context (3. Com C)	4. Epi K_C	4. K Epi W_C	4. Epi W_C
Pedagogy			
20. Pedagogical Purpose	1. Ped K_P	4. K Ped W_P	4. Ped W_P
21. Pedagogical Reference	1. Ped K_R	1. K Ped W_R	1. Ped W_R
22. Epistomological Context (3. Ped C)	4. Epi K_P	6. K Epi W_P	6. Epi W_P

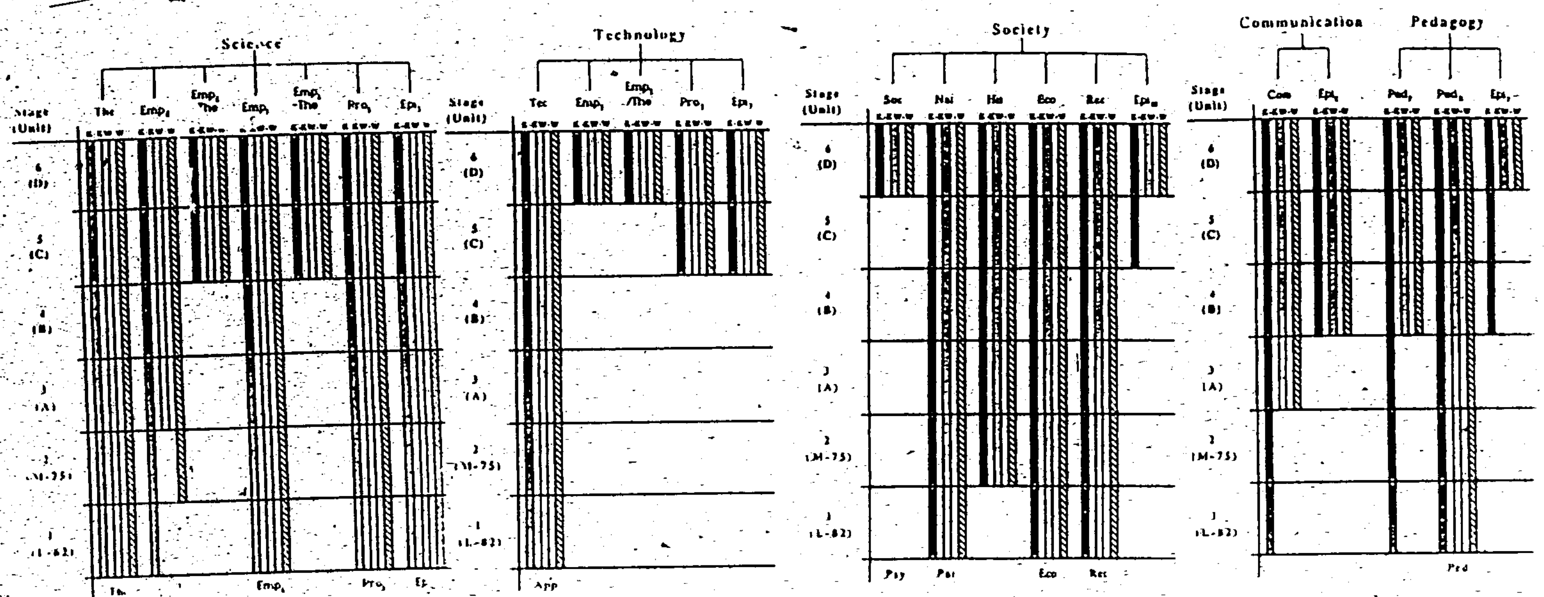


The Evolution of the STSC Taxonomy
- Stage Versus Knowledge Form
Figure 4.24

intermediate changes were outlined previously in this chapter, stage by stage.

3. Figure 4.25 (the bar graphs) summarizes graphically the changes in all sixty-six categories. The original ten knowledge forms appear on the bottom and the final twenty-two on top. This table is important because the history of the triads within each knowledge form is represented. An analysis of this evidence suggests that new categories are sometimes recognized first as the knowledge (K) component of a K-KW-W triad. The KW-W components of the triad follows at a later stage. See Emp_E, Epi_{SS}, Com, Ped_P, and Epip categories in Table 4.2 as examples of this phenomenon. Future discoveries of knowledge forms are likely to follow the same pattern.

The number of knowledge forms went from ten to twenty-two. According to the taxonomy conceptualized in Stage 1, it was predicted that ten kinds of knowledge would be found in the textbook discourse classified in Stage 2. The completed research could be reconstructed as a series of six predictions for which evidence was gathered as a test of the predictions. After each test an analysis and evaluation of the evidence led to a confirmation or revision of knowledge forms in the STSC Taxonomy. The synthesis part of the research saw the taxonomy grow from ten to sixty-six categories. The complexity of the taxonomy eventually led to the collapsing of the taxonomy into five emphases and an epistemological triad.



The Evolution of the STSC Taxonomy
- Stage Versus K-KW-W Triad
Figure 4.25

The above description of the research process would best be described as a general reconstruction. More specifically the researcher would describe the research process as a series of up to 6742 tests of the taxonomy. (6742 is the total number of tallies made in classifying six chapters of chemistry textbook discourse.) Each of these tests was a conceptual test as well as the empirical test. The categories were continually tested conceptually in terms of their definitions and their relationships to each other. As described several times earlier, the practice-theory interface saw plenty of action, both within the researcher's self deliberations and between the taxonomic research and the STSC Chemistry project.

The summary of the evolution of the STSC Taxonomy would not be complete without coming full circle back to epistemology. An early version of the design for this study called for the classification of textbook discourse in search of evidence for the epistemological approaches taken by textbook authors; i.e., the authors' normative perspectives, the authors' epistemology-in-use, and/or the authors' epistemological paradigm(s). The semi-final version of the research design involved the search for evidence of kinds of epistemological content (e.g., Epi_S and Epi_T) in textbook discourse. Part of the final design saw the analysis of the evidence used to support the suggestion that the nesting of K-KW-W triads into knowledge forms and the nesting of knowledge forms into curricular emphases was epistemologically driven. The whole 22 x 3 taxonomic matrix can be collapsed in two dimensions into STSCP emphases. An eventual criterion for creating a curricular emphasis was the identification of epistemological content specific to that emphasis. For example, communication was created as a curriculum emphasis because there was evidence of students being asked in textbook discourse to understand the way in which communication systems come to be accepted in the scientific community. Students were being asked to list criteria for evaluating scientific communication systems. The distinctive origin and nature of communicative knowledge led to the creation of a communication emphasis when only component knowledge forms (Com and Epi_C) had been discovered. Epistemological content was obviously an important criterion which could override other shortcomings.

Epistemology infiltrated and informed this study in a whole variety of ways, including chronologically, a conceptualization in Stage 1 of the epistemological paradigms of textbook authors as demonstrated within normative perspectives on curriculum content, the discovery in Stage 1 and 2 of an epistemological framework of K-KW-W triads in each knowledge form, a search, beginning in Stage 3, for epistemological content in textual discourse, the nesting of knowledge forms into epistemologically driven curricular emphases in Stage 5, and the use of epistemology as pedagogy by STSC Chemistry students.

Each of these applications of epistemology are introduced and illustrated in this chapter of the research report and helped lead to the development of the STSC Taxonomy. The terms are used in the context of this research report to emphasize the important control position that epistemology held in the study. Whether the STSC Taxonomy system becomes accepted in the science-education community will itself depend on a whole range of epistemological criteria, including sociological factors.

Chapter 4 above, presents the history of the evolution of the STSC Taxonomy of Curricular Discourse from State 1 through Stage 7. The version of the STSC Taxonomy at the end of Stage 7 is presented in Table 4.11. The multi-stage collection of evidence, the analysis of the evidence, the evaluation of the taxonomy, the criteria for the evaluation, and the synthesis of the next version of the taxonomy is reported. The history and description of the STSC Taxonomy is continued in Chapter 5 where the results from Stage 8 and Stage 9 of the study are presented.

Table 4.11
The STSC Taxonomy

Emphases and Knowledge Forms	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
	The K-KW-W (Epistemological) Triad		
Science			
1. Theoretical	The K	K The W	The W
2. Empirical$_E$ (experiential)	Emp K_E	K Emp W_E	Emp W_E
3. Empirical$_E$—Theoretical	Emp K_E—The K	K Emp W_E—K The W	Emp W_E—The W
4. Empirical$_L$ (laws)	Emp K_L	K Emp W_L	Emp W_L
5. Empirical$_L$—Theoretical	Emp K_L—The K	K Emp W_E—K The W	Emp W_L—The W
6. Process	Pro K_S	K Pro W_S	Pro W_S
7. Epistemological	Epi K_S	K Epi W_S	Epi W_S
Technology			
8. Technological	Tec K	K Tec W	Tec W
9. Empirical	Emp K_T	K Emp W_T	Emp W_T
10. Process	Pro K_T	K Pro W_T	Pro W_T
11. Epistemological	Epi K_T	K Epi W_T	Epi W_T
Society			
12. Societal	Soc K	K Soc W	Soc W
13. National	Nat K	K Nat W	Nat W
14. Historical	His K	K His W	His W
15. Ecological	Eco K	K Eco W	Eco W
16. Reconstructional	Rec K	K Rec W	Rec W
17. Epistemological	Epi K_{SS}	K Epi W_{SS}	Epi W_{SS}
Communication			
18. Communication	Com K	K Com W	Com W
19. Epistemological	Epi K_C	K Epi W_C	Epi W_C
Pedagogy			
20. Pedagogical Purpose	Ped K_P	K Ped W_P	Ped W_P
21. Pedagogical Reference	Ped K_R	K Ped W_R	Ped W_R
22. Epistomological	Epi K_P	K Epi W_P	Epi W_P

Chapter 5: The STSC Taxonomy of Curricular Discourse

A. Introduction

Seven evolutionary stages in the development of the STSC Taxonomy are presented in Chapter 4. The empirical and conceptual tests that the various stages of the taxonomy went through are documented in Chapter 4. The criteria for making decisions on the possible revision of the system are also presented in their developmental context in Chapter 4.

Chapter 5 includes the results of Stage 8 and Stage 9 of the study. Stage 8 involved writing a description of each of the 66 categories in the STSC Taxonomy of Curricular Discourse along with two example statements that might be found in real textual discourse for each category. The original descriptions and examples developed in Stage 8 are presented in Appendix C. The revised descriptions and examples as recommended by the judges in Stage 9 and as decided after further reflection by the researcher are presented in this chapter. The descriptions and examples for each of the twenty-two knowledge form triads are presented in Table 5.3 through Table 5.24.

The large number of categories in the "final" version of the STSC Taxonomy and the fine distinctions among categories indicated a necessity that examples be written to help operationally define each category. It is essential that the necessary conceptual distinctions be clearly communicated to users of the taxonomy. Writing the descriptions and the definitions was another in the series of internal tests of the ongoing study prediction that the STSC Taxonomy is an adequate description of chemistry textbook discourse.

Following each table is a discussion of the current status of each of the five curriculum emphases and the twenty-two knowledge forms. The category status includes an analysis of the evidence gathered from classifying textual discourse, an evaluation of the taxonomy with respect to each curriculum emphasis and knowledge form triad, and a suggested synthesis, where necessary, of revised or replacement knowledge forms. The category status description was written at the end of Stage 9 and represents the latest thoughts of the researcher with regard to the fine and super-structure of the STSC Taxonomy of Curricular Discourse.

In Stage 9 expert judgement was used to further demonstrate the content validity of the STSC Taxonomy. The examples created to illustrate the categories underwent several revisions during both Stage 8 and Stage 9. Although the results for Stage 9, the expert judgement stage, are presented at the end of this chapter, the suggested changes in the examples which resulted from the scrutiny have been incorporated in the Stage 8 description presented next.

B. A Description of the STSC Taxonomy of Curricular Discourse

To start learning the STSC Taxonomy one needs to study the 22 x 3 matrix presented in Table 4.11. The twenty-two knowledge form categories are nested into five curriculum emphases—science, technology, society, communication, and pedagogy (STSCP). Nested within each knowledge form category is a knowledge-knowledge of a way of knowing-way of knowing (K-KW-W or epistemological) triad. The K and KW categories are knowledge presented to students in textbook discourse. The KW category is procedural knowledge presented in the textbook to help students learn how to obtain this category of knowledge. The K category is the resultant knowledge produced by using procedural knowledge (KW). The way of knowing (W) category is used to classify questions and other required activities in textbook discourse. The epistemological (K-KW-W) triad is very intertwined and one usually cannot classify one component without referring to the other. The knowledge form classified usually requires thinking about the procedural knowledge and/or way of knowing required to produce resultant knowledge. For example, the classification of the statement, "Sulfur is a nonmetal.", requires an examination of the context within which this statement is made. Was this knowledge obtained from an empirical, theoretical, scientific process, or pedagogical (memorized, referenced, or given) way of knowing? The complete K-KW-W triad is consciously required for each and every classification of discourse. The overview above presents the general procedure for using the STSC Taxonomy. The detailed procedures are presented below.

The rules for using the STSC Taxonomy which follow have been developed from experience and experiment to date and continue to evolve as the experience broadens. Like all theoretical and empirical rules this classification scheme is restricted in its application and the rules carry with them a number of assumptions. The rules are suitable to the current version of the STSC Taxonomy and can in the future be changed to suit any particular revision of the Taxonomy.

The rules mainly try to establish a consistent use of the taxonomy. As noted, the 22 x 3 taxonomic matrix should be kept in front of the user of the STSC Taxonomy as reference until the structure of the taxonomy is memorized or until the logic of the structure becomes obvious.

1. Each sentence should be classified at least once. Some sentences need to be classified into two to four categories. The symbols provided in the taxonomic matrix should be written in the margin beside each sentence. Multiple classifications should be separated by a slash.

2. No mast-heads, footers headings, pictures or diagrams are classified.

3. Margin notes are classified.

4. Each line of a table of given knowledge, including the heading, is classified up to a maximum of five entries beyond the heading.

5. Each line of a table with more than five entries is classified only if the table requires student input.

6. A large number of simple examples is classified up to a maximum of five.

C. The Dimensions of the STSC Taxonomy

The STSC Taxonomy is three dimensional, including

1. a curriculum emphases (e.g., science, technology, society, communication, and pedagogy (STSCP) emphases) dimension

2. a knowledge form (e.g., theoretical, empirical, process, and epistemology knowledge forms) dimension that varies from one STSCP emphasis dimension to another

3. an epistemological triad (K-KW-W--kinds of knowledge, knowledge of ways of knowing, and ways of knowing) dimension that is prevalent throughout every knowledge form.

Besides the three dimensional classification, an STSC context category may be added to take care of situations that do not, at that time, appear to the user to fit into the three-dimensional analysis. A description of how each of the dimensions listed above should be used is presented next. A major section with examples follows this rule section.

C1. The Curriculum Emphases Dimension

The curriculum emphases dimension includes science, technology, society, communication, and pedagogy emphases. As the current study evolved, the creation of five general classes of curricular emphases seemed to work best in describing textbook discourse. A more complete description of each curriculum emphasis appears later in this chapter.

1. The science (Sci) emphasis includes knowledge (K) about the natural world as gathered by scientists, students and laymen. Ways of knowing (W) and knowledge of these ways of knowing (KW) are also included in the science category as in all STSCP categories. In the STSC Taxonomy, the definition of science is restricted to the study of natural phenomena and is not used in the general

sense that is sometimes used. For example, the study of technological devices and processes is not part of the science emphasis in the STSC Taxonomy. Skills in the emphases of technology, society, communication and pedagogy may be used by "scientists", but are not to be classified in the science emphasis category.

2. The technology (Tec) emphasis includes the knowledge and study of manufactured products and processes, and of the skills used by anyone manipulating technological products or processes.

3. The society (Soc) emphasis includes the knowledge and study of social interaction of human beings within issues of science, technology and society. The society category is restricted within the current taxonomy to knowledge and study relating science, technology and society (STS) issues. In Chapter 6 recommendations as to how this restriction could be removed are presented.

4. The communication (Com) emphasis includes the knowledge and study of scientific and technological communication as practiced by, for example, scientists, engineers, and technicians.

5. The pedagogy (Ped) emphasis is restricted to the pedagogical statements made in science-education textbooks. There are certain kinds of knowledge and ways of knowing that can best be described as pedagogic rather than scientific or technological. An elaboration of this point of view is presented below.

C2. The Knowledge-Form Dimension

The knowledge form categories vary among curriculum emphases, but include an epistemology knowledge form category in every case. In the curriculum emphasis called science three other categories in addition to epistemology are employed—theoretical, empirical, and scientific process. The empirical and process categories are carried over into the curriculum emphasis called technology but not into other curriculum emphases at this time. For a complete list of the knowledge forms discovered in each STSCP emphasis see Table 4.11—The STSC Taxonomy of Curriculum Discourse. Perhaps later work on the STSC Taxonomy may see a greater carry-over of the knowledge form categories into all STSCP emphases. Suggestions are made in Chapter 6.

C3. The Epistemological Triad Dimension

The third dimension of the STSC Taxonomy has been found by this empirical and conceptual study to have three components—kinds of knowledge (K), knowledge of a way of knowing (KW), and way of knowing (W). This dimension of the STSC Taxonomy is referred to as the epistemological triad or the K-KW-W triad.

1. The knowledge (K) category is <u>resultant</u> knowledge presented to students by the authors of the written materials. The particular knowledge form can be determined by reflecting on the way of knowing that was employed in originally getting that kind of knowledge, and, in some cases, looking at who obtained the knowledge.

2. The knowledge of a way of knowing (KW) category includes procedural knowledge presented to people concerning how to use a particular way of knowing. This procedural knowledge should be specific and should allow the person to then adopt that way of knowing.

3. The way of knowing (W) category is usually an action (a question, problem or task) required of people. This category allows for the classification of questions in textbook discourse. The knowledge form to which the triad belongs is based on the procedural knowledge (KW) used to obtain the answer and upon the resultant knowledge (K) expected.

Once the curriculum emphasis and the knowledge form (e.g., the Theoretical knowledge form category in the Science emphasis) has been determined, a sentence or phrase can be classified within the epistemological triad as to kind of knowledge (K), knowledge of a way of knowing (KW), or way of knowing (W). For consistency the following rules are useful.

1. Some sentences have more than one kind of resultant knowledge (K), procedural knowledge (KW), and/or action required (W). A second kind of K, KW and/or W can be added if appropriate in a single sentence.

2. A second of the same kind of K, KW or W, if appropriate, can be added in a compound sentence.

3. The classification of resultant knowledge (K) within a knowledge form can usually be determined by asking, "What procedural knowledge (KW) was used to get this resultant knowledge (K)?" When tough classifications are encountered, the relationships among K, KW and W should be reviewed to assist in the classification.

D. Summary of Classification Rules and Dimensions

The rules for using the STSC Taxonomy of Curricular Discourse in this study are presented above. The particular use of the taxonomy should determine the particular set of rules used within that context. Several examples of how the STSC Taxonomy can be collapsed or otherwise restricted or revised are provided in Chapter 6. When using STSC Taxonomy the theoretical perspectives of the user are important. Different perspectives can lead to different taxonomic structures and categories. To reiterate from Chapter 2 and 3, the theoretical perspectives that guided the creation of the STSC Taxonomy

1. normative perspectives—perspectives which interest groups attempt to establish as norms in a community (e.g., theoretical, empirical or process perspectives in the science education community)
2. curriculum emphases—explicit or implicit meta-messages provided by a curriculum or textbook (e.g., nature of science, technology, or science-in-society emphases)
3. STS science education—science, technology, and society science education (e.g., a particular multi-perspective curriculum approach that integrates STS emphases into one curriculum or

textbook)

4. practical inquiry—a practical perspective in science education inevitably relates to the classroom-in-use (e.g., What does the STSC Taxonomy do to guide classroom activities?)

5. epistemological content—the ultimate right of students may be to be let in on how the knowledge presented to them in textbook and classroom discourse has come to be accepted in the relevant community (e.g., What makes S, T, S, C, or P knowledge acceptable to the relevant community of scholars?)

According to the conceptual analysis experimental design used in this study, conceptual frameworks such as the STSC Taxonomy should be guided by theoretical perspectives or systematic conceptualizations. If the perspectives change, then the taxonomy should be changed. In the case of the eclectic of perspectives listed above, a flexible taxonomy which reflects a variety of theoretical positions can be created. For example, in the STSC Taxonomy described later in this chapter, the science emphasis knowledge forms reflect more of an epistemological perspective while the society emphasis knowledge forms reflect more of a normative or practical perspective. The status reports on each emphasis and knowledge form below indicate the empirical and conceptual basis for each category.

E. Stage 9: Inter-Rater Agreement Results

The experimental design described in Chapter 3 calls for external judgements of the STSC Taxonomy. Toward this end, six judges were engaged. The judges were chosen as experts in curricular discourse. They were all experienced textbook authors and classroom teachers who had written the **STSC Chemistry** textbook used as a source of textbook discourse for this research. Their general attitude to textbook discourse was that it is always imperfect and in need of revision. Their association with the researcher has been lengthy and reflects an openness that recognizes the value of discussion and intellectual debate. This is the kind of approach that would benefit the evolution of the taxonomy and, as described below, it did.

Two instruments for obtaining a measure of inter-rater agreement on the use of the STSC Taxonomy were developed for this study. The instruments each contained 66 of the 132 examples prepared for the taxonomy categories in Stage 8. Each of the 132 examples was assigned a random number. The odd numbered random examples were placed in one instrument and the even numbered random examples in the second instrument. Three judges were assigned to each of the 66 item instruments and asked to classify each statement or question as Sci, Tec, Soc, Com, or Ped; i.e., one of the STSCP curriculum emphases. After completing this task they were asked to reclassify the same statements and questions as K, KW, or W—one of the epistemological triad categories. No instruction was provided to the judges in addition to the minimal list of instructions in the instruments themselves. The judges were familiar with the STS terminology but were not familiar with the K-KW-W terminology.

The classifications by the six raters were marked against a key based upon the category from which the example was extracted in the STSC Taxonomy. As the ratings were being marked, the researcher checked every "wrong" or mismatched answer against the intent of the example. The object of this exercise was to see if 1. the wording in the example was misleading, 2. the example adequately represented the category intended, and 3. different instructions would be needed for future users of the STSC Taxonomy. The assumption was not made that agreement by all the raters meant that the example would not be revised. All examples were reviewed in the final stages of preparing this research report. The quantitative results of the classification exercise completed by the raters are presented in Table 5.1 and Table 5.2 as a coefficient of correspondence expressed as a percentage. At this point the key was considered correct. Revisions to the key and to the examples resulted in 100 % agreement by the judges.

Table 5.1
Inter-Rater Agreement on Taxonomic Elements

Rater Number	Numbered Examples	Initial Score	Rescore with Discussion
1	Odd	68 %	100 %
2	Even	84 %	100 %
3	Even	78 %	100 %
4	Odd	69 %	100 %
5	Even	70 %	100 %
6	Odd	74 %	100 %

The rescore in Table 5.1 resulted from a discussion of "wrong" or mismatched answers between the researcher and the rater. Revisions

Table 5.2

Summary of Expert Judgement Response by Category Element

Randomized Sequence Number	Category Reference Number	RATER RESPONSE	(* agreement)	Taxonomic K -	Category KW -	Elements W
1.	34	*	Com	K	Sci	W
2.	2	*	*		Sci	K
3.	10	*	*	K	Sci	W
4.	54	*	*	K	Tec	W
5.	124	*	*	K	Ped	W
6.	77	*	Sci	Ped	Soc	W
7.	133	*	Ped		Com	W
8.	33	*	Com	K	Sci	W
9.	28	*	*	K	Sci	W
10.	3	*	*	K	Sci	W
11.	56	*	*		Tec	K
12.	97	*	*		Scc	K
13.	30	KW	*		Sci	W
14.	47	*	*	K	Tec	W
15.	76	K	*	K	Soc	W
16.	69	*	*	K	Soc	W
17.	8	*	*		Sci	K
18.	71	*	Tec		Soc	W
19.	112	*	Ped/Com	K	Com	W
20.	125	W	*		Ped	W
21.	60	*	Com		Tec	W
22.	94	K	*	K	Soc	W
23.	48	K	*	K	Tec	W
24.	80	*	Tec		Soc	K
25.	5	*	*		Sci	W
26.	15	*	*	K	Sci	W
27.	43	K	*		Sci	W
28.	79	*	Sci		Soc	K
29.	122	KW	*		Ped	K
30.	31	*	*		Sci	K
31.	39	KW	Ped		Sci	K
32.	64	*	*	K	Tec	W
33.	41	*	Ped	K	Sci	W

Randomized Sequence Number	Category Reference Number	RATER RESPONSE	(* agreement)	Taxonomic K -	Category KW -	Elements W
34.	23	KW/W	*		Sci	W
35.	78	*	*		Soc	K
36.	37	*	*		Sci	W
37.	91	*	*		Soc	K
38.	68	*	*		Soc	K
39.	12	K	*		Sci	W
40.	38	*	*		Sci	W
41.	14	KW	*		Sci	K
42.	18	KW/W	*		Sci	W
43.	61	KW	Ped/Tec		Tec	K
44.	70	*	*	K	Soc	W
45.	9	*	Tec	K	Sci	W
46.	131	*	Sci		Ped	W
47.	114	*	Ped		Com	W
48.	35	K	Sci		W-Sci	W
49.	73	*	*		Soc	K
50.	27	*	*	K	Sci	W
51.	82	K	*	K	Soc	W
52.	120	*	*		Ped	W
53.	11	*	*		Sci	W
54.	119	*	*		Ped	W
55.	13	KW	*		Sci	K
56.	21	*	*	K	Sci	W
57.	46	*	*		Tec	K
58.	81	*	*	K	Soc	W
59.	99	*	Ped	K	Soc	W
60.	13	*	Com		Ped	W
61.	127	*	*		Ped	K
62.	130	*	*	K	Ped	W
63.	32	*	*		Sci	K
64.	7	*	*		Sci	K
65.	20	*	*		Sci	K
66.	119	*	*	K	Ped	W

Randomized Sequence Number	Category Reference Number	RATER RESPONSE	(* agreement)	Taxonomic K -	Category KW -	Elements W
67.	44	K	Sec/Ped		Sci	W
68.	106	K	*	K	Com	W
69.	57	K	*	K	Tec	W
70.	66	*	*		Tec	W
71.	24	KW	*		Sci	W
72.	86	*	*		Soc	K
73.	88	*	Sci	K	Soc	W
74.	16	*	*	K	Sci	W
75.	40	KW	*		Sci	K
76.	116	K	*		Ped	K
77.	128	KW	*		Ped	K
78.	102	*	*		Soc	W
79.	58	K	*	K	Tec	W
80.	84	*	*		Soc	W
81.	22	*	*	K	Sci	W
82.	92	*	*		Soc	K
83.	17	*	*		Sci	W
84.	104	KW	*		Com	K
85.	95	*	*		Soc	W
86.	45	*	*		Tec	K
87.	85	*	Sci		Soc	K
88.	129	*	*	K	Ped	W
89.	69	*	*		Soc	K
90.	26	*	*		Sci	K
91.	117	K	*	K	Ped	W
92.	108	KW	*		Com	W
93.	1	*	*		Sci	K
94.	74	*	Tec		Soc	K
95.	53	K	Tec	K	Tec	W
96.	87	*	Sci	K	Soc	W
97.	83	*	*		Soc	W
98.	19	*	*		Sci	K
99.	36	K	Sci		W-Sci	W

Randomized Sequence Number	Category Reference Number	RATER RESPONSE	(* agreement)	Taxonomic K -	Category KW -	Elements W
100.	123	*	*	K	Ped	W
101.	6	*	*		Sci	W
102.	111	*	*	K	Com	W
103.	121	KW	Tec		Ped	K
104.	89	*	*		Soc	W
105.	55	*	*		Tec	K
106.	42	K	*	K	Sci	W
107.	109	*	*		Com	K
108.	110	*	*		Com	K
109.	75	*	Soc	K	Soc	W
110.	101	*	*		Soc	W
111.	96	*	*		Soc	W
112.	100	K	*	K	Soc	W
113.	107	KW	*		Com	W
114.	105	K	*	K	Com	W
115.	93	*	*	K	Soc	W
116.	56	*	*		Tec	W
117.	63	*	Ped/Tec	K	Tec	W
118.	25	*	*		Sci	K
119.	4	*	*	K	Sci	W
120.	52	*	*		Tec	K
121.	103	*	*		Com	K
122.	98	*	*		Soc	K
123.	51	*	*		Tec	K
124.	50	*	*		Tec	W
125.	72	*	*		Soc	W
126.	59	*	*		Tec	W
127.	90	*	*		Soc	W
128.	62	*	*		Tec	K
129.	115	*	Tec		Ped	K
130.	126	*	Sci		Ped	W
131.	29	KW	*		Sci	W
132.	49	*	*		Tec	W

occurred on many of the examples—mostly wording changes to clarify meaning and highlighting to focus attention. The major difficulty encountered was that each example has two dimensions—the STSCP emphases and the K-KW-W epistemological triad. For example, the STSCP curriculum emphasis is often portrayed by providing a KW-phrase along with a K-statement or a W-question. For the questions below the answer is the same, H_2O in all cases, but the curriculum emphasis changes due to different ways of knowing required to answer the question.

Ped W: From memory, what is the chemical formula for water?

Sci W: From Lewis Molecular Theory, what is the chemical formula for water?

The difficulty that arose is that in order to set the context and present some resultant knowledge or a question, some procedural knowledge (KW) is often provided. In the above statements the procedural knowledge phrases—"From memory" and "From Lewis Molecular Theory"—establish that the emphasis is pedagogy and science, respectively. The procedural knowledge context in some of the example statements is quite lengthy and caused the raters to classify the statement as KW rather than K or W. The problem is two fold. First, the examples are one sentence long without a paragraph or page of context as would be found in textual discourse. Second, the raters were asked to classify the statement into only one K-KW-W category. The solution to this problem cannot be to provide a paragraph, because a short example is needed when describing each category. However, the raters did make clear that the focal point of the examples should be highlighted in some way to assist the potential user of the taxonomy. Either that, or the description should classify the above kind of questions as KW/W, just as the researcher did when classifying "real" text from a textbook. The positive aspect of this problem is that it becomes obvious that one must either read or infer procedural knowledge in order to classify resultant knowledge (K) or required action (W). The same is true for classifying objectives as knowledge or application when using Bloom's Taxonomy of Educational Objectives.

Another major change in the rescore (i.e., increasing all scores to 100 %) was due to the researcher verbally defining categories such as ecological and national for the raters. The raters then agreed that, if that was the definition used, then the answer was what the researcher had given. The raters were also given explanations as to why these categories were created; i.e., the theoretical perspectives behind the STSC Taxonomy were discussed as criteria for category creation. Although the researcher had revised the set of 132 examples several times previously, the classification of the examples by the raters and the discussions which resulted were beneficial to the evolution of the STSC Taxonomy.

During discussions with the six raters over their "wrong" answers to the exercise of classifying 66 examples taken from the description of the STSC Taxonomy, some problem areas were identified. Problems with the wording of the examples were noted and incorporated in the rewriting and highlighting of the examples. The results of this revision are presented in the next section of this chapter. However, during Stage 9 some definitional problems with knowledge forms with curriculum emphases became apparent. These definitions provide necessary transitional background to the status reports that are provided along with the description of each curriculum emphasis and knowledge form in the next section. These definitions will also have to be identified for emphasis to any potential user of the STSC Taxonomy.

1. Theoretical knowledge (The K) is knowledge of a theory or model plus the knowledge predicted by the theory or explanations provided by the theory. Theoretical knowledge is nonobservable knowledge.

2. Generalizable empirical knowledge (Emp K_L) is knowledge predicted or retrodicted by the law or generalization.

3. Experiential empirical knowledge (Emp K_E) is observational knowledge obtained by someone other than the student plus the knowledge of a law or generalization.

4. Scientific process knowledge (Pro K_S) is knowledge produced by students themselves in and around a laboratory context. The evidence gathered by students in an experiment is an example of process knowledge. A laboratory report is another example of process knowledge. However, this kind of knowledge does not appear in textbooks, it appears in student notebooks and laboratory notebooks. Most process knowledge presented in textbooks is methodological (K Pro W_S). Due to its definition, the complete epistemological [illegible] for process knowledge does not appear in

textbook discourse.

5. The technological process category (Pro_T) involves the student use of technological devices to obtain knowledge. Technological process skills have often in the past been called psychomotor skills or scientific process skills. The perspectives of STS science education and the epistemology view of technology led to the definition of technological skills used in this study.

6. If the student is not involved directly, process-like knowledge is classified as empirical or theoretical knowledge. All process knowledge could be classified as empirical or theoretical, but then researchers would not have any idea of the amount of independent student laboratory work required within a textbook. The empirical and theoretical categories are justified by the epistemology of science, while the process category is justified from normative and practical perspectives.

7. The ecological category is included in the society emphasis. There are arguments on both sides of this, but if an analyst wants a measure of ecological textbook knowledge this topic category must be created. Ecological statements are usually classified secondarily into science or technology categories as well. Human ecology, including safety instructions in the laboratory, are included in the ecological category.

8. National and historical knowledge is usually a double classification, either mutually or with some other knowledge form. For a single national classification the work described must be

done by the original inventor of a theory, law, or technology. For a single historical knowledge tally, no other knowledge form should accompany the historical knowledge.

9. Knowledge which is given (without reference to evidence or theory) or is referenced or memorized is classified as pedagogical reference knowledge (Ped K_R). This category provides a measure of the amount of textbook knowledge which is not backed by theoretical or empirical constructs.

10. Epistemological knowledge is knowledge about the criteria for getting knowledge accepted by the relevant community. Memorized knowledge, for example, is classified for what it is, pedagogic knowledge. The explication of epistemological content is not the purpose of this study but the recognition of epistemological content is a purpose of this study. Epistemological content in the **STSC Chemistry 10** textbook was recognized and classified into STSCP categories.

When first using the STSC Taxonomy the best suggestion for users is to keep the one page 22 x 3 matrix in front of one for the first while. Additional clarification of each category is provided within the description of the STSC Taxonomy System which follows.

F. Content Validity of the Curriculum Emphases

The six judges were also asked to comment on the perceived content validity of the STSC Taxonomy as it might be used for classifying textbook discourse and guiding the writing of textbooks. In this part of the study each judge was only validating one of the STSCP curriculum emphases. The judges were matched to a curriculum emphasis in which they had the most amount of textbook writing experience. The Nature of Science Instrument provided the judge with a list of the seven science knowledge forms in the STSC Taxonomy, a description of each epistemological triad within each knowledge form, and two examples for each of the 21 categories. After reading the list, the descriptions, and the examples, the judges wrote a response to the following prompt.

> "From your experience in chemistry education please comment on the appropriateness or usefulness of this classification system."
>
> 1. Describes accurately:
> 2. Guides future work:
> 3. Simplicity/complexity:
> 4. Restrictions and assumptions:

These prompts were kept short and open-ended in order to elicit responses that were broad and unrestricted. The judges were, however, familiar with the terms as criteria for judging the acceptability of empirical constructs in science. In the **STSC Chemistry** materials which they wrote, the characteristics of laws and generalizations acceptable to the scientific community are listed as "describes", "predicts" and "simple". These terms are similar to the prompts provided to the judges. The judges were asked to respond to these prompts twice—once with regard to the validity of the knowledge forms in the STSCP curriculum emphasis that they were examining, and once more in relation to the validity of the K-KW-W epistemological triad. Some of the judges provided detailed responses and edited the wording of the examples while other judges provided general comments.

In general the judgements were positive and constructive. The judges were provided with minimal instructions for using the taxonomy. Their comments were solicited twice—once after the test of inter-rater agreement and again after the test of content validity. Some representative judgements are provided below. The judgements general to the STSCP emphases and specific to the knowledge forms within the STSCP curriculum emphases are presented first. The K-KW-W epistemological triad judgements are presented in the next section of this chapter.

1. Describes Accurately:

   A. "Generally it [the STSCP scheme] does describe accurately."

   B. "Sometimes an overlap of [STSCP] categories, but this classification does a better job than any other I've seen. In fact, this is the first scheme I've encountered that I would call successful."

   C. "Does a good job of explaining and differentiating a very complex and intertwined area."

   D. "[The STSCP scheme] accurately describes the components of emphasis in STS-type materials."

   E. "It is not immediately obvious to me why Emp_E and Emp_L are separated . . . ."

   F. "Works well—most knowledge can be labelled easily with this [STSCP] system."

   G. "The society category is a problem because the subcategories apply to other areas as well (e.g., historical, ecological)."

The judges seemed to agree that the STSCP classes of curriculum emphases could be used to <u>adequately describe textbook discourse</u>.

Through a combination of use of the STSC Taxonomy on the inter-rater agreement instrument with the unclassified random examples and on the individual STSCP emphases instruments with the classified examples, the judges perceived the STSC Taxonomy as an accurate description of textbook discourse. In the sciences, fundamental characteristics of classification systems include: describes accurately current observations, predicts or guides further observations, is simple to use, is restricted in its use, and carries certain assumptions. These same characteristics have been used as criteria to test the validity of the STSC Taxonomy. The judges were asked to react to the Taxonomy on the basis of these characteristics. The second criterion of classification systems reacted to by the judges as they used and inspected the STSC Taxonomy was "guides future work".

2. Guides Future Work:

A. "[The STSC Taxonomy] would certainly be useful if for no other reason than to focus, increase awareness, and make explicit the "real" reason for the printed words in a curriculum material."

B. "[The STSC Taxonomy] should be the way of evaluating whether or not materials are really STSCP or just say they are."

C. "As a teacher, the System makes one aware of some of the components of the Society aspects of STS materials. As an author, the System is very helpful in guiding the phrasing of curriculum materials. The System should be helpful to researchers examining teacher and student perspectives of the Society aspect of S-T-S interconnections."

D. "[The STSC Taxonomy] is useful for curriculum developers, for assessing balance of emphases."

E. "[The STSC Taxonomy] simplifies creation of educational materials—makes it easy to clarify and categorize the intent of such materials."

F. "Yes, [it guides future work] particularly for materials that want students to consciously consider communication [as a curriculum emphasis]."

"Awareness", "consciousness" and "explicitness" seem to be key words used by the judges to evaluate the usefulness of the STSC Taxonomy for guiding future work. A classification should help to organize and bring to consciousness isolated knowledge. The judges seem to concur that the STSC Taxonomy can be helpful to guide future research and development in chemistry education. The next criterion used to judge the STSC Taxonomy was simplicity. The responses of the judges are presented below.

3. Simplicity/Complexity:

A. "Moderately complex; requires quite a bit of getting used to."

B. "[The STSC Taxonomy] is fairly simple to use, especially after a few examples are considered."

C. "The system is quite complex. It would take at least a one day workshop to enable an uninitiated person to use the system."

D. "Easy to understand, explain and apply."

E. "Relatively simple and straight forward."

F. "As long as it is understood that the instrument can be used on several levels of sophistication (subcategories), the simplicity will vary."

The judges expressed the concern that the STSC Taxonomy was more complex than simple. The second major opinion expressed was that the analytical framework is easy to learn in restricted form, such as a 5 x 1 STSCP matrix or a 3 x 1 epistemological triad matrix. This concern is attended to in Chapter 6, where the STSC Taxonomy is shown to be flexible enough to be shaped into a variety of forms by the user. Besides the two matrices mentioned above, a 5 x 3 STSCP-epistemological triad taxonomic matrix or some expansion thereof is possible. Each STSCP emphasis can be expanded partially or fully, independent of each other, in order to meet the needs of the user. Simplicity is contextual—what is complex in one context can be simple in another context. In the researcher's view the STSC Taxonomy has the flexibility to react to many different contexts of use. The judges were then asked to respond to a prompt that required listing some restrictions and assumptions that they felt accompanied the taxonomy.

4. Restrictions and Assumptions:

   A. "[Restricted to] a particular set of definitions."

   B. "[Assumes] detailed nature of science knowledge [for the user]."

   C. "[Restricted in use] to those with some training or practice in the system."

   D. "[The] major problem [is] in clearly establishing [the] different categories—probably impossible."

   E. "Materials always exhibit "overlap" of categories—one accepts that they are not sharply bounded but generally defined."

   F. "The STSC [Taxonomy] is most useful with materials which emphasize the interconnections among science, technology, and society. It would not be very useful in analyzing a traditional theoretical chemistry course."

The judges commented on the restrictions and assumptions related to the specific use of the STSC Taxonomy and alluded to its general use. From the perspective of the researcher the formal evidence gathered in this study is restricted to the classification of textbook discourse in an applied and descriptive chemistry textbook (ALCHEM 30, the thermochemistry unit) and to an STS chemistry textbook (STSC

Chemistry 10). The conceptualization of the STSC Taxonomy is restricted to the five theoretical perspectives used to guide the study—normative perspectives, curriculum emphases, STS science education, practical inquiry, and epistemology.

G. Validity of the Epistemological Triad

The judges reacted to the same criterial characteristics for the validation of the epistemological triads—describes the past, predicts and/or guides the future, and is as simple as possible, as they did for the STSCP curriculum emphases. These judgements were obtained on two occasions—with the unclassified inter-rater agreement instruments and with the classified content validity instruments. The responses to the prompt that the K-KW-W triad describes textbook discourse accurately are presented blow.

1. Describes Accurately:

   A. "The Triad accurately describes all curriculum materials in science, not just STS-type materials."

   B. "In terms of classroom materials this [triadic] classification is probably more useful than STSCP for the analysis and production of materials . . . ."

   C. "[The epistemological triad is] an accurate description which should be applicable to all science education materials."

   D. "I'm not comfortable with this [triadic] classification scheme—it does not fit well with my perception of classes of knowledge. The concept of different "ways" of knowing is useful and simple, and has had direct impact on my writing and teaching and [on] student awareness of . . . what we are doing."

E. "The system is complete and seems accurate."

F. "[In the examples] if a lot of KW is given but it happens to be worded as a question, I am not convinced that it best illustrates [the] W category."

One of the difficulties that the judges claimed to have was in differentiating between the K-KW-W textbook stimulus triad and the W-KW-K student response triad. The STSC Taxonomy for classifying textbook discourse employs only the K-KW-W triad. No student responses are classified. The response is, however, anticipated in order to classify the way of knowing required. A second difficulty encountered by the judges was the classification of K (resultant knowledge) and W (action required) examples which contained KW (procedural knowledge) phrases. The KW phrases are necessary for the STSCP classification and confused the K-KW-W classification in some examples. A long KW phrase is underlined in the example below. The latter part of the statement is classified as W (action required).

KW/W: Use the theory of conservation of atoms and state of matter generalizations to write a balanced chemical equation.

This problem disappears when classifying textbook discourse rather than an single sentence (acontexual) example. The statement above would be classified as both KW and W in textbook discourse and need not be restricted to a primary classification as in the instrument responded to by the judges. The next criterion for judging the epistemological triad that the judges responded to was "guides future work". The responses are presented below.

2. Guides Future Work:

A. "[The epistemological triad] should be useful in determining whether materials are basically "given knowledge" or place more realistic demands on the reader [i.e., KW and W statements in some balance with K statements]"

B. "[I am] not sure about the applicability to classroom talk/materials construction for high school kids."

C. "By making the user more aware of the 'kinds of knowledge', the [epistemological] triad can increase pedagogical insight for curriculum writers and classroom teachers."

D. "[The epistemological triad may be] useful for growth assessment."

E. "[Guides future work] particularly in the curriculum planning stage before materials are actually written."

F. "The System provides a breakdown for (means of analyzing) curriculum materials which teachers can draw to students' attention, and which can help authors write more clearly. The System provides valuable starting categories for researchers examining curriculum writing."

G. "Useful not only for writing but also [for] evaluating other curriculum materials. The awareness (at least at an initial level) of the triad is a significant pedagogical tool. I don't recall anything in my teacher education and practice that as clearly analyzes and defines curriculum materials in a meaningful epistemological way."

The epistemological triad was viewed by the judges as guiding the future work of teachers, authors and researchers. Balance, awareness, and clarity of writing were key terms used by the judges. Two sets of interpretations were placed on the validation of the epistemological triad—an inter- and an intra-triad set of interpretations. Some judges saw greater value in looking inside the triad, while others valued the classification of ways of knowing identified by the various triads. The responses of the judges to a prompt about the relative simplicity of the triad concept are presented below.

3. Simplicity/Complexity

A. "The three [epistemological triad] categories are quite simple once a few examples have been examined."

B. "The [triad] system is relatively simple once the terminology is sorted out."

C. "A bit tricky to distinguish between the [K-KW-W] categories, probably because this is a new (to me anyway) way of looking at things."

D. "[The] major complexity is the KW/W destinction. W is difficult because KW for this classification exercise is insufficient or at least minimal."

E. "[The epistemological triad] is moderately complex, but with a little practice this part of the [STSC] classification scheme becomes easier to use."

F. "The [epistemological] triad is somewhat harder to use than the STSC classification system because the three categories are not as easy to identify, at least initially."

G. "With the limited experience I've had using either part of the classification, I'm actually quite surprised that I could do as much as I did."

It should be emphasized that the verbal and written instructions were purposely kept minimal in order to get an indication of the simplicity/complexity criterion. From the response of the judges more instruction would appear necessary. The single sentences that the judges classified were not in the context of a paragraph or textbook, as was the case for the researcher during Stages 2-7 of this study. Also, the judges were asked for a single dominant K-KW-W class, whereas in the researcher's case multiple classifications were allowed. The judges were in effect put in a "worst case" scenario.

Evidence indicates that alternate individual descriptors for the K-KW-W triad may help to define the classes better but the K-KW-W connection is somewhat lost by these name changes. For example, the judges indicated that the KW (knowledge of a way of knowing) category is somewhat easier to conceptualize as "procedural knowledge" or "methodological knowledge". Also the K (knowledge) category might be better described as "resultant knowledge". The researcher's experience with describing the W (way of knowing) category indicates that this category is best described as questions, activities and "required actions." Somehow, knowledge, procedural knowledge, and activities (K-PW-A) is not as aesthetic a description as the K-KW-W triad. The last prompt responded to by the judges asked them to state perceived restrictions or assumptions associated with the taxonomy.

4. Restrictions and Assumptions

A. "The Triad would seem to apply to a wide range of curriculum materials."

B. "The use of the [epistemological] Triad [in this exercise] is based on the assumption that curriculum statements can be categorized on the basis of a single sentence, and that the context of the sentence is not required."

C. "The System [as used in this research exercise] assu[illegible] the authors' intent (as to the kind of knowledge) ca[illegible] inferred from one or two sentences."

The judges, due to the task assigned to them, identified the assumption about categorizing single sentence textbook discourse taken out of the context of a paragraph, textbook, or curriculum outline. The researcher found this less of a problem in Stages 2-7 when classifying larger sections of textbook discourse. However, a user who is not familiar with what was to be learned in the past would have difficulty classifying the way of knowing required of a student by the textbook question. Familiarity with the curriculum experiences of the student as inferred from past textbooks and course outlines is necessary for using the STSC Taxonomy (as it is for Bloom's Taxonomy).

The restrictions associated with the K-KW-W epistemological triad in the current study primarily focus on its use as an analytical framework for textbook discourse. No sequencing within or interactions between triads were studied. No student answers were classified in the current study. Although the potential for these uses of the STSC Taxonomy was pointed out by the judges, the present study was restricted to classifying chemistry textbook discourse.

H. Summary of Stage 8 and Stage 9

The above part of Chapter 5 presents the results of Stage 8 and Stage 9 of this study. Stage 8 involved the writing of the descriptions and two example statements for each of the 66 categories in the 22 x 3 STSC Taxonomy of Curricular Discourse. The descriptions helped to conceptualize and the examples helped to operationalize each category. The STSC Taxonomy had evolved through Stages 1-7 and no significant changes were made during Stage 8—the taxonomy appeared to be stable. The writing of the descriptions and examples was another of the series of conceptual tests for the taxonomy to pass. The rules for the use of the STSC Taxonomy were formalized and introductory statements to each of the STSCP emphases and to the epistemological triad were written. The rules, descriptions and examples were revised later as a result of the tests of inter-rater and content validity operations in

Stage 9.

The triangulation of tests of content validity on the STSC Taxonomy continued in Stage 9. Six judges each classified half of the 132 examples as a test of the inter-rater agreement of users of the taxonomy. This was a difficult assignment for the judges because the statements to be classified were single sentences provided without context and because the judges were provided with little or no training. The most important outcome of Stage 9 was the further revision of rules, descriptions, and examples as a result of difficulties encountered and suggestions by the judges. In general, the tests of inter-rater agreement and content validity were positive, and where problems were encountered revisions were made and the evolution of the STSC Taxonomy continued.

I. The STSC Taxonomy Status

The suggested revisions to the descriptions and examples prepared in Stage 8 of this study and critiqued in Stage 9 are presented in the following series of tables—Table 5.3 through Table 5.24. The table number corresponds to the knowledge form number in the STSC Taxonomy. Experience in Stage 8 and Stage 9 indicated that underlining the focus of the description and the example led to greater understanding. This procedure is followed in presenting the 66 descriptions and 132 examples for the twenty-two knowledge form triads in Tables 5.3-5.24. These tables contain the latest definitions for each of the sixty-six categories. Although suggestions are made in this section for future revisions and tests of the taxonomy, the taxonomy elements developed during Stage 1-9 remain intact.

An unofficial tenth stage in this research study has been the process of reflecting on the status of the Taxonomy of Curricular Discourse. The evolution of the taxonomy over the nine official stages of the study is described in Chapter 4 and in Chapter 5 (to this point). The process of and the attitude to change adopted during this study need not and should not change. The next series of sections in this chapter presents a current status report on each of the STSCP curriculum emphases and each of the knowledge form triads. Each status report presents an analysis of the evidence gathered by classifying textbook discourse, an evaluation of the empirical and conceptual support for the category, and a suggested synthesis to revise the taxonomy based upon the arguments presented.

J. The Science Emphasis Status

A science emphasis in the STSC Taxonomy of Curricular Discourse includes various knowledge forms which in turn include resultant knowledge and procedural knowledge components presented to people and include action required of people. The nature of science emphasis in The STSC Taxonomy of Currricular Discourse is defined by seven knowledge form categories including theoretical (The), empirical (experience or experimental) (Emp_E), linked experiential-empirical knowledge and theoretical (Emp_E-The), empirical (law or generalization) (Emp_L), combined generalized-empirical knowledge and theoretical (Emp_L-The), scientific process (Pro_S), and scientific epistemology (Epi_S) knowledge forms. Each of these knowledge forms has a corresponding triad of resultant knowledge (K), procedural knowledge (KW), and action required (W) components.

The categories have been derived from the literature, from the experience and intuition of the researcher and colleagues, and from the empirical research itself. The original three components—theoretical, empirical, and scientific process skills—were expanded upon by the researcher during the trial application of the taxonomy to the "Energy" units of the ALCHEM materials (1975 and 1982 editions). Each of the nature of science knowledge form triads are described and examples are provided below. In order to illustrate the more subtle aspects of the classification, an attempt has been made in the examples to relate the discourse content whenever possible to the chemical compound water. Following each category description is a discussion of the current status of the knowledge form in the STSC Taxonomy.

Table 5.3
The Theoretical Knowledge Form Triad

1. The Theoretical Knowledge Form

K: The K (theoretical knowledge) includes resultant theoretical knowledge (K) presented to a person. Theoretical knowledge includes knowledge that is not directly observable or measurable; e.g., atoms, molecules, bonds, and intermolecular forces. Knowledge which results from a theoretical way of knowing (i.e., the use of a theory) fits into this category. The following knowledge results from using a theory.

E.g., The oxygen atom in the water molecule is surrounded by two lone pairs of electrons and two bonding electrons.

E.g., The water molecule contains two polar covalent bonds.

KW: K The W (knowledge of a theoretical way of knowing) is procedural knowledge (KW) presented to a person about a theoretical way of knowing; i.e., how a specific theory may be used to explain or predict a particular phenomena. The specificity of the procedural knowledge may vary from hints to detailed examples.

E.g., The Lewis Molecular Theory may be used to explain the empirical formula for water, H_2O, by using electron dot models of oxygen and hydrogen atoms.

E.g., The stereochemical shape of the water molecule may be predicted by VSEPR theory. Draw a Lewis Model of the water molecule and then apply the theoretical rule that four groups of electrons will repel one another to form a tetrahedral distribution of electrons around the oxygen atom.

W: The W (a theoretical way of knowing) requires action by a person. The person must use knowledge of a theory to explain or predict some phenomena or effect. The word "explain" should connotate a theoretical response. The word "predict" may require context to determine if an empirical or theoretical way of knowing is required to answer the question.

E.g., Explain the relative boiling points of water and hydrogen sulfide.

E.g., Predict the shape of the water molecule.

Category Status

The theoretical knowledge form (The) as described in Table 5.3 tallied 10 % over the four **STSC Chemistry** units of textual discourse classified. This score tied the scientific process knowledge form (Pro_S) for second highest behind communication (Com) at 16 %. The existence of the theoretical knowledge form along with empirical and epistemological knowledge forms is well supported empirically by the evidence gathered in this study and conceptually by the literature reviewed. This knowledge form holds a very central position in science and science education. The **STSC Chemistry** textbook, for example, presents as epistemological content the information that the two major scientific ways of knowing are theoretical and empirical.

Theoretical knowledge is often described loosely as knowledge which has not been tested or "proven". This is not the case for theoretical knowledge in the field of science. Theoretical knowledge may be very tentative or well supported by the evidence. The degree of certainty varies with the amount of evidence that supports the theoretical knowledge. Theories that can both explain past observations and predict new observations are most highly valued within the scientific community. These explanations and predictions are theoretical knowldge (The K) derived from using theoretical rules from theories as procedural knowledge (K The W). The theories are only theoretical knowledge when they appear as resultant knowledge in textual discourse. For example, the Bohr Model of the atom is theoretical knowledge only when an historical context is set to illustrate the derivation of the theory. An interesting open-ended question is, "What way of knowing is used to derive a theory?" A starting point answer is that a combination of empirical and theoretical ways of knowing are needed to produce theoretical knowledge. If this is true, can a theory be pure theoretical knowledge?

Table 5.4
The Empirical (Experience) Knowledge Form Triad

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2. The Empirical (Experience) Knowledge Form

K: Emp K_E (experiential-empirical knowledge) is resultant knowledge presented to a person, based upon the experience or experiment of someone else. This empirical knowledge usually appears as qualitative or quantitive descriptions of a phenomena. This same knowledge reported by a student would be classified as resultant process knowledge (Pro K_S).

E.g., Water is a colorless liquid at room conditions.

E.g., The mass of ice used in the experimental determination of the molar heat of fusion of water was 15.04 g.

KW: K Emp W_E (knowledge of an empirical way of knowing related to experience or experiment) is procedural knowledge presented to people relative to how to obtain this kind of knowledge. To differentiate this category from K Pro W (knowledge of a process way of knowing), K Emp W is restricted to a third person type of involvement, whereas K Pro W is specific to the person (usually in the laboratory).

E.g., The bond angle of the hydrogen-oxygen-hydrogen bond in water can be determined by the X-ray analysis of ice.

E.g., From experience people can know the characteristics of the three states of matter of water.

W: Emp W_E (an experientially related empirical way of knowing) when required of a person calls on a third person's reported experience outside of the laboratory or calls on a scientist's reported experiment. First person experience or experiment is classified as Pro W_S or Pro W_T.

E.g., Describe the behavior of water upon freezing in a large lake.

E.g., Describe the effect of adding water vapor to a gas mixture in an experiment similar to that done by Raoult or Dalton.

Category Status

The empirical (experience) knowledge form (Emp_E) described in Table 5.4 was evident in 3 % of the **STSC Chemistry** textbook discourse classified. A total of 13 % of the discourse had an empirical component, but the Emp_E category was restricted to resultant and procedural knowledge and action-required statements concerning experience or experiment by a third person. The evidence from the discourse indicated that it was possible to separate this kind of knowledge from empirical knowledge which was conceptual (i.e., generalization and law based) and from empirical knowledge gathered by the student personally. This separation worked conceptually and also made sense from a practical perspective. Users of The STSC Taxonomy of Curricular Discourse could gather evidence of the extent of the various kinds of empirical knowledge found in curricular discourse, or they could collapse the empirical subcategories into one major empirical category if their context dictates.

The splitting of empirical knowledge into experiment and concept based knowledge allows authors and teachers to be more specific about alternate ways of knowing available to students. For example, the experience of seeing a chemical reaction such as copper and silver nitrate occur is an alternate way of knowing to that of conceptually predicting the reaction from a generalization. The distinction is fairly obvious in textbook discourse. The researcher's experience in the classroom supports the importance of making this distinction to students.

Table 5.5

The Empirical (Experience)—Theoretical Knowledge Form Triad

3. The Empirical (Experience)—Theoretical Knowledge Form K: Emp K_E–The K (empirical experience and theoretical knowledge) is resultant knowledge presented to a person that combines empirical knowledge gained from experience or experiment with knowledge gained theoretically. There should be a strong link between the empirical and the theoretical knowledge that is presented. The two parts to the sentence should not make sense if separated and classified separately. Unrelated Emp K_E and The K should be coded as Emp K_E/The K and recorded as separate tallies. E.g., The observation that small bugs can walk on water can be explained by creating the concept of intermolecular forces. E.g., One way of explaining the boiling point of water relative to hydrogen sulfide was to invent the theory of hydrogen bonding.
KW: K Emp W_E–K The W (knowledge of an empirical way of knowing and a theoretical way of knowing) is procedural knowledge that assists in knowing how to obtain knowledge relating empirical and theoretical statements. E.g., Experience with states of matter may be combined with the theory of conservation of atoms to write a balanced chemical equation for the electrolytic decomposition of water. E.g., Research chemists are able to use sophisticated equipment to obtain the conductivity and pH of water, and then use a theory of equilibrium to explain this evidence.
W: Emp W_E—The W (a combination empirical and theoretical way of knowing) requires dual action of a person to describe, predict and/or explain something from experience or experiment. E.g., How would a chemist start to test and explain the observation that snow flakes come in many shapes? E.g., Determine the state of matter of water at SATP and use stereochemistry and intermolecular force theory to explain this observation.

Category Status

The empirical (experience)—theoretical (Emp_E-The) knowledge form described in Table 5.5 was not introduced until Stage 6 of the study when the discourse in Unit C—"Communicating and Predicting Chemical Formulas"—was classified. Only 2 % (26 tallies) and 0 % (5 tallies) of the Unit C and D discourse, respectively, were classified in this category. However, the conceptual appeal for a knowledge form with empirical and theoretical knowledge connected within one sentence overcame the small amount of empirical evidence for its existence.

Informal evidence from The Author Group indicates that they are trying to progressively integrate empirical and theoretical knowledge after initially separating them for pedagogic efficiency reasons. For example, empirical and theoretical knowledge is split into two half units about elements in Unit A in **STSC Chemistry**. The split becomes the top half and bottom half of the page for the structure of matter topic in Unit H, and eventually becomes integrated within paragraphs and sentences within the acids and bases unit. Each of these three textbook units (chapters) was written with a nature of science curriculum emphasis. The concept of an empirical-theoretical dialectic may well become explicit epistemological content in future editions of the **STSC Chemistry 30** textbook. As such, this knowledge form may open up further paths in the conceptualization of epistemological content for students.

Table 5.6
The Empirical (Law) Knowledge Form Triad

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4. The Empirical (Law) Knowledge Form

K: Emp K_L (law or generalization based empirical knowledge) is resultant knowledge presented to a person that has been predicted or retrodicted from a law or generalization (i.e., by an Emp W_L). Sentences out of context, such as the examples below, must provide knowledge of the procedure used to produce the given knowledge. Square brackets are used for this procedural knowledge compontent below.

E.g., [From your generalization on the spontaneity of redox reactions,] the electrolysis of aqueous sodium sulfate is predicted to result in the decomposition of water.

E.g., [From the law of equilibrium], the predicted hydronium ion concentration in the solution is 2.4 mmol/L.

KW: K Emp W_L (knowledge of an empirical way of knowing from a law or generalization) is procedural knowledge presented to the person concerning how to use a law or generalization to predict or retrodict an unknown variable.

E.g., The amount of heat gained by water in a calorimeter can be predicted by multiplying the volume times the volumetric heat capacity times the change in temperature.

E.g., The Le Chatelier Principle may be used to predict the shift in equilibrium when sodium hydroxide is added to water.

W: Emp W_L (an empirical way of knowing from laws or generalizations) requires a person to predict an unknown variable in a law from the data available.

E.g., [Use solubility generalizations to] predict whether the following ionic compounds have high or low solubility.

E.g., [Use a conservation law to] predict the volume of water that must be added to 10 mL of concentrated sulfuric acid in order to dilute the concentrated acid to 0.75 mol/L.

Category Status

The empirical law (Emp_L) knowledge form described in Table 5.6 tallied six percent of the discourse in **STSC Chemistry 10.** The category is best understood by the requirement that an empirical concept (i.e., an empirical definition, generalization or scientific law) must be employed to produce Emp K_L. A law may itself be produced by experiment, Emp W_E, and is therefore classified as Emp K_E. When a law is used as procedural knowledge it is classified as K Emp W_L. In the classroom the student should know how scientific laws are produced as resultant knowledge and how they are used as procedural knowledge (although not necessarily using this terminology).

The terminology of this study puts theories and laws together as conceptual knowledge. This use seems consistent with the views of others such as Gowin (1984). Gowin's "epistemological V" is used as a heuristic device to indicate how knowledge is created. Gowin lists philosophy, theories, principles, conceptual systems, and regularities in events or objects as conceptual knowledge. The empirical (experience) kind of knowledge is referred to as "events and objects" in Gowin's V but no reference is made to the epistemology of experiential knowledge. Experiential knowledge (Emp K_E) is produced as resultant knowledge, and experiential knowledge (K Emp W_E) is used as procedural knowledge within the structure of the STSC Taxonomy. The STSC Taxonomy appears to describe a greater range of knowledge production than Gowin's V, although the conceptual basis is similar.

Table 5.7
The Empirical (Law)—Theoretical Knowledge Form Triad

The Empirical (Law)—Theoretical Knowledge Form

K: Emp K_L—The K (knowledge of an empirical law and a related theory) is resultant knowledge presented to a person which combines knowledge predicted from a law and theoretical knowledge that explains the law. The knowledge conveyed must be in the same sentence and must be related empirical and theoretical knowledge.

E.g., The increase in the average kinetic energy of the water molecules was [predicted indirectly by the laws of thermodynamics to be] 368 kJ.

E.g., The 42 MJ of heat [predicted from heat laws for the phase change of water] may be explained as an increase in chemical potential energy.

KW: K Emp W_L—K The W (knowledge of an empirical way of knowing from laws and generalizations and knowledge of a theoretical way of knowing from theories) is procedural knowledge presented to people on how to predict, or in the case of a theory how to explain, a physical phenomena.

E.g., The shift in equilibrium in the water solution may be predicted by using the Le Chatelier Principle and explained using collision and rate of reaction theories.

E.g., The states of matter in this reaction in a water environment may be predicted from solubility generalizations, while the solubility might be explained by molecular polarity or hydrogen bonding.

W: Emp W_L-The W (an empirical way of knowing from laws and generalizations combined with a theoretical way of knowing from theories) is an action required of a person that combines knowledge of the use of laws, generalizations and theories.

E.g., Predict [from Le Chatelier's Principle or the Equilibrium Law] and explain [from collision-rate theory] the shift in equilibrium when a strong base is added to a water sample.

E.g., [Use the theory of conservation of atoms and reaction and solubility generalizations to] write a balanced chemical equation including states of matter for the reaction of potassium metal with water.

Category Status

The empirical (law)—theoretical (Emp_L-The) described and exemplified in Table 5.7 combined knowledge form is found in fairly complex textbook discourse. The discourse may not appear to be complex to a familiar reader, but sentences such as chemical equations, upon classification, are seen to contain both empirical (law) and theoretical knowledge forms. This knowledge form would likely be more evident in higher level chemistry textbooks, although it did poll four percent of the total discourse after being created during the second last stage of classifying discourse. A user of the taxonomy must decide whether the Emp_L-The combination must be in the same sentence, adjacent sentences, or adjacent paragraphs. If a user wishes to simplify the taxonomy this combined knowledge form can be collapsed back to separate Emp_L and The categories without losing any classificatory ability.

Statements such as, "The periodic law may be explained by the Bohr Model of the atom.", are an important part of curricular discourse. The epistemological dialectic between empirical and theoretical concepts is highlighted by these statements. Another example is "After 300 years an acceptable theory has not yet been created to explain Newton's Law of Universal gravitation." General statements like these are on the fine line between the epistemological (Epi_S) knowledge form and the Emp_L—The knowledge form. More specific statements such as, "The existence of eight elements in Period 2 of the periodic table is explained by a maximum of eight electrons in the second energy level of an atom.", belong in the Emp_L—The category.

Table 5.8
The Scientific Process Knowledge Form Triad

6. The Scientific Process Knowledge Form

K: Pro K_S (scientific process knowledge) is resultant knowledge from a student using a scientific process way of knowing in a science-education laboratory. Generally the scientific process words or a science-education context for school textbooks must accompany the knowledge in order to classify the knowledge as process knowledge. This category does not include psychomotor skills used to operate technological devices as these are classified as technological process skills. The context must be student science-education.

E.g., [The students observed that] the water rose the highest in the smallest diameter capillary tube.

E.g., The [student] interpretation of the disappearance of the ice from the sidewalk was that the ice sublimed.

KW: K Pro W_S (knowledge of a process way of knowing in a scientific context) includes procedural knowledge for students to follow in a science education experiment or experience. This category includes definitions of process skills, because these definitions generally include instructions of how to apply a particular skill. Knowledge of a technological skill is not included here.

E.g., The experimental design of your experiment should state the manipulated, responding and controlled variables along with a summary of the procedure being used.

E.g., The evaluation at the conclusion of your laboratory exercise should include five elements—an answer to the stated problem; an evaluation of the prediction; an evaluation of the theory, law, generalization or experience (TLGE) used to make the prediction; an evaluation of the experimental design; and an attempt, if necessary, to restrict, revise or replace the TLGE (i.e., a synthesis).

K-KW: K Pro W—Pro W_S (knowledge of a process way of knowing combined with a process way of knowing) is a category created to classify those statements in science-education that give the "recipe" to the person that he or she then follows. The statement is procedural knowledge of how and/or when to do a laboratory procedure and also requires action of the person to complete the instruction in a process way. This is an optional category in the STSC Taxonomy that can provide evidence of the extent of "recipe" versus independent laboratory work done by students.

E.g., Add 15.0 mL of water to the solid solute and stir the mixture until the solute is all dissolved.

E.g., Obtain about a mole (one heaping tablespoonful) of ice and add it to the styrofoam calorimeter containing 100 mL of water at about 30°C.

W: Pro W_S (a scientific process way of knowing) generally requires the person to state a problem, design an experiment, identify variables, predict, make a table of evidence, collect evidence, analyze evidence, and/or evaluate an experiment. Because the instructions (K Pro W_S) are missing after an initial request statement, the number of Pro W tallies has to be determined from experience with the laboratory activity. Guidelines have to be established previous to using this category as to the maximum tallies that will be recorded for independent work. The Pro W category is separated from the K Pro W—Pro W_S category in order to get an estimate of the relative independence of the laboratory work being done.

E.g., What interpretation may be put on your observations of aqueous solutions?

E.g., Design and perform a laboratory experiment to determine the molar heat of fusion of ice.

Category Status

The creation of the scientific process knowledge form (Table 5.8) was supported strongly by the evidence gathered. Of the twenty-two knowledge forms in the "final" STSC Taxonomy, Pro_S tied for second at ten percent of the total **STSC Chemistry** discourse classified. From a practical perspective any prospective user would have to modify the definition of this knowledge form to suit the context of use.

Scientific process knowledge as defined here is found in student laboratory reports and generally not in textbooks. The user of the taxonomy must decide whether to include given sections of laboratory experiments, sample laboratory reports and personal experience as process knowledge. Most process knowledge in textbooks should be classified as procedural knowledge (K Pro W_S). If a hard line is taken on applying the definition, a textbook has no Pro K_S.

Table 5.9
The Epistemology (in Science) Knowledge Form Triad

7. The Epistemology (in Science) Knowledge Form

K: Epi K_S (epistemological knowledge in a scientific context) is resultant knowledge presented to people in relation to the limits and validity of specific scientific knowledge. Epistemological knowledge (Epi K_S) is specific to a particular situation and results from an epistemological way of knowing (Epi W_S) and should be differentiated from general knowledge given about an epistemological way of knowing (K Epi W_S), in square brackets below.

E.g., The VSEPR Theory is accepted by the scientific community [because the theory is able to explain and predict the shape and/or polarity of molecules, such as the water molecule].

E.g., The scientists expressed uncertainty [because of the lack of evidence and because of a skeptical scientific attitude].

KW: K Epi W_S (knowledge of an epistemological way of knowing) is procedural knowledge presented to people concerning the use of an epistemological way of knowing (i.e., information concerning the limits and validity of scientific knowledge, the nature or origin of scientific knowledge; and/or the theory of knowledge). Criterial procedures for judging whether knowledge is acceptable to the scientific community are common statements in this category.

E.g., The criteria that should be used to judge a theory which is acceptable to the scientific community is the ability of the theory to explain existing effects (e.g., the polarity of the water molecule), and to predict future effects (e.g., the bond angle of the water molecule).

E.g., When a theory cannot predict accurately, it should either be restricted to predicting within a restricted situation, or revised such that it is able to predict more accurately, or replaced with a new theory that is able to predict accurately.

W: Epi W_S (an epistemological way of knowing in science) requires action of people when they are questioned about the grounds for, the validity of, or the limitations of specified scientific knowledge or ways of knowing.

E.g., State the restrictions and assumptions associated with the Bronsted-Lowry Theory of acids and bases as employed within this last section covered in the textbook.

E.g., Why did Arrhenius have such great difficulty in getting his theory of ionic dissociation accepted by the scientific community?

Category Status

The epistemology of scientific knowledge category (Epi_S) defined and exemplified in Table 5.9 was found in seven percent of all discourse classified in the **STSC Chemistry** textbook. A high of 13 % of discourse in Unit A, "Periodic Laws and Atomic Theories", was classified as epistemological. No attempt was made in this study to critique or correct the epistemological content presented in the textual discourse. However, the researcher felt that the **STSC Chemistry** textbook presented more Epi_S than any other academic chemistry textbook in his experience. The extent of school level epistemological content that can be presented and tested in a pedagogically simple manner may be determined and encouraged by the inclusion of this knowledge form in the STSC Taxonomy.

K. The Technology Emphasis Status

A technology emphasis speaks to the nature of the technological enterprise and its resultant knowledge as well as including technological skills and problem-solving processes and technological products (devices) and engineering processes. During the 1960's and 1970's the technology category was been given relatively less emphasis in science education. The current push for a technological component in science education seems to include a broader base than was apparent in previous curricula. Technological problem solving skills and attitudes are starting to be recognized as important curriculum emphases. Technology is now being recognized as being something more than "applied science".

The definition of technological literacy has been increasingly refined during the 1980's by writers such as Botting (1980), George (1981), Harrison (1983), Pacey (1983), Kline (1986) and others. The **STSC Chemistry** authors, in an internal document presented in Appendix B, have identified eight categories of technological understanding for guiding their teaching and textbook writing. They list technological information of interest, products, processes, communication, process skills, and problem solving, as well as, technology-science interdependence and technology and societal change categories. For technology-science interdependence the authors try to provide explicit examples of technology leading science, science leading technology, and a science-technology dialectic. Specific content in the STSC **Chemistry** textbook includes a definition of technology as "the study, production or use of a manufactured product or process", a list of criteria for judging a technology (i.e., economic, works reliably, and is simple), categories for classifying contexts for using technology (i.e., consumer, commercial and industrial), and a classification system for classifying STS issue perspectives (i.e., scientific, technological, economic, ecological and political). All of these are used by STSC Chemistry students in their study of technologies and of the nature of technology in a high school chemistry education context.

As reported in the S-STS Reporter and the STS Research Network Missive, there are many such attempts being made to increase the technological literacy of students. The STSC Taxonomy of Curricular Discourse does not specify the substantive content that should appear in a technology emphasis but does classify this content in such a way that a balanced view of technological literacy may be attainable. In the current STSC Taxonomy the technology curriculum emphasis classifies knowledge and ways of knowing into four knowledge forms—1. technology (Tec), 2. empirical technology (Emp_T), 3. technological process (Pro_T), and 4. epistemology of technology (Epi_T). A description and status report for each of these knowledge forms is now presented.

Table 5.10
The Technology Knowledge Form Triad

8. The Technology Knowledge Form K: Tec K (technological knowledge) is resultant knowledge presented to people concerning industrial, commercial or consumer products and processes. Tec K refers to manufactured products and designed processes (i.e., technological applications). What appears to be procedural knowledge (K Tec W) may in fact be resultant knowledge if the procedure is stated as a product of technological research.) E.g., A water-wall might be used to store solar energy absorbed by the wall in a passive-solar home. E.g., The hot-water process for extracting oil from tar-sands has proven to be the most acceptable process yet invented.
KW: K Tec W (knowledge of a technological way of knowing) is procedural knowledge presented to people concerning technological skills, attitudes, problem-solving approach, engineering skills, and empirical rules for predicting technological solutions to problems. E.g., Water may be electrolytically decomposed in a Hoffman apparatus by employing a catalytic-electrolyte such as sodium sulfate. E.g., Water may be used to mine sodium sulfate (salt cake) from the bottom of lakes.
W: Tec W (a technological way of knowing) is action required of a person and is evidenced by a need to suggest changes, for example, in a technological process that might make the process more efficient, more economical, more simple, and/or less polluting. E.g., Suggest changes to the Hoffman apparatus that would be necessary to the industrial production of hydrogen fuel from water on a large scale. E.g., Design an industrial process to extract sodium sulfate from the bottom of a lake.

Category Status

According to the evidence gathered by the classification of discourse in **STSC Chemistry 10**, the technology knowledge form defined in Table 5.10 does exist. An analysis of the evidence show that six percent of the total textual discourse classified fitted into this knowledge form with the majority being resultant Tec K. This knowledge form was an original category from Stage 1 of the research. The other knowledge forms in the technology emphasis were not established until the last stage of classifying discourse. Distinguishing the Tec knowledge form from the Emp_T knowledge form is difficult at times and is somewhat arbitrary. The context for Tec K is the description or use of technological products or processes. These technological products are by analogy the theories and models classified into the theoretical (The) knowledge form in the science emphasis. Technological applications is a term that is suited to this category and connotes a different emphasis than the more common term, practical application. This is another example of the STSC Taxonomy of Curricular Discourse providing not only concepts to assist discussions on curricular discourse, but also a language for these discussions.

Table 5.11
The Empirical Technology Knowledge Form Triad

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9. The Empirical Technology (Emp_T) Knowledge Form

K: Emp K_T (empirical knowledge in a technological context) is resultant knowledge presented to a person concerning work done by a third person (e.g., a chemical engineer). The knowledge must not be from a chemistry education laboratory (Pro K_T) or an industrial situation (Tec K). This category would include technical data and measurements made with various technological devices.

E.g., [The technician determined that] the pH of the rain water was 5.68.

E.g., The chemical engineer adjusted the flow rate to 500 L/s to increase the efficiency of the process for removing bromine from sea water.

KW: K Emp W_T (knowledge of an empirical way of knowing in a technological context) is procedural knowledge presented to a person concerning the methods used by engineers and technicians in their work.

E.g., The technician reads the water flow-rate from the meter by making sure that the error due to parallax is kept to a minimum.

E.g., The chemical engineer tests the quality of the water leaving the plant by using conductivity and photometric measurements.

W: Emp W_T (an empirical way of knowing in a technological context) requires action of a person to indicate how a measurement might be made or a process regulated or controlled.

E.g., Describe how a fully equipped technician would sample and measure the pH of rain water.

E.g., What kind of a technological device does an engineer use to measure the flow of a gas through a pipe?

Category Status

There was little evidence in the textual discourse to support the separate existence of an empirical knowledge form in technology (Table 5.11). The need for such a knowledge form was not realized until the last stage of classifying discourse, which involved the textbook unit with a technology emphasis. The conceptualization of the Emp_T knowledge form during Stage 7 was required to separate general knowledge about an industrial process (K Tec W) from specific knowledge about tasks completed by engineers and technicians (K Emp W_T). Perhaps Tec K and Emp K_T could be compared to the conceptual and experiential empirical knowledge forms in the science curriculum emphasis (i.e., Emp K_L versus Emp K_E). The Tec category is more construct oriented while the Emp_T category is more experience oriented. Both of these knowledge forms are mentioned in technological literacy outlines (e.g., Kline, 1986) and now both appear in the STSC Taxonomy of Curricular Discourse. The users of the taxonomy must decide if this category of knowledge is useful to their current task.

Table 5.12
The Technological Process Knowledge Form Triad

10. The Technological Process (Pro_T) Knowledge Form

K: Pro K_T (technological process knowledge in a science-education context) is resultant knowledge from a student Pro W_T in a laboratory. The same process knowledge created in a chemical technologist or engineer would be classified as Emp K_T. If a student is using a technological device to obtain evidence in a science education laboratory, the resultant knowledge is Pro K_T. A strict interpretation of this definition in the first person would result in no Pro K_T in textual discourse.

E.g., The volume of water measured by a student using a pipet was 10.0 mL.

E.g., In a laboratory simulation, a student found that the best container for water in a passive-solar greenhouse was a polyethylene container painted flat-black.

KW: K Pro W_T (knowledge of a process way of knowing in a technological context) is procedural knowledge presented to a active student concerning a method of operating a piece of technology or of controlling a technological process.

E.g., When titrating in the school laboratory, you should rinse all equipment with water both before and after use.

E.g., When designing a low-energy, passive-solar home for your school project, a water wall should be located to the south-west or west in order to store solar heat during the part of the day when excess heat is entering the home.

W: Pro W_T (a process way of knowing in a technological context) requires students to complete activities in the laboratory that require the use of technological devices and skills.

E.g., Determine the mass of your filter paper plus precipitate.

E.g., Light your bunsen burner and boil 150 mL of water.

Category Status

In spite of being a late entry into the STSC Taxonomy of Curricular Discourse, the technological process (Pro_T) category as described and exemplified in Table 5.12 tallied <u>five percent of the discourse</u> in **STSC Chemistry 10.** More significantly, <u>20 % of the discourse in Unit D</u> of the text was classified as Pro_T. This strong empirical support for the Pro_T knowledge form in Unit D was divided evenly over the K-KW-W triad—6 %, 7 % and 7 %, respectively. In retrospect, some discourse that had been classified in previous units as scientific process could have been classified as technological process. Also some, if not all, of the Pro K_T classified could have been classified as K Pro W_T or Emp K_T. A strict definition of the process knowledge form in the science and the technology curriculum emphases requires that only a student can produce Pro K_T, personally. The user of the taxonomy must make this decision.

An awareness of the dependence of science and society on technology can be increased by the reconceptualization of a process as technological if the process involves the use of a technological device or skill. For example, The Author Group STSC Emphases descriptions in Appendix B lists general and specific <u>technological process skills</u>. The **STSC Chemistry 10** Reference Section (1986) also classifies these kind of skills as <u>technological</u>. The language in this case is the message. If for example, cooking was more often referred to as a technological skill, then a greater awareness of the technology-society link might be fostered.

Table 5.13
Epistemology (in Technology) Knowledge Form Triad

11. Epistemology (in Technology) Knowledge Form

K: Epi K_T (epistemological knowledge in a technology context) is specific, resultant knowledge presented to people in relation to the limits and validity of technological knowledge. The resultant knowledge should come from applying an Epi W_T to a specific situation. More general epistemological knowledge usually fits into the knowledge of an epistemological way of knowing (K Epi W_T) category.

E.g., Upon analyzing Charles Hall's search for a nonaqueous solvent for alumina it is apparent that the search is an example of a systematic trial and error approach to technological problem solving.

E.g., The bottom-line test of a technological process for the electrolytic decomposition of water by photoelectricity that was used by the engineers was the cost efficiency of the process.

KW: K Epi W_T (knowledge of an epistemological way of knowing in a technological context) is general procedural knowledge presented to people concerning how technological knowledge comes to be accepted within the engineering community, along with knowledge concerning the nature, the limits and the validity of technological knowledge.

E.g., When judging any new technique which is acceptable to the engineering community, the technology must be economic, it must work reliably, and it must be simpler than the competition.

E.g., When differentiating between science and technology one can say that technology is very empirical and involves a systematic trial-and-error approach.

W: Epi W_T (an epistemological way of knowing in a technological context) is required of people who must answer questions concerning the nature, validity, or limitations of technological knowledge.

E.g., What are the attributes of an industrial process for the electrochemical production of electricity from water that would make the process acceptable to the engineering community?

E.g., Describe the life cycle of a technological device from the time that it is invented to the time it is discarded or replaced by a competing device.

Category Status

The evidence from classifying discourse in **STSC Chemistry** Unit D suggests that the epistemology of technological knowledge described in Table 5.13 can be found in curricular discourse. Eight percent of the Unit D discourse was classified as Epi_T, followed by Epi_S at 5 % and Epi_{SS} and $Epi_{C/P}$ at 2 % each. Conceptually, it seems to follow that if there is epistemological content within a science curriculum emphasis, there should be parallel content within a technology curriculum emphasis. For example, the **STSC Chemistry** textbook (1986: D1) presents technology (compared to science) as studying manufactured (rather than natural) products and processes, being more empirical (rather than theoretical) in nature, emphasizing methods and materials (rather than ideas), valuing how well something works (rather than explains), and often being local (rather than international). Regardless of the degree of acceptance of these definitional statements about technology, this kind of content qualifies as being epistemological. The nature of technology as a human enterprise is being presented.

L. The Society Emphasis Status

A society emphasis in science curriculum materials is primarily identified as being issue oriented. The issue may be an ecological issue, such as nuclear energy, toxic rain, pesticides, energy crises, resource crises, drugs, and air and water pollution. Alternately, the issue may be capable of reconstuction from within the scientific community, such as scientific honesty and the recognition of parapsychology as a science, or from outside the community, such as the issue raised by the critical theorists concerning the mechanistic and reductionist orientations claimed to exist within the scientific community. These categories of societal knowledge are less epistemological and more content laden than the knowledge form identified in the science and technology emphases in the STSC Taxonomy.

Other aspects of a science-in-society curriculum emphasis are less issue oriented and more historical or societal oriented. Within the STSC Taxonomy, sociological, national and historical knowledge presented within science curriculum materials is considered to be part of a science-in-society emphasis. Although the term "science-in-society" is being used at this point, it should be recognized that "science-and-technology-in-society" may be a more appropriate term for this emphasis. Many of the issues are more directly technology-in-society issues than they are science-in-society issues.

Several high school chemistry textbooks have presented chemistry content within a science and technology in society context with varying degrees of success (e.g., Chemistry: A Cultural Approach by Kieffer (1971), Applied Chemistry by Stine (1978), and ALCHEM by Jenkins et al (1982)). The STSC Chemistry textbook, used as a source of discourse for this study, uses the pedagogic device of classifying perspectives on an issue. The exercise promotes the idea that there are many perspectives that may be taken on any issue, and that a multi-perspective view is considered desirable. Science and technology are only two of twelve perspectives identified and these two perspectives are shown to be only part of a global or pluralistic view of society.

Table 5.14
The Societal (Sociological) Knowledge Form Triad

12. The Societal (Sociological) Knowledge Form

K: Soc K (societal knowledge) is resultant knowledge presented to people concerning a particular society or culture. This knowledge results from a Soc W and appears as knowledge that might normally be presented in a social studies text rather than a science textbook.

E.g., Western societies are reliant on high technology for food, shelter and recreation.

E.g., We, in our modern society, tend to look for technological fixes for our problems.

KW: K Soc W (knowledge of a societal way of knowing) is procedural knowledge presented to people about how to answer societal questions (Soc W). Societal knowledge (Soc K) should be a result of this kind of procedural knowledge.

E.g., A sociologist gathers evidence to answer a stated sociological problem by using one or more of three techniques—interviews, questionnaires or observation.

E.g., A sociologist may use the technique of "walking in someone elses shoes" or may "step back" from society in making more subjective or objective observations, respectively.

W: Soc W (a societal way of knowing) is action required of people. This way of knowing provides people with Soc K.

E.g., Take 15 min from your day to observe and record the dependence of your family on science and technology.

E.g., Try to stand back from your society and interpret the effect of removing technology from your everyday life pattern.

Category Status

The societal (Soc) knowledge form (Table 5.14) was one of the last categories created in this study. With only 14 tallies out of a grand total of 5507 for the **STSC Chemistry** textbook, the Soc knowledge form received very little empirical support. However, the late entry of the Soc category into the taxonomic structure and the conceptual imperative that created it led the researcher to retain the category. Further extensive tests of this category, particularly by classifying curricular discourse with a societal emphasis, are necessary. The degree of certainty concerning the "belongingness" of the Soc knowledge form is low at this point.

Perhaps the Soc knowledge form should become an empirical knowledge form within the society emphasis. As illustrated by the example statements presented in the table above, societal knowledge (Soc K) may be produced empirically by sociological, anthropological, or historical research. The procedures for producing Emp K_{SS} would be classified as K Emp W_{SS} if this change was made. The aesthetics of this move for the STSC Taxonomy is important—the science and technology curriculum emphases have empirical knowledge forms and the society emphasis would now parallel that.

The next move might be to create a societal process knowledge form (Pro_{SS}) which would allow users of the taxonomy to conceptualize and/or classify sociological, anthropological or historical activities by students. The current taxonomy does not allow for these types of activities. Of course, as for the science and technology knowledge forms, textbook discourse would not, in the strict sense, contain Pro K_{SS}. Only student notebook, assignment, and classroom types of discourse could contain student generated knowledge as Pro K_{SS}. This, in itself, indicates the potential (the fruitfulness) of continuing to evolve the STSC Taxonomy of Curricular Discourse.

Table 5.15
The National Knowledge Form Triad

13. The National Knowledge Form

K: Nat K (national knowledge) is resultant knowledge presented to people that provides places and/or names regardless of where the places are on Earth or elsewhere. The knowledge given need not be intended for testing purposes to be classified as national knowledge. A subcategory of national knowledge is Canadian knowledge.

E.g., Ron Gillespie of McMaster University in Hamilton ON co-developed the VSEPR theory of stereochemistry.

E.g., The high-efficiency (95-98 % efficient) condensing gas furnace, now being marketed by an American firm, was originally developed by a Canadian in Manitoba.

KW: K Nat W (knowledge of a national way of knowing) is procedural knowledge presented to a person concerning a national way of doing something. A name or place of the originator must be mentioned to classify as K Nat W.

E.g., To predict the shape of molecules, Canadian Ron Gillespie used VSEPR Theory.

E.g., To make the gas furnace more efficient the Canadian solution was to improve the heat exchanger to the point that combustion water vapor condensed.

W: Nat W (a national way of knowing) requires people to use a nationally developed theory, law or generalization to explain, describe or predict an unknown effect or to use national experience (particularly engineering experience) to guide actions or to use rational technology to achieve a goal. The way of knowing is only national if an historical context is set by giving the name or place of the originator of this way of knowing. The way of doing or knowing may not be considered national now but was originally, before the rest of the engineering or scientific community accepted the approach.

E.g., Use the VSEPR Theory, co-developed by Canadian Ron Gillespie, to predict, as he originally would have, the shape of the water molecule.

E.g., Describe how the Canadian inventors of the high-efficiency (condensing), gas furnace were originally able to extract heat from the combustion water vapor.

Category Status

The national knowledge form (Nat) defined in Table 5.15 tallied 4 % of the **STSC Chemistry 10** discourse. Conceptually the category has no obvious epistemological significance. The creation of the category was content, and perhaps even politically, driven rather than epistemologically or pedagogically driven. From a practical perspective one may wish to know the extent of national-context knowledge presented in curricular discourse. If this kind of knowledge form is of interest to the user, then the Nat category can be retained. However, the category can also be dropped if it is not valued.

An alternate perspective on the national category is that it can be used by teachers, authors, curriculum developers and evaluators to determine the extent of international character of scientific, technological, societal and communicational knowledge presented to students. From this perspective the national category could be renamed "international". The user of the taxonomy must decide.

Table 5.16
The Historical Knowledge Form Triad

14. The Historical Knowledge Form	
K:	His K (historical knowledge) is resultant knowledge presented to people as a result of employing an historical way of knowing (His W). Historical knowledge (e.g., dates) is often accompanied by national knowledge (i.e., names and places).
E.g.,	H. Urey is credited with discovering heavy water at Columbia University in 1931.
E.g.,	The first heavy-water moderated and cooled nuclear reactor in the world was built in the early 1950's.
KW:	K His W (knowledge of an historical way of knowing) is knowledge presented to a person that would train the person how to employ an historical way of knowing. This category is unlikely to appear in science materials unless historical research methods are described.
E.g.,	When Jacob Bronowski investigated the history of a scientific idea (i.e., in The Ascent of Man), he used an approach of relating the scientific and social presuppositions of the era to one another.
E.g.,	In the video series and book, Connections, James Burke presents an alternate view of historical analysis by relating technological advances to historical "progress".
W:	His W (an historical way of knowing) is required of people who must answer questions concerning the reporting and interpretation of history.
E.g.,	Discuss how the water wheel may have influenced the development of the cottage industries in Britain during the industrial revolution.
E.g.,	Discuss how the concept of earth, air, fire and water as the elements of all things influenced the history of both science and society in the middle ages.

Category Status

One percent of all discourse in the STSC **Chemistry 10** textbook was found to contain historical knowledge as described in Table 5.16. Only one tally out of forty-eight total was His W, the other forty-seven tallies were His K statements. This evidence is not unexpected in a science textbook. A complete and more balanced knowledge form triad would likely be found in a social studies or history textbook.

It was found that historical knowledge is usually accompanied by national knowledge (i.e., names and places) or by scientific, technological or communicational knowledge. If historical knowledge was not classified, then the remaining information in most sentences could be classified within other available categories. For example, the statement, "Insulin was discovered in 1921.", appears at first to be entirely a historical statement (His K). However, the statement, "Insulin was discovered.", could be classified as empirical knowledge (Emp K_S or Emp K_T), although the author has not made the procedure obvious. Dual classification is probably the most suitable for most historical statements.

Historical procedural knowledge (K His W) could alternately be classified as empirical (K Emp W_{SS}) or process (K Pro W_{SS}) procedural knowledge. In the latter case the student would work independently to produce knowledge. National and historical knowledge forms are in a sense topical knowledge. By analogy national and historical knowledge are to empirical knowledge (Emp K_{SS}) in a societal emphasis as thermochemistry and electrochemistry are to empirical knowledge (Emp K_S) in a science emphasis. Future users of the STSC Taxonomy of Curricular Discourse will be presented with these alternatives and will have to make their own decisions.

Table 5.17
The Ecological Knowledge Form Triad

15. The Ecological Knowledge Form

K: Eco K (ecological knowledge) is resultant knowledge presented to people concerning the environment, including human ecology. Laboratory safety, waste disposal, air and water pollution, and nuclear war are all examples of contexts for presenting ecological knowledge.

E.g., Research shows that the eye may be damaged to a greater extent by basic solutions than by acidic solutions.

E.g., Environmental research indicates that lake water containing phosphates from detergents becomes clogged with weeds and algae.

KW: K Eco W (knowledge of an ecological way of knowing) is procedural knowledge presented to a person about how to gain ecological knowledge

E.g., The effect of PCBs on humans must be extrapolated from experiments on small animals or by doing health studies on humans exposed to PCBs.

E.g., To treat an eye threatened by chemicals, flush the eye with water for at least 15 min.

W: Eco W (an ecological way of knowing) requires action of people to answer ecological questions or solve ecological problems.

E.g., Determine the effect of various kinds of soil on the buffering of acid rain.

E.g., What environmental effects might be expected when a large hydroelectric dam is built?

Category Status

The ecological knowledge form (Eco) as exemplified in Table 5.17 was one of the original ten knowledge forms identified in Stage 1 of this study. The strong lobby for environmental studies that began in the 1970's led many science educators to value ecological knowledge highly. Since Draft 1 of the STSC Taxonomy was more a result of identifying normative perspectives expressed by interest groups than of classifying textual discourse, the ecological category was an obvious inclusion.

However, the inclusion of ecological knowledge in the STSC Taxonomy is anything but epistemologically driven. The fact that ecological studies have been described as a "subversive science" indicates that ecological knowledge crosses-over between the science and the society curriculum emphases. If the environmental context is ignored, ecological statements could be classified within a science or a technology emphasis. If the user of the STSC Taxonomy wishes to obtain an estimate of the amount of ecological context in curricular discourse, perhaps a parallel content or topic taxonomy that would classify ecological content, along with national, historical, and reconstructional knowledge, would be appropriate. Perhaps the taxonomy needs to remain flexible enough to reflect the needs of the user. For example, a science educator may want to leave the taxonomy as is, while a social educator may wish to use epistemolgoical categories (e.g., The and Emp) in the society emphasis and use normative categories (e.g., nuclear energy and acid rain) in the science and technology emphases. The purist may not like the eclectic of epistemological and topical categories, but a pragmatist may view the eclectic differently. The relevant community of scholars will decide.

Table 5.18
The Reconstructional Knowledge Form Triad

16. The Reconstructional Knowledge Form.

K: Rec K (reconstructional knowledge) is resultant knowledge presented to a person as a result of someone else employing a reconstructional way of knowing. Reconstructional knowledge is knowledge of presuppositions and interests related to a particular social issue, and within science education this knowledge is related to science-in-society issues.

E.g., Politicians in Ontario have been forced by electorate interest-groups to take a stance on the acid-rain issue.

E.g., The rapid use of energy resources by our "me generation" will likely gain us a very ignominious reputation in the history of Earth.

KW: K Rec W (knowledge of a reconstructional way of knowing) is procedural knowledge presented to people concerning how to critically identify and analyze a social issue with the underlying assumption that a reconstruction of some aspect of society is required.

E.g., A reconstructional or critical approach to social issues requires one to identify the interests (e.g., political, economic and social), and presuppositions of the principal actors who are in positions of power or who want to be in positions of power.

E.g., Scientific and technological knowledge and attitudes are just a couple of the many forms of knowledge and attitudes necessary to becoming informed on a science-in-society issue.

W: Rec W (a reconstructional way of knowing) requires actions of people to critically analyze a situation presented to them. The critical analysis must attempt to get to the underlying foundations of a particular social, economic or social structure which exists in a particular situation. The question most often asked is, "In whose interest is this change being made (or not being made)?"

E.g., Write a critical appraisal of why, although the technology exists to divert water from Northern Alberta to Southern Alberta, the current provincial government is being very cautious in its proposals on this issue.

E.g., Why do you think operators of tar sands plants are allowed to continue to allegedly spoil the fishing grounds of the native population on the Athabasca River in Northern Alberta?

Category Status

Evidence for the reconstructional (Rec) knowledge form (Table 5.18) was a low two percent of total discourse in STSC Chemistry 10. The numbers of tallies were 11, 32, 69 and 18 for the four textbook units of discourse classified. Considering that chemistry discourse was being classified, perhaps this number of tallies could be considered to be relatively high. However, as a test of the "belongingness" of the reconstructional knowledge form in the STSC Taxonomy, the number of tallies was adequate but not ideal.

From a normative perspective the user who values the reconstructional category might be very interested in the amount of this kind of knowledge appearing explicitly in a textbook. Often the critical theorist would search for implicit messages in textual discourse (e.g., messages that science is for boys only or that science is always "right"). The STSC Taxonomy is not suitable for this purpose, but the exclusion of the reconstructional knowledge form from the taxonomy would remove the existence of this kind of knowledge from consciousness. In a democratic society procedural knowledge of the K Rec W variety could be regarded as indispensable and this view could influence its inclusion in some form of a taxonomy of curricular discourse.

Table 5.19
The Epistemology (in Society) Knowledge Form Triad

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17. The Epistemology (in Society) Knowledge Form

K: Epi K_{SS} (epistemological knowledge in a science-in-society context) is knowledge presented to people that resulted from an Epi W_{SS} being employed by someone else. The nature, validity and limitations of a societal (sociological) knowledge is addressed in regard to a specific situation. Epistemological knowledge differs from reconstructional knowledge in its analytic and political orientations, respectively.

E.g., Analysts suggest that the President does not appear to understand the expression of uncertainty by scientists studying acid rain.

E.g., Critics claim that the government erred in the procedures used to conduct a poll of its citizens on the fluoridation of water.

KW: K Epi W_{SS} (knowledge of an epistemological way of knowing in a science-in-society context) is procedural knowledge concerning how knowledge comes to be accepted by various segments of society.

E.g., To assess the validity of polls one must closely examine the population sampling techniques used.

E.g., When assessing the validity of knowledge about society one should look to see whether a variety of sociological and anthropological techniques were used to produce the knowledge.

W: Epi W_{SS} (an epistemological way of knowing in a science-in-society context) is required of a person when analyzing the restrictions, presuppositions, values, and perspectives employed by segments of society when selecting sides on an issue.

E.g., Why did the citizens come to believe that the toxic waste storage facility would be safe?

E.g., Assess the legitimacy of the research design used by the researchers who concluded that the sulfur extraction plant was not causing problems for near-by citizens.

Category Status

The empirical support for the epistemology of societal knowledge (Epi_{SS}) category (see Table 5.19) in the **STSC Chemistry** discourse did not build confidence in this category as a significant contributor to the STSC Taxonomy. Only twenty-four tallies out of 5507 were classified as Epi_{SS}. However, this category is very important to the structure of the taxonomy. The internal logic of the taxonomy demands that all five of the STSCP curriculum emphases be anchored by an epistemology knowledge form. Even though one might not expect to find many examples to this knowledge form in science textbooks, Epi_{SS} adds a certain aesthetic completeness to the STSC Taxonomy. Also, if the taxonomy is to eventually be used to classify curricular discourse other than science curriculum discourse, then knowledge forms like Epi_{SS} are going to be necessary. The creation of theoretical and empirical knowledge forms in the society curriculum emphasis, as discussed earlier, would provide greater support for the Epi_{SS} category. The logic for inclusion would be the same as for the Epi_S and Epi_T categories that contain Emp categories. The inclusion of the epistemology of societal knowledge leaves the STSC Taxonomy of Curricular Discourse more open to evolution and to wider application.

M. The Communication Emphasis Status

The nature of scientific communication is usually neglected as an overt issue in science education textbooks. Someone, somewhere makes a decision as to how something should be communicated within the scientific community. Seldom is the process by which scientific communication is legitimized discussed with students. Some obvious examples of communication systems employed in science are Arabic number symbols, SI metric units and symbols, IUPAC symbols for the elements, IUPAC nomenclature rules, international quantity symbols, rules for expressing certainty of quantitative data, and methods for expressing the appropriate degree of certainty in scientific talk.

An explicit treatment of how communication systems come to be accepted in the scientific community is presented to a degree in the **STSC Chemistry** textbook. This exposition of the nature of scientific communication in the **STSC Chemistry** textbook forced the evolution of the taxonomy of curricular discourse, herein, to create a curriculum emphasis for communication. The authors of the textbook had previously declared that one unit—"Communicating and Predicting Chemical Formulas"—would carry a communication emphasis (by their definition). It was not until later that a communication emphasis was created in the STSC Taxonomy by the researcher's definition (i.e., a curriculum emphasis must be anchored by an epistemology knowledge form supported by evidence of epistemological content in textbook discourse).

Table 5.20
The Communication Knowledge Form Triad

18. The Communication Knowledge Form K: Com K (communicational knowledge) is knowledge presented to people as a result of a Com W. Rules of communication would be classified as K Com W, whereas knowledge resulting from using these rules would qualify as Com K. E.g., The chemical formula for sodium sulfate decahydrate is [internationally communicated as] $Na_2SO_4 \cdot 10H_2O_{(s)}$. E.g., According to the certainty rule, the predicted molar heat of fusion of water from this experimental design should be communicated to three significant digits.
KW: K Com W (knowledge of a communicational way of knowing) is procedural knowledge presented to people concerning rules for communicating in science and/or science education. E.g., Instead of calling $H_2O_{(l)}$, hydrogen oxide, the scientific community prefers to call this substance by its trivial name, water. E.g., SI Metric Rules suggest that the mass of water should be communicated as, for example, 12.7 g, using all symbols rather than a combination of symbols and abbreviations or words such as in 12.7 gm. or 12.7 grams.
W: Com W (a communicational way of knowing) is action required of a person in science whenever an accepted set of communication rules (e.g., SI metric or IUPAC nomenclature) are employed in any type of communication. This category of statement is often accompanied by procedural knowledge and/or other kinds of required action. E.g., Read out loud the following chemical equation for the decomposition of water. E.g., Predict the mass of water reacted and communicate your problem solving technique.

Category Status

There was considerable evidence to support the existence of a communication (Com) knowledge form (Table 5.20) in the **STSC Chemistry** textual discourse. The Com category ranked number one with 16 % of the grand total of discourse for Units A-D in the **STSC Chemistry** 10 textbook. Tied for second were the theoretical (The) and scientific process (Pro_S) knowledge forms. In one unit—"Communicating and Predicting Chemical Formulas"—a full thirty-three percent of the textual discourse was classified as Com. This unit had been written by the authors with a communication emphasis in mind. They obviously achieved their goal.

The high ranking of communication as a knowledge form in science curriculum discourse is easy to accept when the evidence is presented, but the category is often implicit or taken-for-granted until brought to a higher level of consciousness. The authors of the **STSC Chemistry** textbook attempt to increase the consciousness of their students to scientific communication by including exercises which ask students to translate English statements into international symbols and vice versa. The conscious use of an agreed upon set of symbols for international communication within the scientific community is potentially a powerful device for increasing the emphasis on communication in science instruction.

None of the current lists of curriculum emphases reviewed in Chapter 2 and summarized in Table 2.1 include communication as an emphasis. Communication is mentioned in other lists of curriculum components (e.g., Nay's process skills (1972) and Aikenhead's STS outline (1986)), but is not given the status that communication is by the STSC **Chemistry** authors or by the STSC Taxonomy presented herein.

As for the future status of the communication knowledge form, one might speculate that a single category loaded as heavily as the Com category would eventually be split. Currently there are only two knowledge forms in the communication emphasis of the taxonomy—Com and Epi_C. What would an empirical or theoretical category in communication look like? Perhaps other categories such as a communciation process knowledge form (Pro_C), including communication process skills, could be conceptualized and examples could be sought in curricular discourse.

Table 5.21
The Epistemology (of Communication) Knowledge Form Triad

19. The Epistemology (of Communication) Knowledge Form

K: Epi K_C (epistemological knowledge in a communication context) is knowledge presented to a person as a result of the use of an Epi W_C in a specific situation. The epistemological knowledge should relate to the way in which a system of communication gets accepted within the scientific community.

E.g., The IUPAC rule for communicating the name of a chemical hydrate has not received wide acceptance by the international community of chemists.

E.g., The rule for communicating significant digits that requires scientific notation is not as acceptable now that the simpler method of using SI prefixes is available.

KW: K Epi W_C (knowledge of an epistemological way of knowing about communication) is procedural knowledge presented to a person concerning the nature, limits and validity of communication systems used within the scientific community.

E.g., When analyzing a system of communication acceptable to the scientific community, the communication system should be simple and precise and as international as possible.

E.g., When analyzing and evaluating the language used in scientific communication, the language should reflect the nature of science by appealing to the evidence that supports or conflicts with a prediction made by a theory, law or generalization.

W: Epi W_C (an epistemological way of knowing) is required of people when they are asked to question the reason why a communication system might be accepted by the scientific community.

E.g., Comment on the necessity for using a system of significant digits when communicating values in the scientific community.

E.g., Why is the SI system of units and symbols superior or inferior to the English system of measurement?

Category Status

The epistemology of communication (Epi_C) knowledge form as described in Table 5.21 was introduced in Stage 5 during the classification of discourse in the "Communication and Prediction of Chemical Formulas" unit. Initially only an Epi K_C category was created and the full K-KW -W triad did not evolve until Stage 7. The total number of occurences of Epi_C discovered was 31 or one percent of the total discourse classified.

Conceptually this category is very important to the structure of the STSC Taxonomy. A criterion for the creation of a curriculum emphasis is that an epistemological knowledge form must be discovered in curricular discourse or conceptualized on philosophical or logical grounds. The grounds for creating the Epi_C category were found in the **STSC Chemistry** textual discourse. The textbook lists and asks students to learn the criteria for judging scientific communication systems; i.e., the systems should be international, precise and simple (1986: B24). The concepts of "shared meaning" and translation from English to international symbols are also repeated throughout the four units of discourse. This discourse provides evidence that the Epi_C class of knowledge is real.

N. Pedagogy Emphasis Status

Within science curriculum materials, and more covertly within science papers or lectures, pedagogy (Ped) plays a very important role. In order for any scientific knowledge or way of knowing to be accepted within the scientific community, the members of the community must be educated or convinced of the validity of new scientific knowledge.

Some of the knowledge and ways of knowing presented within school situations must of necessity be presented without supporting evidence or supporting theories. Usually this approach is covert, but if people are to become students of science they need to become conscious of how they know something at any particular point in their education. People need to become partners in their education, just as scientists need to know how and with what certainty something is known in their particular field of expertise. People may accept and understand better the science education they are getting if they are let in on the purpose of a particular approach. People are also more likely to understand the nature of the scientific enterprise if they are let in on the parallels between the nature of science and the nature of pedagogy. Some examples are presented on the following pages, but a common example that is heard in most science or science-education expositions is, "It is convenient to represent [this] as . . . .".

The current status of the pedagogy emphasis in the STSC Taxonomy is that three knowledge forms have been identified to help describe science textbook discourse—pedagogical purpose (Ped_P), pedagogical reference (Ped_R), and epistemology of pedagogy (Epi_P). Each of these categories worked reasonably well for classifying textbook discourse although arguments are presented below to suggest that parallel knowledge forms to the science and technology emphases might be appropriate.

Table 5.22
The Pedagogical Purpose Knowledge Form Triad

20. The Pedagogical Purpose Knowledge Form

K: Ped K_P (knowledge of pedagogical purpose) is resultant knowledge presented to people to assist them in knowing what they are to do within a particular science-education exercise assigned to them. This category often lists the purpose of the learning exercise as determined by a third person.

E.g., [According to the authors] the purpose of this laboratory work is to gain a better appreciation of the importance of water as a "universal" solvent.

E.g., [According to the test constructors] the purpose of the examination is to test chemisty content as well as STSC knowledge.

KW: K Ped W_P (knowledge of a pedagogical way of knowing in a pedagogical purpose context) is procedural knowledge presented to people concerning how to determine, or question, the purpose of a particular learning experience. K Ped W_P may also include how to provide clear instructions. This category is probably more applicable to teachers rather than students and is more likely to appear in teachers' guides than in curriculum materials.

E.g., When approaching a unit of subject matter teachers should restrict the number of curriculum emphases to one or two.

E.g., When reading a laboratory assignment students should be sure to differentiate between the purpose of a laboratory exercise and the problem to be answered by the experiment.

W: Ped W_P (a pedagogical way of knowing related to pedagogical purpose) requires people to determine the purpose of, or the instructions required in order to complete, a teaching/learning assignment.

E.g., What was the purpose of going into the laboratory to determine the molar heat of water?

E.g., What kinds of questions should be expected on the test for this unit?

Category Status

The pedagogical purpose (Pedp) knowledge form (Table 5.22) occurred 179 times in the **STSC Chemistry 10** textbook for a 3 % proportion of the discourse classified. Exercises, in particular, contained instructions to students that were classified as K Ped Wp. This procedural knowledge, like all procedural knowledge, was originally created as resultant knowledge by someone else (e.g., the authors or other pedagogues). When attempting to classify this kind of knowledge in textual discourse the context of presentation is very important. The student is a user of this procedural knowledge not a producer of procedural knowledge and therefore procedural statements are classified as K Ped Wp in textual discourse.

The above does not preclude the student from becoming a producer of procedural knowledge. Learning how to learn, learning personal study skills, and identifying one's learning style would qualify as pedagogical process skills and would produce a new category of knowledge, Pro Kp. Of course, this kind of knowledge, like all Pro K, would not appear in textual discourse since students are the producers. If a Prop) knowledge form exists, then perhaps an empirical pedagogy (Empp) knowledge form also exists. It seems logical and consistent to suggest that pedagogical knowledge is produced empirically by pedagogues and that this knowledge is presented to students in textual discourse. For example, instructions, hints, examples, lists of study skills, and ways of remembering things are presented to students in textbooks as a result of the empirical work of pedagogues.

Table 5.23
The Pedagogical Reference Knowledge Form Triad

21. The Pedagogical Reference Knowledge Form

K: Ped K_R (knowledge in a referenced (or given or memorized) context) is knowledge presented to people with the understanding that the given knowledge will always be given (presented) in the near future, or is referenced knowledge which the person will have to reference (look up) in the future, or is given or referenced knowledge which must become memorized knowledge for the future. In the following examples a K Ped W_R phrase establishes that the knowledge statement is pedagogic and not, for example, empirical.

E.g., From memory, the equilibrium constant for water at SATP is 1.01×10^{-14} mol^2/L^2.

E.g., From referencing the periodic table, the boiling point of oxygen is -183^oC.

KW: K Ped W_R (knowledge of a pedagogically referenced way of knowing) is procedural knowledge concerning how or when a given, referenced, or memorized way of knowing can be employed. People are often presented with instructions as to how to use a table of values that may be provided for reference.

E.g., When a specific heat capacity other than for water is required in a quantitative prediction, the heat capacity will be given in the problem or must be referenced from a table of heat capacities provided.

E.g., To develop an understanding of the concept of phase and temperature changes, requires a combination of ways of knowing including the time honored memorized, referenced, and given ways of knowing.

W: Ped W_R (a pedagogically given, referenced, given or memorized, way of knowing) is required of persons to answer a question.

E.g., Use the CRC Handbook of Chemistry and Physics to reference the ionization constant for water at 50^oC in order to perform the following prediction.

E.g., From memory, what is the H-O-H bond angle in water?

Category Status

The pedagogically referenced (Ped_R) knowledge form as defined in Table 5.23 was supported fairly evenly by the occurence of this category in the **STSC Chemistry** textbook discourse. Three percent (181 tallies) of the Unit A-D discourse was classified as belonging in the Ped_R triad. Perhaps of more importance is the epistemological significance of this Ped_R knowledge form. A considerable amount of what students learn, especially early in their science education, is based upon a given (e.g., in the question), referenced (e.g., from a table), or memorized way of knowing. A taxonomy of curricular discourse must account for this reality. The authors of the **STSC Chemistry** textbook, for example, have made the use of given, memorized and referenced ways of knowing explicit within the discourse, similar to the examples above. The presentation of Ped_R procedural knowledge (K Ped W_R) is often in answer to the student question, "How am I supposed to know that?" A common answer is, "You memorize it."

From an epistemological perspective, knowledge resulting from memorizing or referencing (K Ped W_R) is pedagogic. If one memorizes the chemical formula for water, then the chemical formula produced is Ped K_R. It is not until the student is presented with an empirical way of knowing that the knowledge can be produced as Emp K or is presented with a theoretical procedure that the resultant knowledge is The K. The STSC Taxonomy is fruitful in that it presents a potential for sorting out the differences in knowledge according to the context.

Table 5.24
The Epistemology (in Pedagogy) Knowledge Form Triad

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22. The Epistemology (in Pedagogy) Knowledge Form

K: Epi K_p (epistemological knowledge in pedagogy) is resultant knowledge presented to people (e.g., teachers reading a teachers' guide) that results from an Epi W_p way of knowing. Epi K_p is usually quite situational and specific because it results from applying a Epi W_p to a specific situation. The knowledge should speak to the limitations, validity and assumptions associated with pedagogical knowledge.

E.g., The researcher insisted that this empirical knowledge from the classroom is supported by formal educational research, but still requires a theoretical construct with some explanatory power.

E.g., Scientists believe that the invention of the hydronium ion to represent a hydrated proton is justified on the basis of pedagogic convenience.

KW: K Epi W_p (knowledge of an epistemological way of knowing in a pedagogical context) is procedural knowledge given to people concerning 1. the way in which science-education knowledge is validated and accepted within the science-education community, 2. the limits of and assumptions associated with this kind of knowledge, and 3. the nature of pedagogy itself.

E.g., When analyzing pedagogic ways of knowing, look for given, referenced and memorized ways of knowing.

E.g., A way to test predictions from any theories or generalizations of teaching and learning is to gather evidence in the classroom situation.

W: Epi W_p (an epistemological way of knowing in a pedagogical context) requires people to employ K Epi W_p to answer questions about the validity and nature of knowledge about teaching and learning.

E.g., What ways of knowing the chemical formula and state of matter at room temperature of water were used by you in your last chemistry education course?

E.g., How do generalizations and theories of learning get to be accepted by the science-education community?

Category Status

The epistemology of pedagogical knowledge (Epip) category (Table 5.24) of the STSC Taxonomy of Curricular Discourse was supported by the evidence to the extent of one percent of all **STSC Chemistry** discourse classified. Although the empirical support for this knowledge form is low, the category is likely to last because of the epistemological imperative of having an Epi knowledge form in each curriculum emphasis. All five curriculum emphases—science, technology, society, communication and pedagogy (STSCP)—in the STSC Taxonomy are anchored by an Epi knowledge form.

Other conceptual arguments used to justify an Epip knowledge form include epistemological content presented in textual discourse and in classroom discourse and evaluative statements presented in teachers' editions of textbooks. For example, in the **STSC Chemistry** textbook students are presented with the epistemological knowledge that their knowledge can be classified as empirical, theoretical, given, memorized or referenced. The latter three ways of knowing are classified in the STSC Taxonomy as pedagogic; i.e., there is no empirical or theoretical basis used to justify the existence of this knowledge—it is taken on pedagogic faith. Much of the knowledge presented in science lectures in schools and universities could be classified as pedagogic. The researcher's experience with taking notes on the scientific language (i.e., appeal to evidence and theories) during lectures suggests that only a small percentage of lecturers provide epistemological context to the content presented.

In classroom discourse teachers may indicate to students that experience or research suggests that they should learn, study or write exams by following given procedures. By presenting the basis for this knowledge, teachers are introducing or modelling an epistemological approach for students to use when accepting knowledge. Although little of this kind of knowledge is presented in current textbooks, it seems appropriate to suggest that the epistemology of learning is central to all activities in school.

O. Chapter Summary

Chapter 5 presents the results of Stage 8 and Stage 9 plus "final" descriptions with examples and status reports for the sixty-six categories in the STSC Taxonomy of Curricular Discourse presented in Table 5.25. The primary result of Stage 8 was the writing of the formal descriptions of each category of the taxonomy that existed after Stages 1-7. Two example textbook discourse statements were written to accompany each of the sixty-six descriptions. A set of rules for using the STSC Taxonomy, as well as descriptions of the five curriculum emphases (STSCP) and the three epistemological triad (K-KW-W) categories, were also written and rewritten during Stage 8. These activities served as conceptual tests of the structure of the taxonomy. The classification of real discourse from the ALCHEM and **STSC Chemistry** textbook had served as a series of empirical and conceptual tests of the evolving taxonomy during Stages 2-7. Stage 8 serves as an intense analysis of each knowledge form triad in an attempt to conceptualize the taxonomy for potential users.

Stage 9 involved having six judges classify the example statements developed in Stage 8 and then critique one of the curriculum emphases presented in the taxonomy. The judges are experienced and expert classroom teachers and textbook authors who have spent considerable time refecting on the content and goals of a pluralistic science education program. They made many recommendations for changes in the wording of the example statements, for new descriptions of categories, and for reconceptualizing the procedural knowledge category.

These recommendations are incorporated in the "last" rewriting of the STSC Taxonomy descriptions and examples presented in the latter part of this chapter in a series of twenty-two tables. The category status discussions which were written for each curriculum emphasis and each knowledge form in the taxonomy reflected the views of the six judges. An attempt is made in each status report to summarize the evidence and conceptual basis for each category. Critical suggestions are also made as to the future evolution of the current taxonomy. These suggestions are elaborated upon in the next chapter.

Table 5.25
The STSC Taxonomy at the End Stage 9

Emphases and Knowledge Forms	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
	The K-KW-W (Epistemological) Triad		
Science			
1. Theoretical	The K	K The W	The W
2. Empirical$_E$ (experiential)	Emp K_E	K Emp W_E	Emp W_E
3. Empirical$_E$—Theoretical	Emp K_E—The K	K Emp W_E—K The W	Emp W_E—The W
4. Empirical$_L$ (laws)	Emp K_L	K Emp W_L	Emp W_L
5. Empirical$_L$—Theoretical	Emp K_L—The K	K Emp W_E—K The W	Emp W_L—The W
6. Process	Pro K_S	K Pro W_S	Pro W_S
7. Epistemological	Epi K_S	K Epi W_S	Epi W_S
Technology			
8. Technological	Tec K	K Tec W	Tec W
9. Empirical	Emp K_T	K Emp W_T	Emp W_T
10. Process	Pro K_T	K Pro W_T	Pro W_T
11. Epistemological	Epi K_T	K Epi W_T	Epi W_T
Society			
12. Societal	Soc K	K Soc W	Soc W
13. National	Nat K	K Nat W	Nat W
14. Historical	His K	K His W	His W
15. Ecological	Eco K	K Eco W	Eco W
16. Reconstructional	Rec K	K Rec W	Rec W
17. Epistemological	Epi K_{SS}	K Epi W_{SS}	Epi W_{SS}
Communication			
18. Communication	Com K	K Com W	Com W
19. Epistemological	Epi K_C	K Epi W_C	Epi W
Pedagogy			
20. Pedagogical Purpose	Ped K_P	K Ped W_P	Ped W_P
21. Pedagogical Reference	Ped K_R	K Ped W_R	Ped W_R
22. Epistomological	Epi K_P	K Epi W_P	Epi W_P

Chapter 6: Summary, Major Findings and Recommendations

A. Summary of Research Questions

The current study set out to develop an analytical framework for classifying discourse found in science textbooks. The two guiding questions addressed by the research were:

1. What theoretical perspectives may be employed as conceptual organizers for developing an analytical framework to describe science textbook discourse?

2. What analytical framework may be employed to describe science textbook discourse?

The answers to these questions are perceived to be important to furthering knowledge about the structure of subject matter content in textbook discourse. The subject matter research was not based on the analysis of a topic into concepts and subconcepts and associated methodologies (Gagne, 1964). Neither was the analysis in terms of objectives (Bloom, 1956), meaningfulness (Ausubel, 1968), logic (Piaget, 1974) or hidden curriculum (Apple, 1974). The analysis of the textbook discourse was in terms of the knowledge infrastructure at a normative knowledge form and at an epistemological level. An alternative analytic framework was sought that was based on descriptive terms (such as empirical, theoretical and epistemological) taken from the language of the philosophy of science.

B. Summary of Research Design

The research design methodology is called conceptual analysis (Mahung, 1980). According to Mahung, the initial phase of conceptual analysis involves the establishment of a theoretical perspective or systematic conceptualization. In the current study an eclectic group of theoretical perspectives was employed including normative perspectives (Kass and Jenkins, 1982 and 1986), curriculum emphases (Roberts, 1982), STS science education (Bybee, 1985; Aikenhead, 1986), practical pedagogy (Schwab, 1969 and 1971; Connelly, 1982) and epistemological content (Gowin, 1978, Munby, 1982; Nadeau and Desautels, 1984). These perspectives were not only sought as <u>an eclectic group of views on curriculum structure</u> but they also provided criteria used for the ongoing development and evaluation of a taxonomy of curricular discourse. Each of these perspectives represents a view about curriculum that is held by a significant proportion of the science education community. A unifying attempt was made to account for all of these views within the taxonomy of discourse. The results of this attempt are discussed later in this chapter.

The second stage of conceptual analysis as described by Mahung is the development of an analytical framework. The analytical framework in this study translated into a taxonomic classification of knowledge forms. As presented in Chapter 4 the taxonomic framework underwent a series of evolutionary changes as the six units of textbook discourse were classified. The **STSC Chemistry 10** (1984) textbook discourse was chosen for classification because of a declared compatibility with the theoretical perspectives chosen to guide the formation of the taxonomy (i.e., normative perspectives, curriculum emphases, STS science education, practical pedagogy and epistemological content). As the taxonomy evolved through the nine stages of the research study, each of the theoretical perspectives was emphasized at a particular point. The analytical framework started as a 10 x 1 taxonomic classification of normative perspectives and "finished" as the 22 x 3 Taxonomy of Curricular Discourse with twenty-two knowledge forms, each including an epistemological triad, nested into five curriculum emphases.

The nine stages through which the taxonomy evolved included an initial conceptualization of a taxonomy of knowledge forms in Stage 1. During Stage 2 through Stage 7 six chapters (units) of textbook discourse were classified sentence by sentence. Each act of classifying was considered to be a test of the content validity of the taxonomy. The revisions to the taxonomy during or after each stage are documented in Chapter 4. During Stage 8 a description and two example textual discourse statements were written by the researcher for each of the sixty-six categories in the 22 x 3 STSC Taxonomy. This stage allowed for additional critical reflection on the super and fine structure of the taxonomy. The results for Stage 8 are presented in Chapter 5.

Stage 9 involved the use of expert judges to obtain an inter-rater agreement estimate on the classification of randomized sets of the example statements prepared by the researcher during Stage 8. This exercise provided considerable feedback leading to the revision of many of the examples. The judges were also asked to comment on the perceived content validity and utility of the classification of textbook discourse using two of the dimensions of the STSC Taxonomy—the STSCP curriculum emphases dimension and the K-KW-W espistemological triad dimension. Their comments are presented in Chapter 5 and were used in writing a status report on each of the twenty-two knowledge forms. The "final" descriptions, examples and status reports are presented in Chapter 5.

A practical perspective is apparent in the third stage of the conceptual analysis methodology—the application of the analytical framework. In the current study, the practical contexts for applying the framework were two-fold—the writing of the **STSC Chemistry** textbooks by The Author Group members and the teaching of high school chemistry by these same teacher-authors, including the researcher. This third stage was not a formal part of the research and no results are reported. However, the influence of the practical was important to increasing the confidence of the researcher as to the intelligibility, plausibility and fruitfulness of the taxonomy. The classroom-in-use also provided for the active involvement of three of Schwab's four commonplaces—the subject matter, the teacher, and the student—in a restricted but important form of deliberative inquiry. The dialectic between the research study and the **STSC Chemistry** curriculum project is evident in that in retrospect it is difficult to decide from which context ideas originated. In a dialectic methodology such as this one mutual benefit arises from the relationship. Although the purpose of this research study was not stated in terms of an immediate influence on the practical, the **STSC Chemistry** project is a specific example of this influence. Some of the mutual influences are discussed in Chapter 4 and Chapter 5.

C. A Summary of Procedures, Evidence and Analysis

A search for a taxonomy of knowledge forms found in science textbook discourse involved the classification of six units (chapters) of textbook discourse from the ALCHEM 30 and **STSC Chemistry 10** textbooks. The textbook discourse was classified sentence by sentence and in some cases phrase by phrase. Categories from the then-current taxonomy were used as the classification key. The initial taxonomy had four curriculum emphases nesting ten knowledge form categories—academic (theoretical, empirical and process), application (applicational, parochial and ecological), pedagogic (pedagogical and psychological), and implicit (epistemological and reconstructional). Nested within each knowledge form a K-KW-W epistemological triad was discovered. The epistemological triad is displayed in the taxonomic matrix as a second dimension, as in Table 6.1

C1. The Creation of the Epistemological Triad

The K-KW-W triad was found to represent two kinds of knowledge and one required action (e.g., question). Early in the study evidence indicated that the superordinate structure of textbook discourse could be classified into one of these three categories of the epistemological triad. As presented in Table 6.2 and in Figure 6.1 the proportions of tallies over the full range of discourse classified

Table 6.1
Initial Taxonomy of Chemistry Textbook Discourse

Emphasis and Knowledge Form	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
	The Epistemological (K-KW-W) Triad		
Academic			
1. Theoretical	The K	K The W	The W
2. Empirical	Emp K	K Emp W	Emp W
3. Process	Pro K	K Pro W	Pro W
Applicational			
4. Applicational	App K	K App W	App W
5. Parochial	Par K	K Par W	Par W
6. Ecological	Eco K	K Eco W	Eco W
Pedagogical			
7. Pedagogical	Ped K	K Ped W	Ped W
8. Psychological	Psy K	K Psy W	Psy W
Implicit			
9. Epistemological	Epi K	K Epi W	Epi W
10. Reconstructional	Rec K	K Rec W	Rec W

Table 6.2
Distribution of K, KW and W Discourse in STSC Chemistry 10

STSC Chemistry Unit	Resultant Knowledge (K) (#)	(%)	Procedural Knowledge (KW) (#)	(%)	Action Required (W) (#)	(%)	Total Tallies (#)	(%)
Unit A	529	53	208	21	259	26	996	100
Unit B	363	32	264	23	525	46	1152	100
Unit C	463	41	229	20	443	39	1135	100
Unit D	702	57	217	18	317	26	1236	100
Total	2057	46	918	20	1544	34	4519	100

* Table 6.2 omits STSC context tallies.

provided strong supporting evidence for the existence of the triad. In textbook discourse the triad includes resultant knowledge (K) produced by a person employing procedural knowledge (KW) as a result of required action (W).

K – resultant knowledge presented in textbook discourse

– produced as the result of a required action (e.g., question)

– tells what the answer to a previous question was

KW – procedural knowledge presented in textbook discourse

– knowledge of a way of knowing in textbook discourse

– tells how to produce knowledge

W – required action presented in textbook discourse

– required way of knowing in textbook discourse

– questions and activities in textbook discourse

The K-KW-W triad is called an "epistemological" triad because the classification of a knowledge form in textbook discourse depends on a determination of the procedural knowledge used to obtain the knowledge. The determination of the origin of knowledge is part of the definition of epistemology. The use of the K-KW-W triad to specify the origin of specific knowledge is in this sense epistemological. The "K-KW-W" symbol remains as a vestige of the original names for the triadic components—"K" for knowledge, "KW" for knowledge of a way of knowing, and "W" for way of knowing. The symbol has a certain aesthetic that has contributed to its retention.

Once this relationship was conceptualized and practiced, the reseacher proceeded to classify complete textbook chapters, sentence by sentence. Rules were established and followed. More importantly, if presented knowledge or questions could not be classified according to an existing epistemological triad, then a new category was created. Sometimes K-KW-W triads were created when, for example, only procedural knowledge (KW) was evident in the textbook discourse. An example of a K-KW-W epistemological triad is provided below.

Resultant K: The mass of calcium carbonate produced was 2.69 g.

Procedural KW: The mass of calcium carbonate produced can be determined by precipitation and filtration.

Required W: What is the mass of calcium carbonate produced?

In order to decide on how to classify the above question the textual context of the question must be determined. The textual context must be searched for evidence of the procedural knowledge that is expected to be used to answer the question. Sometimes the context of the question is difficult to discern, while other times more than one procedure is discernible from the context. For example, the context for the above question might be the student laboratory (classified as Pro W, a process way of knowing) or the classroom Emp W_E, an empirical way of knowing from third party evidence. If the student had more than one way of answering the question, or if more than one way of knowing was necessary, then the question was classified into two categories. For example, predicting the answer to the above question by using the stoichiometric method involves a combination of an empirical and a theoretical way of knowing (i.e., Emp W_L—The W).

C2. The Evolution of the STSC Taxonomy

The evolution of the taxonomy resulted from a continuous dialectic between the conceptual components of this analytical framework and the evidence gathered by classifying textbook discourse. The research design might be described as gathering evidence for about 7500 tests (in six units of textbook discourse) of the prediction that the taxonomic classification was an adequate description of the science textbook discourse. If conflicting evidence was gathered, then the taxonomy was revised, and more evidence was gathered for testing the same prediction again.

Various kinds of revisions were made. For example, context and perspective categories were established early in the research study to deal with anomalies (i.e., discourse that could not be classified within the existing taxonomy). Eventually this solution was seen as an attempt to save the then current classification system from major revisions. Therefore, during the classification of the third unit of textbook discourse, major revisions were made on the basis of established empirical and conceptual criteria. The conceptual criteria were derived from the five theoretical perspectives used to guide the evolution of the taxonomic framework for curricular discourse. These criteria are listed in Chapter 4.

Frequency tallies of discourse for each category formed the empirical evidence which supported or conflicted with the predictions made. A significant proportion of frequency tallies provided supporting evidence for the existence of a knowledge category in science textbook discourse. Excessive tallies were grounds for considering whether the category should be split into two or more categories. The lack of tallies was not interpreted as sufficient grounds for eliminating a category. A lack of a category within which to classify a sentence or phrase of textbook discourse was considered sufficient evidence for the invention of a new category that had strong conceptual support from one or more of the guiding theoretical perspectives.

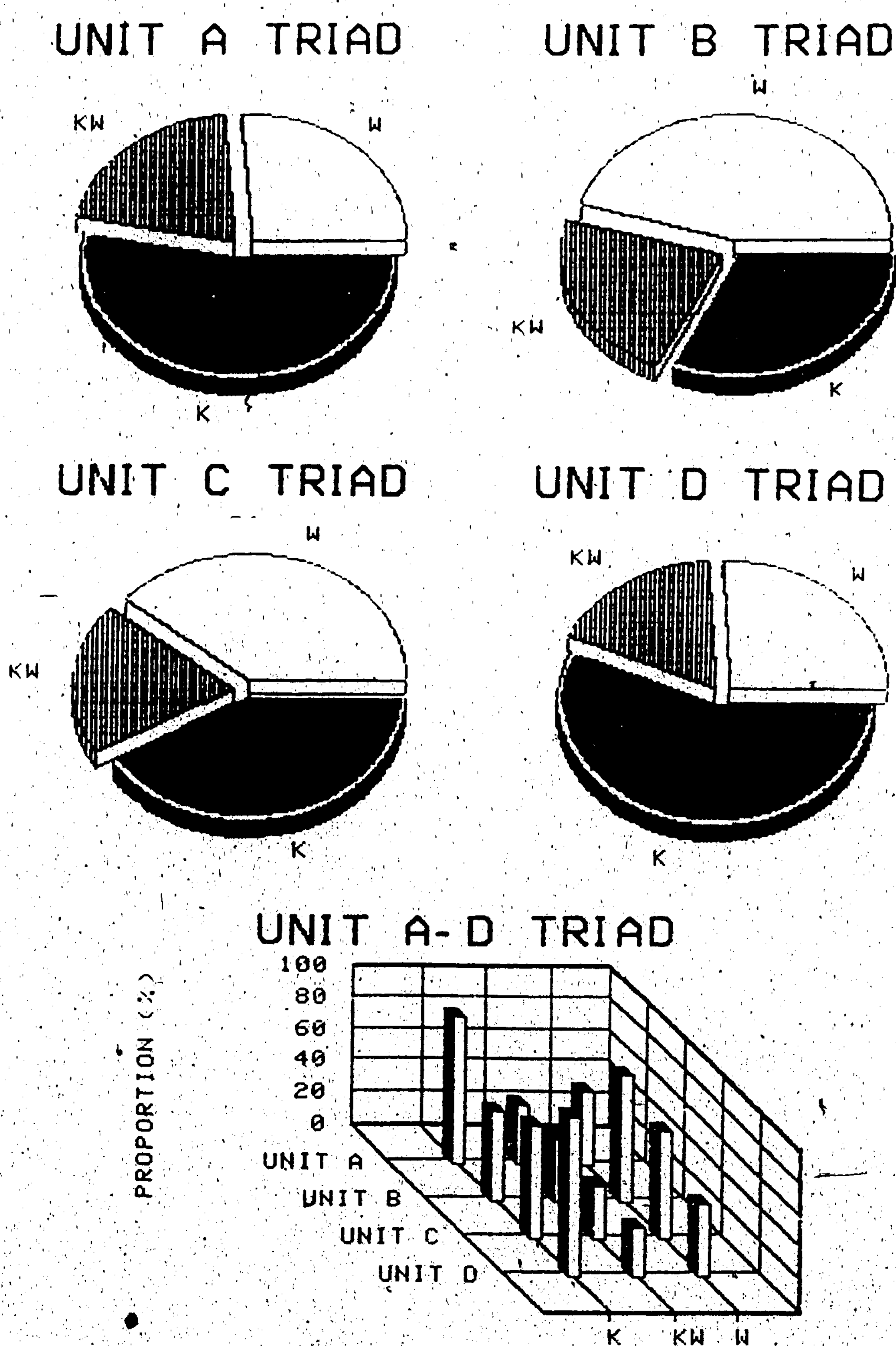
The conceptual criteria for revising the analytical framework (i.e., the STSC Taxonomy) were derived from the guiding theoretical perspectives. For example, from the perspectives of STS science education and of curricular emphases, STS curricular emphases were established. From the perspective of epistemology, K-KW-W triads, and theoretical, empirical, theoretical-empirical, and epistemological knowledge forms were created. From the perspective of epistemology, a communication emphasis was established. Evidence for communicational epistemological content in textbook discourse necessitated this creation of a communication emphasis. From the perspective of epistemology, the criterion for creating a curricular emphasis is the discovery of epistemological content within that context.

From the practical (pedagogic) perspective of the researcher as teacher and textbook author, a pedagogy emphasis was created to accompany the previous STSC emphases. Evidence gathered from classifying textbook discourse verified this prediction. A strong pedagogic emphasis was discovered—ranging from 10 % to 15 % of total discourse per chapter of discourse classified. From a practical perspective, the societal emphasis in the STSC Taxonomy was described in terms of knowledge forms of interest to the community of science educators, rather than paralleling the more epistemological knowledge forms (i.e., theoretical, empirical and process) found in the science and technology emphases. Also from a practical perspective, scientific and technological process skill categories were created and defined in a restrictive way because of practical interest in the amount of independent laboratory work done by students. Without this interest the laboratory work required of students through textbook discourse could be classified into the standard theoretical and empirical knowledge form categories employed by scientists and described by philosophers of science.

The dialectic between conceptual and empirical criteria and the dialectic between the research of the researcher and the practice of the researcher as teacher and author contributed substantially to the development of the 22 x 3 taxonomic matrix of knowledge and ways of knowing found in science textbook discourse. (The dialectic methodologies used in this research were not unlike the theoretical-empirical dialectic category described in the STSC Taxonomy.) Notwithstanding the disclaimer about the STSC Taxonomy not being applied as a part of this research study, the results from Stages 4-7 were used independently by the authors of the **STSC Chemistry 10** textbook as an indication of the accuracy of their matching of STSC emphases with textbook chapters. For example, as communicated in Figure 6.1 the **STSC Chemistry 10** chapter with a nature of science emphasis registered 55 % science content; the technology emphasis chapter tallied 41 % technology content; the communication emphasis chapter tallied 34 % communication content; while the science-in-society chapter only registered 9 % societal content. The first three results were encouraging to the authors, while the latter result indicated that additional science-in-society content seemed appropriate in that chapter. The distribution of curriculum emphases for each unit of textual discourse classified is displayed graphically in Figure 6.1.

C3. Summary

In summary, the research design, procedures, evidence, and analysis employed in this research study involved the conceptualization and empirical testing of a series of taxonomic classifications of knowledge forms found in science textbook discourse. The research was guided by an eclectic group of theoretical perspectives including normative perspectives, curriculum emphases, STS science education, practical inquiry, and epistemology. If the same methodology (i.e., conceptual analysis) was employed with the same textual discourse, but with different theoretical perspectives, the analytical framework developed may have been different than the STSC Taxonomy. In this sense the research and the research products are theory and value laden.



Evidence for the Existence of the Epistemological Triad
Figure 6.1

D. Summary of Research Findings

The following summary of research findings is presented with reference to the guiding questions and the theoretical perspectives presented earlier in this report. The guiding questions for the research are repeated below.

1. What theoretical perspectives may be employed as conceptual organizers for developing an analytical framework to describe science textbook discourse?
2. What analytical framework may be employed to describe science textbook discourse?

Both of the above research questions were answered for the first time during Stage 1 of the study. At that time the answer to Question 1 concerning the guiding theoretical perspectives was the same as the answer to Question 2 concerning the analytical framework to describe science textbook discourse. Ten categories of knowledge promoted by ten interest groups were identified. Each of these interest groups had their own favorite knowledge form that could be justified from their theoretical perspective on science education. The initial criterion for the existence of a knowledge form was the existence of a supporting interest group. The initial assumption was that if a large interest group could be identified then its favorite form of knowledge must be well established and recognized by the general science education community. The use of these established knowledge forms, it was reasoned, would be a good place to start. The search for these knowledge forms in textual discourse began at the end of Stage 1 of the study.

A false start on Stage 2—classifying textbook discourse in a Grade 12 thermochemistry unit—sent the initial classification system back for revisions almost immediately. Some conceptual work concomitant with the empirical exercise of classifying discourse led to the creation of the epistemological triad as described in Section C1 earlier in this chapter. The result was the 10 x 3 taxonomic system presented in Table 6.1 above.

Over the next couple of stages of the study during the classification of discourse in chemistry textbooks, the implicit theoretical perspectives guiding the development and evaluation of the taxonomy became explicit. The general goal of the exercise had always been to develop a taxonomy that was pluralistic in its views and had a potential to unify diverse but important views in the field of science education. The second formal set of theoretical perspectives identified were carried through to the end of the study. The five guiding perspectives identified, in answer to Question 1 in the problem statement, are <u>normative perspectives</u>, <u>curriculum emphases</u>, <u>STS science education</u>, <u>practical inquiry</u>, and <u>epistemology</u>. A "final" evaluation, and thus a post-study answer to Question 1, is presented later in this chapter. The five theoretical perspectives used as conceptual organizers for developing the Taxonomy of Curricular Discourse are described below.

1. <u>Normative perspectives</u> on curricular knowledge result when interest groups value certain knowledge forms more highly than

other forms of knowledge (Factor and Kooser, 1981; Kass and Junkins, 1986). An analytical framework organized around normative perspectives would incorporate kinds of knowledge preferred by a variety of interest groups. In the STSC Taxonomy normative knowledge forms of all major interest groups are included.

2. The theoretical perspective associated with <u>curriculum emphases</u> is that a curriculum content may be presented with a variety of meta-lessons (e.g., nature of science) (Roberts, 1982). Curriculum emphases by their broad nature are useful as superordinate organizers for analytic frameworks concerned with curricular knowledge. In the Taxonomy of Curricular Discourse five curriculum emphases are used to nest twenty two knowledge forms.

3. <u>STS science education</u> is a theoretical perspective which conceptualizes the integration of science, technology and society content, contexts and issues into a single science course. An analytical framework guided by the STS perspective would have to be organized with STS components. In the current case of the STSC Taxonomy STS was used to provide three of five (STSCP) curriculum emphases.

4. <u>Practical inquiry</u> is a theoretical perspective which values dialectic interaction at the theory-practice interface in a field such as pedagogy. An analytical framework developed from this perspective must be adaptable and relevant to a practical context. In the STSC Taxonomy a practical perspective was used along with a normative perspective to justify the inclusion of a number of

knowledge forms which might otherwise have been deleted.

5. An <u>epistemological</u> perspective is concerned with the nature and origin of knowledge. An analytical framework guided by this theoretical perspective would judge knowledge forms on the basis of their epistemological flavor. In the Taxonomy of Curricular Discourse an epistemological perspective was used to evaluate and create knowledge forms and curriculum emphases.

The guiding questions and theoretical perspectives led to the development of an analytical framework—the Taxonomy of Curricular Discourse—for classifying chemistry textbook discourse.

D1. The STSC Taxonomy

The STSC Taxonomy developed in this study as an analytical framework for describing chemistry textbook discourse is presented in Table 6.3 and described below. The 22 x 3 taxonomic framework summarizes the curriculum emphases, knowledge forms, and epistemological (K-KW-W) triads found in science textbook discourse. The 22 x 3 framework may be collapsed in a variety of ways (e.g., into a 5 x 1 framework of curriculum emphases). The curriculum emphases that are used to nest the textbook discourse knowledge forms are STSCP—science (Sci), technology (Tec), society (Soc), communication (Com), and pedagogy (Ped). From a practical perspective the STSCP emphases may represent the extent of interest within a particular science education context. Another way of collapsing the full STSC Taxonomy is on the second dimension—the epistemological (K-KW-W) triad. From a practical perspective the STSC Taxonomy has developed with the flexibility to collapse to suit the restricted purposes of the user. A complete description of the Taxonomy of Curricular Discourse including descriptions of and examples for all sixty-six categories and a status report on all five curriculum emphases and twenty-two knowledge forms is presented in Chapter 5. The following information summarizes the detailed results in Chapter 5.

D2. The Epistemological Triad

According to the STSC Taxonomy, all science textbook discourse can be classified into one of three categories—resultant knowledge (K), procedural knowledge (KW), or required action (W). Evidence to support this contention is presented in Figure 6.4. Resultant knowledge (K) may be conceptual knowledge (e.g., theories, laws, generalizations, or definitions), observational knowledge, knowledge predicted or retrodicted from theories, laws or generalizations, explanations from theories, descriptions from laws or generalizations or even resultant knowledge which provides a procedure. Procedural knowledge (KW) is knowledge used by people to produce knowledge. The KW category includes, for example, knowledge of scientific skills, technological skills, problem solving, and communication rules, as well as knowledge of how to use a theory to explain and/or predict observations and how to use a law or generalization to predict future observations. Examples, experimental designs, laboratory procedures, steps to solving problems, and how to substitute into formulas are procedural knowledge (KW). Every one of the twenty-two knowledge forms in the STSC Taxonomy has procedural knowledge. A criterion for creating a KW category is that, if a form of knowledge (K) exists, then a corresponding procedural knowledge (KW) is necessary to produce that kind of knowledge.

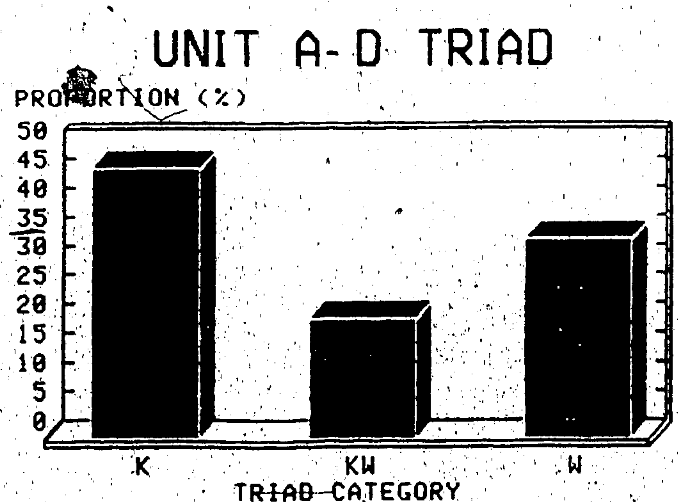
The action required (W) component of the K-KW-W epistemological triad in the STSC Taxonomy allows for the classification of questions, exercises, laboratory activity, and homework assignments in textbook discourse. Anything required of a student, rather than presented as knowledge, is classified by the user of the STSC Taxonomy as W. The way of knowing (W) may be classified on the basis of the kind of procedural knowledge used or the resultant knowledge expected in the answer. In the current study the students' answers as depicted in Figure 6.3 were not classified—the classification was restricted to textbook discourse as in Figure 6.2. The only context in which the student discourse was classified was in the researcher's classroom and this was not a formal part of the current study.

D3. The Science Emphasis

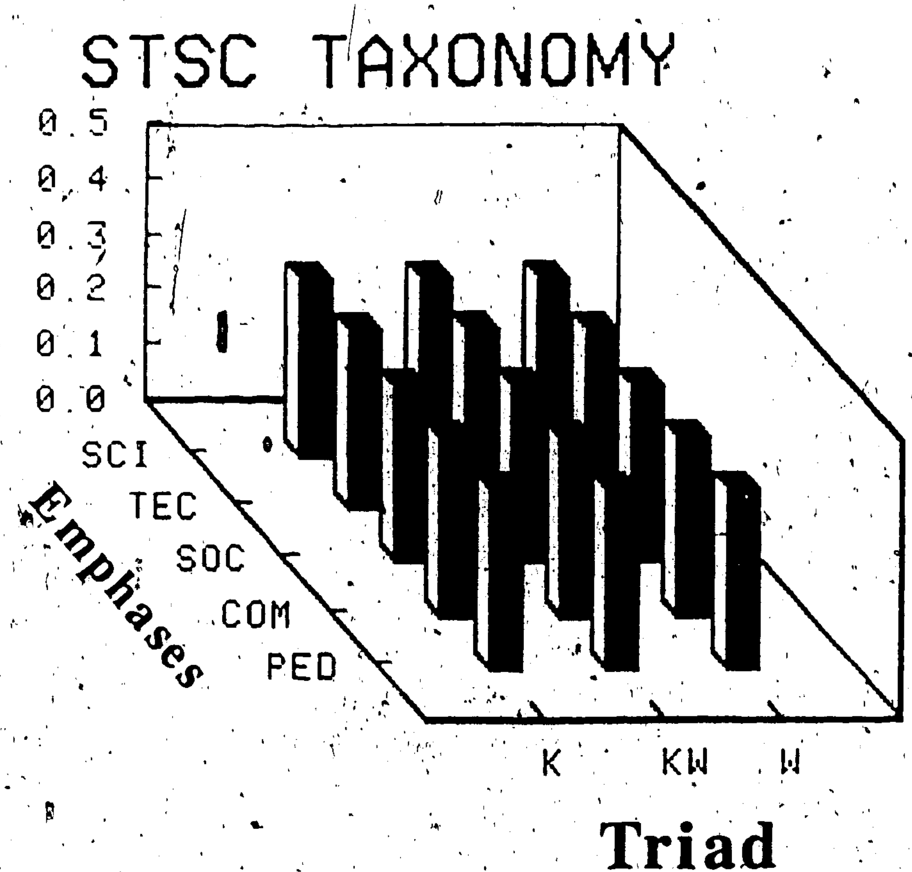
A third form of the STSC Taxonomy after the collapsed 5 x 1 STSCP curriculum emphases version and the 3 x 1 K-KW-W epistemological triad version is the combined 5 x 3 taxonomic framework. A representation of a 5 x 3 framework is presented in Figure 6.5. This framework was not useful in itself for this study, although it may be useful for paragraph count methodologies in another context. In the current study each STSCP curriculum emphasis was subcategorized into component knowledge forms. From a philosophy of science perspective theoretical and empirical knowledge categories were conceptualized within the

The Textbook Discourse Triad
Figure 6.2

The Student Discourse Triad
Figure 6.3



The Evidence for the Epistemological Triad in Units A-D
Figure 6.4



A Collapsed 5 x 3 Framework for the STSC Taxonomy
Figure 6.5

context of classifying textbook discourse. In the STSC Taxonomy, theoretical knowledge includes theories, models, theoretical definitions, and explanations and predictions from theories. Empirical knowledge includes conceptual knowledge such as laws, generalizations, and empirical definitions (Emp_L), and predictions, retrodictions and descriptions from these constructs, as well as qualitative and quantitative observations (Emp_E). The empirical category is divided into the two categories—the conceptual (Emp_L) knowledge form and the experiential (Emp_E)knowledge form—both because the category loads heavily when tallying the classifications and because of the conceptual differences between laws and observations as kinds of empirical knowledge.

As can be seen in the STSC Taxonomy portrayed in Table 6.3, two additional categories were created to acknowledge and detect the presence of an empirical—theoretical dialectic (Emp-The) in science. The presence of this Emp-The dialectic in scientific thinking was reflected in evidence found for its existence in textbook discourse classified in this study. For example, in Stage 4—the classification of discourse in the **STSC Chemistry 10** chapter on chemical reactions—2 % of discourse was classified as Emp_E-The and 10 % of textbook discourse was classified as Emp_L-The. Conceptually the Emp—The category becomes increasingly important as the degree of sophistication of the textual discourse and of epistemological arguments advances.

The scientific process category (Pro_S) was initially created because it represented a normative perspective adopted by a

Table 6.3
The STSC Taxonomy of Curricular Discourse

Emphases and Knowledge Forms	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
	The K-KW-W (Epistemological) Triad		
Science			
1. Theoretical	The K	K The W	The W
2. Empirical_E (experiential)	Emp K_E	K Emp W_E	Emp W_E
3. Empirical_E—Theoretical	Emp K_E—The K	K Emp W_E—K The W	Emp W_E—The W
4. Empirical_L (laws)	Emp K_L	K Emp W_L	Emp W_L
5. Empirical_L—Theoretical	Emp K_L—The K	K Emp W_E—K The W	Emp W_L—The W
6. Process	Pro K_S	K Pro W_S	Pro W_S
7. Epistemological	Epi K_S	K Epi W_S	Epi W_S
Technology			
8. Technological	Tec K	K Tec W	Tec W
9. Empirical	Emp K_T	K Emp W_T	Emp W_T
10. Process	Pro K_T	K Pro W_T	Pro W_T
11. Epistemological	Epi K_T	K Epi W_T	Epi W_T
Society			
12. Societal	Soc K	K Soc W	Soc W
13. National	Nat K	K Nat W	~~Nat W~~
14. Historical	His K	K His W	His W
15. Ecological	Eco K	K Eco W	Eco W
16. Reconstructional	Rec K	K Rec W	Rec W
17. Epistemological	Epi K_{SS}	K Epi W_{SS}	Epi W_{SS}
Communication			
18. Communication	Com K	K Com W	Com W
19. Epistemological	Epi K_C	K Epi W_C	Epi W_C
Pedagogy			
20. Pedagogical Purpose	Ped K_P	K Ped W_P	Ped W_P
21. Pedagogical Reference	Ped K_R	K Ped W_R	Ped W_R
22. Epistomological	Epi K_P	K Epi W_P	Epi W_P

significant part of the science education community. To differentiate independent student laboratory work from classroom problem solving and third person work, the scientific process category was defined as laboratory-context work completed by students. This was a practical, rather than an epistemological, decision. In science education research, including textbook writing, the amount of student laboratory work is often a variable of interest to science educators. This type of definition for scientific process virtually eliminates the resultant process knowledge from textbook discourse. By definition only the student can produce Pro K. This definition could be a useful distinction in future research where student discourse is included in the classification of curricular discourse. The inclusion of the Pro_S knowledge form establishes epistemological context (i.e., who created the knowledge) as a criterion for creating categories in the STSC Taxonomy.

An epistemology category (Epi) occurs in each STSCP curriculum emphasis in the STSC Taxonomy. This category allows for the classification of knowledge of an epistemological nature given to students in textbook discourse. The epistemology knowledge form addresses the validity, nature and origin of knowledge. This is the only knowledge form that appears in all five curriculum emphases. The major criterion for creating and justifying the creation of a curriculum emphasis category is the existence of distinctive epistemological content relevant to the curriculum emphasis.

The above represents a summary of the science knowledge forms in the STSC Taxonomy. Complete descriptions and status reports on each knowledge form are presented in Chapter 5. A critique of the science emphasis in relation to the total taxonomy is presented in later sections of this chapter.

D4. The Technology Emphasis

The results of the search for knowledge forms in a technology emphasis appear in the STSC Taxonomy. The number of technology knowledge forms increased from one to four during the course of the study. The technology knowledge form (Tec) includes knowledge of technological products and processes in consumer, commercial and industrial contexts. If a study required the separate information, this category could be split into products and processes. The empirical technology category (Emp_T) is similar to the empirical science category. The difference is one of context (e.g., manipulating technological devices) and personnel (e.g., engineers and technicians). A person must be directly or indirectly involved for an Emp_T classification rather than a Tec classification. The technological process category (Pro_T) involves laboratory work done by students. many of the technological process skills as defined by the STSC Taxonomy have in the past been called scientific or psychomotor skills. The perspectives that provided the criteria for this decision were STS science education and the nature of technology. Epistemological textbook content on the nature of technology (Epi_T) is fairly scarce in science textbooks. However, this research found that a fairly significant 8 % of the textbook discourse in the stoichiometry chapter of **STSC Chemistry 10** could be classified as Epi_T. The current interest in technological literacy should increase the understanding of the nature of technology by science educators and students alike. The inclusion of the Epi_T category in the Taxonomy of Curricular Discourse allows for future discourse to be described in terms of the extent of presentation of epistemological knowledge about the nature of technology.

D5. The Society Emphasis

The society emphasis is different in that it contains normative rather than epistemologically determined knowledge forms. Because of the interest in societal, national (e.g., Canadian context), historical, ecological, and reconstructional knowledge in the educational community, and because the STSC Taxonomy is a science education analytical framework, the society category does not include theoretical, empirical, and process skill knowledge forms. If the STSC Taxonomy was revised to classify social studies textbook discourse, the latter categories would likely be created. A social studies taxonomy of discourse might also list topics (e.g., energy, weapons and toxic waste) under science and technology rather than the The, Emp, and Pro knowledge forms.

D6. The Communication Emphasis

In science education, communication is an explicit consideration. In biology there is an international nomenclature system for biological species, in physics there are international unit and quantity symbols for quantities studied, and in chemistry there are international symbols for chemical formulas and chemical equations. In the current study the strong empirical support for the existence of communicational knowledge and the evidence of epistemological content in the STSC Chemistry textbook discourse led to the invention of a communication curriculum emphasis. There was no reference in the science education literature to such a curricular emphasis, although the importance of scientific communication is generally recognized (e.g., Nadeau and Desautels 1984: 17-19). In science education, systems of communication are numerous. The criteria for acceptance of these communication systems are often not made explicit to students through textbook discourse. Discussions of this nature (e.g., SI metric, significant digits, and inorganic and organic nomenclature) are often restricted to the teachers and exclude the students. The STSC Taxonomy makes the epistemology of scientific communication (Epi_C) an explicit knowledge form for study by students. The only other knowledge form created in the communication emphasis besides Epi_C was a knowledge form called communication (Com). Communication rules are classified as procedural knowledge (K Com W), resultant knowledge is classified as Com K and required use of the rules as Com W.

D7. The Pedagogy Emphasis

The amount of textbook discourse devoted to pedagogy was found to be significant, averaging about 10 % of total textbook discourse. Pedagogic instructions to students and statements of purpose are not the only pedagogic components of textbook discourse. Given, memorized, or referenced ways of knowing presented in textbook discourse are classified in the STSC Taxonomy as pedagogic ways of knowing. If a student is instructed in textual discourse to memorize the chemical formula for water, then this is classified as K Ped W_R. If the student is then in the future asked for the chemical formula for water, the way of knowing employed is Ped W_R. Interestingly, the knowledge which the student produces (i.e., H_2O) would in this context by classified as pedagogical knowledge (Ped K_R) and not as a form of scientific knowledge.

The above example makes explicit the difficulty of classifying knowledge as, for example, empirical or theoretical when the student has no empirical or theoretical basis for predicting that knowledge. The pedagogic knowledge category (Ped K_R), therefore, allows researchers and authors the practical advantage of being able to conceptualize and tally knowledge based on pedagogic convenience rather than on scientific criteria. In the STSC **Chemistry** 10 textbook, for example, students are required to list given, memorized and referenced as alternate ways of knowing to empirical and theoretical. A carry-over of this textbook discourse into the classroom discourse would make students aware of the alternate ways of knowing available to them. The **STSC Chemistry** teacher-authors report the explicit use of alternate ways of knowing as being an important pedagogic methodology in their classrooms.

D8. Summary

In summary an analytical framework of curriculum emphases, knowledge forms, and epistemological triads found in chemistry textbook discourse is communicated by the STSC Taxonomy developed in this research study. The STSC Taxonomy as presented in Table 6.3 is a flexible taxonomy that may be collapsed, expanded or revised to suit the purpose of the user as illustrated in Figure 6.5. The range of knowledge forms found in textbooks and deemed desireable in textbooks is enormous. One of the purposes of developing this analytical framework was to provide a means of conceptually organizing and evaluating the range of knowledge forms in textbook discourse. The answers to the two guiding questions for the study are provided in the structure of the STSC Taxonomy itself. Five curriculum emphases nesting twenty-two knowledge forms and accompanying epistemological triads were conceptually and empirically discovered. Five theoretical perspectives were used to establish the super and fine structure of the taxonomy. If all knowledge is theory and value laden, then these influences on the structure of the STSC Taxonomy are made explicit through the identification of the five theoretical perspectives employed in the process of developing and evaluating the STSC Taxonomy.

E. An Evaluation of Major Findings

In the above sections the problem, research design, procedures and analysis for the study are summarized and a summary report of the synthesis of the Taxonomy of Curriculum Discourse is presented. In the following section an evaluation of the findings is presented. Included in the evaluation is an attempt to judge the relative importance of the various findings as well as indicating the strengths and weaknesses of the research results relative to a set of criteria used to judge taxonomic frameworks. The criteria which are systematically introduced into the evaluation of the research results are derived from Bloom (1956) and Posner et al (1982). As reviewed in Chapter 2

Bloom lists five specific criteria by which the Taxonomy of Educational Objectives and other taxonomies should be judged. The Bloom criteria with Posner's approximate equivalent in brackets are: 1. communicability (intelligibility), 2. usefulness (a valuable domain of study), 3. suggestiveness (fruitfulness), and 4. theoretical consistency (plausibility). In addition Bloom lists a fifth criterion which is specific to taxonomies—the taxonomic ordering should reveal significant relationships among the phenomena. These criteria are invoked in the evaluation of the research results below.

The superordinate structure of curricular discourse in science eduation was classified in the current study on the basis of forms of knowledge. This knowledge form unit of analysis differentiates the STSC Taxonomy developed herein from other superordinate educational research on concepts and subconcepts (Gagne, 1968), on educational objectives (Bloom, 1956), on meaningful learning and advance organizers (Ausubel, 1968), on formal logic (Piaget, 1974), and on the hidden political curriculum (Apple, 1974). The knowledge form as a unit of classification is independent of, although not unrelated to, the unit of classification in the above mentioned superordinate structures. The subject matter and in particular textbook discourse was the focus of the current study. Writers from Schwab (1964) to White and Tisher (1986) have called for a closer examination of the subject matter content as a variable in educational research and instruction. The communication of subject matter is through curricular discourse. The structure of textbook discourse was the focus of the current study.

In order to ensure a wide range of knowledge forms within a taxonomy of curricular discourse, a wide range of curricular perspectives were adopted to guide and provide criteria for judging the development of the taxonomy. Knowledge forms were selected for inclusion into the taxonomy on the basis of criteria generated from within five theoretical perspective. Before suggesting some limitations of this approach, the fruitfulness of the approach is discussed below.

E1. The Epistemological Triad

A first major finding of the study was the presence of the K-KW-W epistemological triad. During Stage 1 of the study it was discovered that all textbook discourse could be classified as resultant knowledge (K), procedural knowledge (KW), or required action (W). This discovery provides a simple and complete structure to the STSC Taxonomy. The epistemological triad is similar to Gowin's (1984) epistemological V. However, Gowin's V is more applicable to conceptual knowledge and student discourse than to a combination of conceptual and observational knowledge and textbook discourse. The empirical existence of a full epistemological triad in textbook discourse and a conceptualization of the triad were criteria for the creation of a particular taxonomic knowledge form. The epistemological grounding of the concept of a knowledge form in an epistemological triad fulfills Bloom's criterion that a taxonomy should reveal significant relationships among phenomena. The K-KW-W triad helps to conceptualize the relationship among resultant knowledge (K), procedural knowledge (KW) and required action (W) statements in curricular discourse.

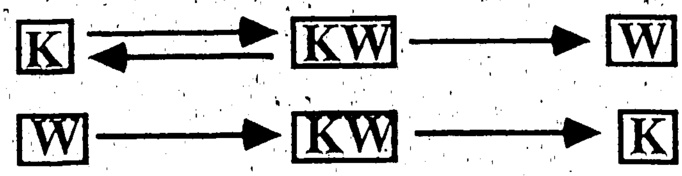
The triad is called an epistemological triad because knowledge of the triad allows a person to conceptualize the epistemological basis for producing and accepting knowledge. The triad conceptualizes the basis for answering the often asked question, "How am I supposed to know that?" If the question is answered very specifically (e.g., "You count the number of lone pair and the number of bonding electrons."), then the answer is the presentation of theoretical knowledge. However, if the answer to the question is more general (e.g., "You use a theoretical way of knowing."), then epistemological knowledge is being presented. The resultant knowledge (K) or the procedural knowledge (KW) is often necessary in addition to the question (W) in order to classify the knowledge form.

The current "usefulness" of the triad can be demonstrated by returning to the question of how a student is to know something. Alternative ways of knowing are often presented in a textbook or classroom but the grounding of knowledge forms in epistemological triads provides a conceptual and language base for communicating among students and teachers and between students and teachers. To refer to ways of knowing as empirical, theoretical, referenced or memorized is not only pedagogically efficient when answering students questions, but the teacher is also modeling epistemological behavior for the students. The conscious use of the triad for writing textbook discourse for presenting classroom discourse, and for receiving discourse has pedagogic potential at all levels of schooling.

E2. The Empirical/Theoretical Dyad

The second major finding of the study was the empirical/theoretical (Emp/The) dyad. The Emp/The dyad and the K-KW-W triad are illustrated in Figure 6.7 and Figure 6.6, respectively. Philosophers of science, popular and serious science writers and science educators have overtly and covertly, through the discourse of science, indicated the existence of an empirical—theoretical dialectic in the production of scientific knowledge. In the science textbook discourse classified in the current study, the split of empirical and theoretical knowledge forms was evident. As a result the original conceptualization of these two (Emp and The) knowledge forms during Stage 1 of the study was strongly supported by the evidence gathered.

By Bloom's criteria for judging taxonomies and taxonomic elements the Emp/The dyad may be viewed as being successful. In terms of "usefulness" and "communicability" the Emp/The dyad has been successfully integrated into the everyday textual and classroom discourse for STSC Chemistry students in Grade 10 through Grade 12. Empirical and theoretical are used to describe kinds of knowledge and ways of knowing. These terms and the distinctions between them seem to be intelligible to high school students. As witnessed in the classroom there seems to be a degree of epistemological harmony between the concept of the Emp/The dyad and the way that students like



The Epistemological Triads in
Textual and Student Discourse, Respectively
Figure 6.6

Empirical → Theoretical

Theoretical → Empirical

The Empirical/Theoretical Dyads in Curricular Discourse
Figure 6.7

Empirical ←→ Theoretical

The Empirical—Theoretical Dialectic in Curricular Discourse
Figure 6.8

to categorize how they know something. To know something empirically or theoretically in addition to memorizing and/or "referencing" knowledge seems to be intellectually satisfying to students, and one might add, also pedagogically satisfying to teachers. Formal research is lacking on the use of the Emp/The dyad in the classroom but Bloom's taxonomic criteria of "suggestiveness" and the "revelation of significant relationships" seem to be amply met by these elements in the STSC Taxonomy.

E3. The Empirical—Theoretical Dialectic

The empirical-theoretical (Emp—The) dialectic as illustrated in Figure 6.8 was conceived during Stage 6 of the study. The presentation of empirical and theoretical knowledge (Emp K_E—The K) within a chemical equation, and more significantly the use of empirical and theoretical procedural knowledge (K Emp W_L—K The W) simultaneously to write a chemical equation are examples of the Emp—The dialectic in science textbook discourse. Two empirical-theoretical dialectic categories were created during the classification of discourse in Unit C—"Communicating and Predicting Chemical Reactions". One dialectic involves the interaction of experiential or experimental empirical knowledge and theoretical knowledge (e.g., "The evidence of . . . led to the development of the . . . theory."). The second dialectic involves the interaction of generalizations and laws as empirical constructs and theories as theoretical constructs (e.g., "The Mendeleyev Periodic Law can be explained by the Bohr Atomic Theory".)

Five and ten percent of the discourse in Unit C of STSC Chemistry 10 was classified as Emp_E—The and Emp_L—The, respectively. The rule established was that in order to be classified in the Emp—The dialectic categories the empirical and theoretical knowledge had to be presented in the same sentence. A chemical equation expressed in international symbols qualifies as a sentence when translated by the reader.

The satisfaction associated with the addition of the two Emp—The dialectic knowledge forms to the STSC Taxonomy is that the separation of empirical and theoretical knowledge forms in science has a feeling of artificiality. One way to perpetuate the artificial character of the empirical-theoretical relationship in textual discourse is to deny the existence of the dialectic relation in a taxonomy of science discourse. Since one of the objectives of the current study was to broaden the consciousness of science educators as to the potential range of knowledge forms available for presentation to students, the denial of a knowledge form that helps to define the nature of science would be reductionist. One has to be aware that a description of anything is less than the "real thing". Since a taxonomy is a descriptive device reduction will occur, but a conscious effort can be made to minimize the effect. The Emp—The dialectic categories serve as a "flag" to warn users of the limitations of a taxonomy as a form of conceptual knowledge.

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to the relevant community (e.g., international, precise, and simple). A pedagogy curriculum emphasis lets students in on what is being done to them. Epistemological (Epi_P) content relates to how pedagogic knowledge comes to be accepted and how pedagogy assists the acceptance of scientific and technological knowledge in the relevant community. Pedagogic knowledge is classified in the **STSC-Chemistry** discourse researched as given, memorized or referenced.

The existence of epistemological content in science textbooks has been recognized for a considerable period of time. In older textbooks Chapter 1 would deal with aspects of the nature of science. What is different about the discovery made in the current study is that a variety of kinds of epistemological content was found in the **STSC Chemistry** textbook discourse. The epistemological content category not only served as a criterion for creating and defining the five curriculum emphases in the taxonomy, the Epi content served as a thread that tied the whole taxonomy together. The Epi knowledge form in each curriculum emphasis made the structure more logical and "communicable" (Bloom, 1956). It also "revealed significant relationships" among the curriculum emphases and provided a definition for curriculum emphases in the context of curricular discourse.

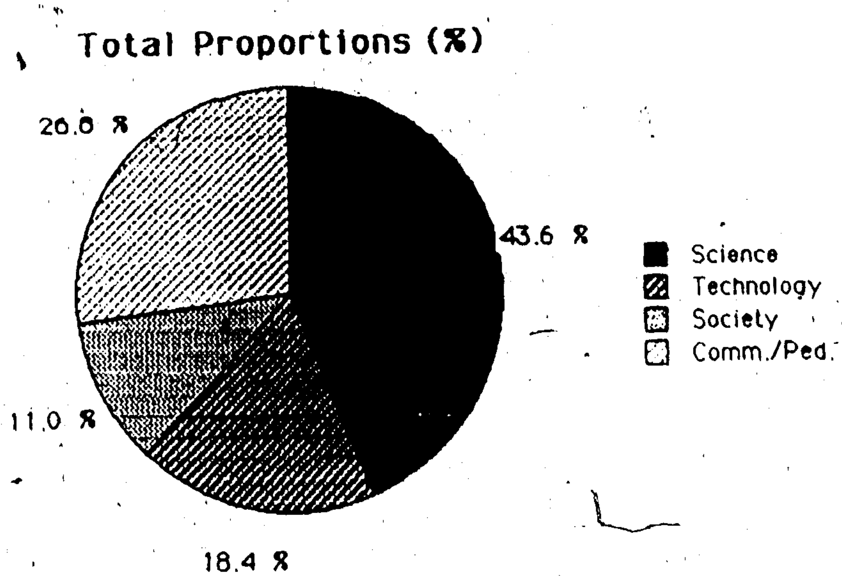
The kinds of curriculum emphases discovered by classifying textbook discourse are somewhat different than those found by others such as Roberts (1982) while classifying science education objectives and policy statements. Roberts defined curriculum emphases in science education as a coherent set of messages to the student about science (rather than within science). Roberts' emphases provide answers to the student question, "Why am I learning this?" The curriculum emphases in the Taxonomy of Curricular Discourse provide answers to the student questions, "How do I know that?" and "Why should I accept that as knowledge?" This emphasizes again that the unit of superordinate structure in the STSC Taxonomy is the subject matter knowledge forms found in curricular discourse and is not objectives, concepts, formal logic, or political messages. That all of these are valuable domains of study is witnessed by the considerable amount of activity and the large followings that each domain has.

E5. An Alternative Definition for STS Science Education

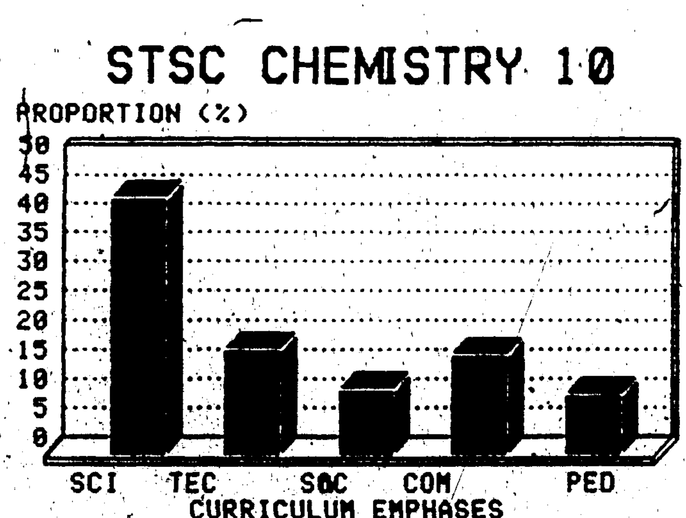
A fourth major finding of the study was the definition of STS (science, technology and society) science education provided by the STSC Taxonomy framework. The integration of the STS theoretical perspective with the perspectives of normative perspectives, curriculum emphases, epistemology and practical inquiry led to a definition of STS science education in terms of knowledge forms found in each category. The current research also showed, not unexpectedly, that STS cannot by itself define a curriculum. The integration of normative perspectives (e.g., empirical, theoretical, process, and epistemological perspectives) held by various science education interest groups into a framework of STS curriculum emphases may be viewed as a advance for the STS movement. The STS movement has a potential for synthesis and for uniting the science education community, but frameworks for this synthesis have to this point been subject matter (e.g., chemistry or general science) or concept specific. The Taxonomy of Curricular Discourse represents one alternative framework from which to describe and/or guide STS science education in the general terms of <u>knowledge forms</u> (see the STSC Taxonomy framework in Table 6.3).

The definition of STS as represented by the STSC Taxonomy provides a relatively equal position to science, technology and society emphases. More common within the literature (e.g., <u>S-STS Reporter</u>, 1987-09) is the S-ST-STS (science—science and technology—science, technology and society) definition where science dominates. In the STSC Taxonomy technology (Tec), empirical technology (Emp_T), technological process (Pro_T), and epistemology of technology (Epi_T) make a strong group of knowledge forms which received considerable "action" when the **STSC Chemistry** discourse was classified. Figure 6.9 communicates the proportions of discourse distributed over the five taxonomic curriculum emphases in the four units of the Grade 10 **STSC Chemistry** textbook.

Figure 6.9 not only communicates the strong support for separate technology and society emphases found in the **STSC Chemistry** discourse, but also indicates that two additional emphases accounting for nearly twenty percent of the textual discourse were present. The communication and pedagogy emphases are often implicit emphases. The Taxonomy of Curricular Discourse (see Table 6.3) provides these significant emphases with equal status and an equal opportunity to be recognized in curricular discourse.



The Distribution of STSC/P Emphases in Units A-D
Figure 6.9



The Distribution of STSCP Emphases in Units A-D
Figure 6.10

Using Bloom's criteria for evaluating taxonomic frameworks, the definition of STS as provided by the STSC Taxonomy does "reveal significant relationships" among the elements of the taxonomy. Each of the STS elements of the taxonomy is related by the common thread of epistemological knowledge forms. This tends to provide a definition of each of these elements that is "consistent with theoretical views" in all three fields of study--science, technology and society studies. In this sense the STSC Taxonomy has a potential for being "useful" over a wider range of studies and provides a concept and language base for "communication" that may allow the three STS fields to decrease the Kuhnian "talking past each other" phenomenon.

E6. Pedagogic Knowledge

During the evolution of the Taxonomy of Curricular Discourse in this study a "pedagogical reference" (Ped_R) knowledge form was created to classify memorized, given and referenced knowledge. This development may help to clarify the difficulty that science educators have in communicating the difference between memorizing some knowledge and having an empirical or theoretical basis for the knowledge. For example, the chemical formula for water may be given, memorized or referenced from a book or the chemical may be predicted empirically or theoretically as communicated in Figure 6.11.

Informal evidence from the STSC Chemistry project indicates that the students find this distinction helpful for knowing how they are supposed to know something. From this practical classroom perspective and from the epistemological perspective of having students question

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E7. The Knowledge Form Tetrad

A knowledge form tetrad of theoretical, empirical, process and epistemological knowledge forms has started to emerge from the analysis of the evidence gathered from the classification of textbook discourse in the current study. The first tetrad was discovered in the early stages of the study and helped to define a science curriculum emphasis. This discovery triangulated with the STS science education and curriculum emphases perspectives in the creation of a science emphasis. Each of these guiding theoretical perspectives supported the other in pointing to the formation of a science discourse emphasis containing a knowledge form tetrad (The_S, Emp_S, Pro_S and Epi_S).

The science tetrad in Figure 6.12 was "suggestive" (to use Bloom's term) of tetrads in other discourse emphases. A similar knowledge form tetrad was eventually created in the technology emphasis which originally was composed of only one and then two elements—technology (Tec) and then Tec and epistemology of technology (Epi_T). The "final" technology tetrad includes technology (Tec), empirical technology (Emp_T), technological process (Pro_T), and epistemology of technology (Epi_T). Figure 6.13 communicates the technology knowledge form tetrad.

Knowledge forms tetrads were not empirically or conceptually obvious within the other three curricular discourse emphases (e.g., society, communication and pedagogy). The discourse classified did not yield empirical support for a tetrad of knowledge forms and from a science education perspective the conceptualization of tetrads in these emphases was not logically established until after the completion of the study. In retrospect, however, knowledge form tetrads for the other emphases could have been conceptualized and tested against textbook discourse. For example, the society emphasis could be conceptualized as being composed of a tetrad of society (Soc), empirical (Emp_{SS}), process ($Pros_{S}$) and epistemological (Epi_{SS}) knowledge forms. Communication and pedagogy emphases might also contain communication and pedagogy conceptual knowledge forms plus empirical, process and epistemology forms.

The <u>conceptual</u> category has to be defined more precisely in each case but it could, for example, contain theories (The), laws and generalizations (Emp_L) in the science emphasis, technologically designed products and process in the technology emphasis, societal structures in the society emphasis, communication concepts and rules in the communication emphasis, and pedagogic approaches and generalizations in the pedagogy emphasis. These conceptual knowledge forms in each emphasis would have to be differentiated from the empirical, process and epistemological forms of knowledge. The empirical forms would include "factual" knowledge produced by a third person, while the process forms would contain first person knowledge. The epistemological knowledge forms in all five curricular emphases have been described in Chapter 5 and example discourse is presented there.

The potential of generalizing the tetrad to all curriculum emphases is that discourse in other school subjects, such as electronics, social studies and English, could be classified. The danger in such a move is that the taxonomy might become too general to be "useful" in a specific area of discourse or too difficult for a subject matter specialist to comprehend. In the latter case, for example, a science specialist might have difficulty discerning conceptual, from empirical, process, and epistemological knowledge in a society or a communication emphasis (although maybe not in a technology or a pedagogy emphasis).

E8. Normative Perspectives

From an epistemological perspective grounded in the philosophy of science, the epistemological triads, the empirical/theoretical (conceptual) dyads, and the knowledge form tetrads are powerful influences on the superordinate and fine structure of the STSC Taxonomy. However, in a Kuhnian sense normative influences also have to be considered. The Taxonomy of Curricular Discourse was originally grounded in a set of ten normative perspectives identified from within the science education community (Kass and Jenkins, 1982 and 1986). The carry-over of historical, national, ecological and reconstructional knowledge forms into the society emphasis of the "final" structure of the STSC Taxonomy is evidence of this continued influence. In the science education community there is significant support for the inclusion of the aforementioned knowledge forms in science curricula. Whether these knowledge forms are epistemologically driven with epistemological triads or whether they fit an empirical/conceptual dyad or a knowledge form tetrad is not important to these interest groups.

Other criteria including affective objectives are involved in including normative knowledge forms in the STSC Taxonomy. Science educators, to varying degrees, want historical, national (or international), ecological and reconstructional knowledge to be included in science curricular discourse. These same science educators also would like to have a method of determining the amount of or a method of bringing to consciousness these kinds of knowledge in curricular discourse. The current version of the Taxonomy of Curricular Discourse is one way of fulfilling this need.

E9. The Practical

Perhaps the most important result in this research was the overall practical thrust of the study. The practical inquiry model of research employed kept the research from straying too far from the criterion of "usefulness". The research was set in the practical context of the writing and evaluating of the STSC **Chemistry** textbook by the members of The Author Group. This research has not documented the processes involved in the classroom-in-use, the epistemologies-in-use, the theoretical perspectives-in-use, and the restricted deliberative inquiry that accompanied the research-practice dialectic in the current study. Nevertheless, categories of knowledge were created that had practical importance, if not epistemological importance. Process knowledge or Canadian content or ecological knowledge were knowledge forms of interest to the science-education community, and for practical reasons they were included in the STS Taxonomy.

This integration of practical, epistemological, STS, and curriculum emphases as theoretical perspectives within one analytical framework is one example of what might be done with the conceptual analysis methodology in educational research. When conceptual analysis contains epistemology as a theoretical perspective an opportunity also arises for the analytical framework to "wrap around on itself". For example, in the current study the attention paid to theoretical, empirical and epistemological knowledge forms helped to develop a research methodology that included each of these components. The empirical-theoretical dialectic within the context of this study is of particular interest. The mutual benefits derived from the dialectic of the "practical world" of the teacher and author with the "conceptual world" of the researcher are immeasurable.

E10. Summary of the Evaluation

Because of the scope of the current study the major findings are numerous and diverse. The theoretical perspectives (systematic conceptualizations) used to guide the study grew from one of normative perspectives to four additional perspectives including curriculum emphases, STS science education, epistemology and practical inquiry. The diversity of theoretical perspectives was protection against a narrowly conceived or inflexible taxonomy of curricular discourse. As is appropriate with all evaluations, the community at large will make the final judgement.

F. Evaluation of the Research Methodology

The research methodology in the current study was one of conceptual analysis (Roberts and Russell, 1975; Mahung, 1980). According to Mahung, the methodology involves three steps—1. the identification of a "theoretical perspective" or "systematic conceptualization" on one of the four commonplaces of curriculum, 2. the development of an "analytical framework" and 3. the "application" of the analytical framework for the analysis of some aspect curriculum. In the case of the current study five "theoretical perspectives" are employed, the analytical framework is a taxonomy of curricular discourse and the application is to science textbook discourse within the subject matter commonplace of curriculum.

The methodology of conceptual analysis served this research study well. The number of theoretical perspectives was increased to five and these perspectives served as useful guides in a complex and lengthy research study. The base of philosophical analysis from which the methodology of conceptual analysis was built by Roberts and Russell (1975) also suited the current study. Concepts, language and methods used by philosophers of science were used to develop the STSC Taxonomy. There was also an attempt to use these same concepts, language and methods to write this research report. On a more modest scale **STSC Chemistry** students are being taught these same approaches. Therein lies some exciting possibilities.

The specific application of conceptual analysis in the current study was to develop the analytical framework. The application of the analytical framework was not to evaluate or analyze curriculum materials as was the case for Mahung (1980) and Kilbourn (1971). The application of the taxonomy to textbook discourse were <u>to evaluate the taxonomy itself</u> in dialectic fashion. The taxonomy was continually evaluated in terms of its ability to accurately describe science textbook discourse. This was in Schwabian terms a "practical evaluation" of an analytical framework that was built using "the arts of the eclectic". The variety of empirical and conceptual support for the taxonomic framework that was developed reflects back well on the research methodology employed.

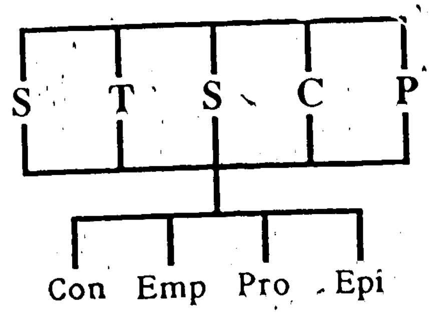
The limitations on the generalizability of the results from the study apply mainly to the restrictions applied to make the research manageable. Knowledge forms in science textbook discourse was chosen as the domain of study. The **STSC Chemistry** textbook was chosen in order to involve a research and practice dialectic between myself as researcher and as a teacher-author of the **STSC Chemistry** textbook. The mutual benefits received from this arrangement are immeasureable, but most certainly confirm Schwab's call for more attention to the research-practice interface in education. As discussed below the removal of restrictions on the application of the Taxonomy of Curricular Discourse will require replication of the study with other textbooks and expansion of the application to other kinds of curricular discourse such as classroom and staff room discourse.

G. Applications and Recommendations

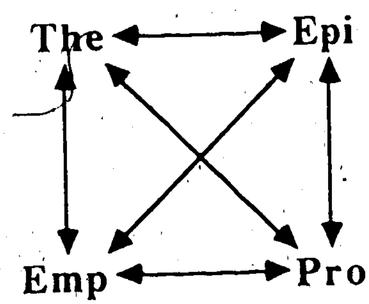
The research results include more than the visible product—the STSC Taxonomy. Therefore the recommendations for application of the results and the recommendations for further research presented below broadly follow the five theoretical perspectives which have guided this study—normative perspectives, curriculum emphases, STS science education, practical, inquiry and epistemology. Some of the recommendations are integrative of these theoretical perspectives, while other recommendations treat the theoretical perspectives separately.

1. From an epistemological perspective a research study might be conducted to investigate if the STSC Taxonomy can be made more symmetrical by having the same knowledge forms in all five STSCP curriculum emphases as communicated in Figure 6.14 and Table 6.4. Also of epistemological interest is the extent of interaction among the knowledge forms in this tetrad. The current study found two interactive categories, Emp_E-The, and Emp_L-The, and started experimenting with a third, Emp_T-The. What other kinds of interactions are appropriate in order that textbook discourse may portray a more authentic view of science and technology? What kinds of interactions are epistemologically possible and pedagogically practical? Possible interactions are illustrated in Figure 6.15.

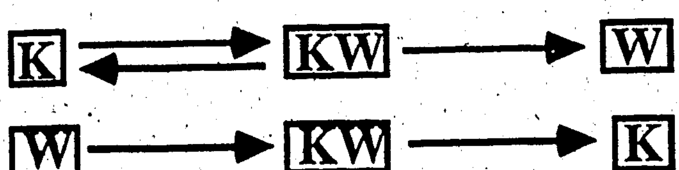
2. From an epistemological perspective further research might be conducted on the K-KW-W epistemological triad. No attempt was made



The Knowledge-Forms Tetrad
Figure 6.14



Interactions Within the Knowledge-Forms Tetrad
Figure 6.15



The Textbook Discourse Triad and
the Student Discourse Triad, Respectively
Figure 6.16

in this research to study the sequencing of K-KW-W triads within textbook discourse. This researcher has seen evidence in textbook discourse of interchanging between knowledge forms (e.g., theoretical and empirical) within K-KW-W sequences. By identifying K-KW-W triads and manipulating this variable, further research may be able to tell educators more about optimum sequencing.

3. Another use for the epistemological triad may be as a controlled variable in, for example, cognitive preference or cognitive dissonance studies. This recommendation not only holds for the epistemological triad but also for knowledge forms. It seems likely that different students prefer different ways of knowing and different kinds of knowledge. The STSC Taxonomy in current or revised form may assist researchers in controlling or systematically manipulating the textbook content variable.

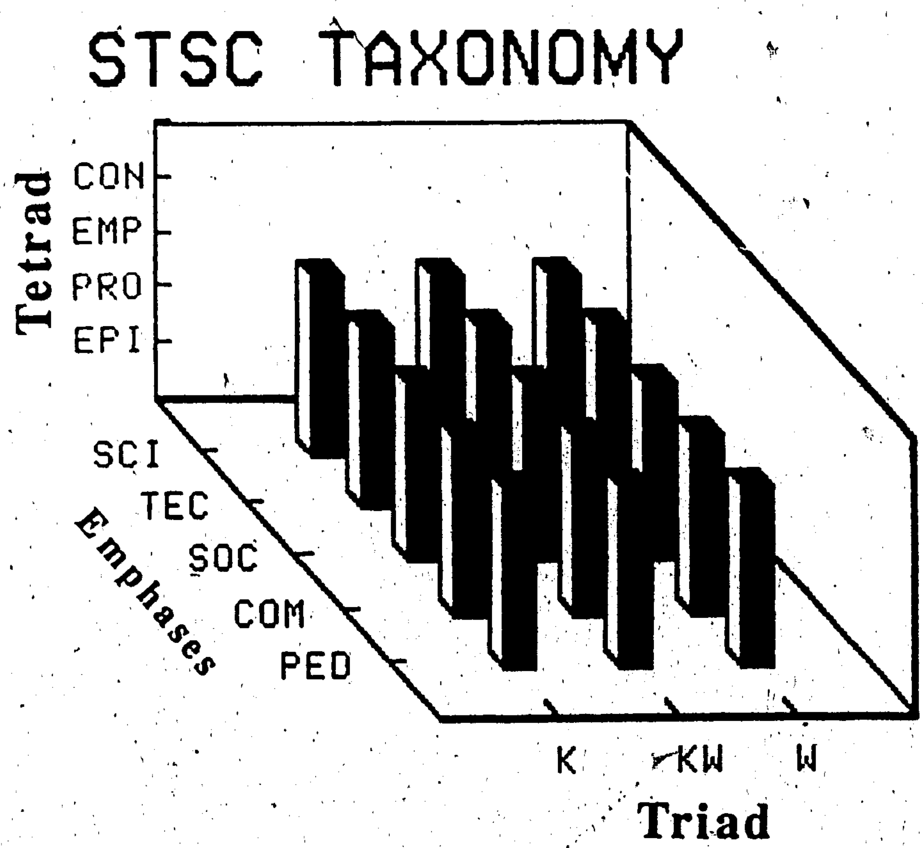
4. This study has been restricted to classifying textbook discourse and has ignored the written responses of students. Of interest would be research to compare the intended way of knowing resulting from a particular K-KW-W triad in textbook discourse with the actual W-KW-K triad when students are responding to questions in textbooks. The triads might be useful for studies of student misconceptions or preconceptions or mistakes or for studies of alternate ways of knowing used by students. Figure 6.16 illustrates the two triads—the textbook discourse triad and the student response triad, respectively.

5. Adjustments to the STSC Taxonomy could provide evidence of the extent of independence of laboratory work. For example, a K Pro W-Pro W category could provide a tally of the number of separate statements in a section of textbook discourse that provide procedural knowledge along with required action. This could be compared to the number of separate Pro W tallies to get a percentage of independent laboratory work required of the student. Currently in the STSC Taxonomy a K Pro W-Pro W statement is tallied separately as K Pro W and Pro W and a valid measure of dependence cannot be obtained.

6. The epistemological preferences of curriculum emphases and knowledge forms by textbook authors, test writers, lecturers, student teachers and classroom teachers could be determined by using the STSC Taxonomy and the results could be provided as inservice feedback.

7. Classroom (verbal) discourse could be monitored or studied using an adapted form of the STSC Taxonomy. The matching of teacher input triads with student output triads could allow for the conceptual analysis of classroom discourse from a particular theoretical perspective. Classroom discourse could also be analyzed for evidence of epistemological content and qualifiers. Epistemological qualifiers are phrases, such as "According to . . .." or "The evidence suggests that . . ..", that make explicit to the students the epistemological basis of scientific knowledge.

In summary the use and future development of the STSC Taxonomy must be accompanied by a set of theoretical perspectives to guide the revisions to this analytical framework. The development and use of any analytic framework is theory and value laden. A final recommendation of the researcher is that, in order to maintain the spirit in which the taxonomy was developed, a multi-perspective approach to the use of the STSC Taxonomy of Curricular Discourse as represented in Figure 6.17 be taken by any user. The "final" form of the taxonomy is presented in Table 6.4.



A Multi-Perspective View of Curricular Discourse
Figure 6.17

Table 6.4
A General STSC Taxonomy of Curricular Discourse

Emphasis Pentad and Knowledge Form Tetrads	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
	The K-KW-W (Epistemological) Triad		
Science			
1. Conceptual	Con K_S	K Con W_S	Con W_S
2. Empirical	Emp K_S	K Emp W_S	Emp W_S
3. Process	Pro K_S	K Pro W_S	Pro W_S
4. Epistemological	Epi K_S	K Epi W_S	Epi W_S
Technology			
5. Conceptual	Con K_T	K Con W_T	Con W_T
6. Empirical	Emp K_T	K Emp W_T	Emp W_T
7. Process	Pro K_T	K Pro W_T	Pro W_T
8. Epistemological	Epi K_T	K Epi W_T	Epi W_T
Society			
9. Conceptual	Con K_{SS}	K Con W_{SS}	Con W_{SS}
10. Empirical	Emp K_{SS}	K Emp W_{SS}	Emp W_{SS}
11. Process	Pro K_{SS}	K Pro W_{SS}	Pro W_{SS}
12. Epistemological	Epi K_{SS}	K Epi W_{SS}	Epi W_{SS}
Communication			
13. Conceptual	Con K_C	K Con W_C	Con W_C
14. Empirical	Emp K_C	K Emp W_C	Emp W_C
15. Process	Pro K_C	K Pro W_C	Pro W_C
16. Epistemological	Epi K_C	K Epi W_C	Epi W_C
Pedagogy			
17. Conceptual	Con K_P	K Con W_P	Con W_P
18. Empirical	Emp K_P	K Emp W_P	Emp W_P
19. Process	Pro K_P	K Pro W_P	Pro W_P
20. Epistomological	Epi K_P	K Epi W_P	Epi W_P

* Conceptual (Con) refers to resultant and procedural knowledge derived from theoretical constructs (e.g., theories) and empirical constructs (e.g., laws).

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APPENDIX A

Custom Tailoring the Chemistry Curriculum to the Culture

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Harry Ainlay Comprehensive
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Canada

Chemistry curricula have always been tailored to a culture and always will be. Chemistry curricula like all other forms of knowledge are socially constructed. The values, ideals and aspirations of the social group constructing curricula are just as important for determining "what is knowledge" for hight school chemistry curricula as for high school social studies. As chemistry teachers, our past (cultural) experiences in chemistry classrooms determine what we teach and how we teach. Too often our experiences have been restricted to theoretical knowledge only, and specifically to theoretical knowledge of interest to the university of our training. The narrow theoretical interests of a university are not necessarily the interests of a high school, a local region, a country, or our planet. A restricted model within the fields of science or curriculum must necessarily carry with it a list of assumptions. Examples of our curricular assumptions and how curricula can be modified to serve a less restricted culture will be provided.

JENKINS

Custom Tailoring the Chemistry Curriculum to the Culture: A Perspective from Canada

"Custom tailoring" is the process of "manufacturing, or dealing in, things made to order" (Webster, 1961). For this paper on custom tailoring the chemistry curriculum to the culture, the client for the custom tailoring is assumed to be our culture — our "particular stage of advancement in civilization" (Webster, 1961). Supposedly chemistry curricula today are "made to order" for our culture(s). Just who is doing the "ordering" is difficult to determine. For example, who would "order" each of the different curricula which are represented by the following questions?

Q1. Write a balanced chemical equation for the electrolytic decomposition of aqueous sodium chloride.

A1. $2NaCl(aq) + 2HOH(l) + \text{energy} \rightarrow H_2(g) + Cl_2(g) + 2NaOH(aq)$

Q2. The electrolytic decomposition of solution-mined sodium chloride is conducted industrially in chlor-alkyli plants in eight of the provinces in Canada (everywhere but Prince Edward Island and Newfoundland). Write a balanced chemical equation for the chemical reaction that occurs at these chlor-alkyli plants.

A2. Same answer as in Q1 above.

Although it would be tempting to try to make a case for there being country-wide perspectives of chemistry curricula, a consideration of the different interest groups (sub-cultures) that exist within all countries would probably be more productive. When the question is asked as to whose interest is served by chemistry curricula, there is usually an immediate shying away from the question as if a sinister plot had been suggested. This is especially true when we as chemistry educators start asking the question "In whose interest?" and start getting back the answer "In our interest." We seem to have a desire to clone ourselves. In chemistry education, we may identify a number of interest groups to which we may simultaneously belong; for example, 1. the "theorists," 2. the "empiricists," 3. the "applicists," 4. the "processists," 5. the "pedagogists," 6. the "reconstructionists," 7. the "existentialists," 8. the "epistemologists," and 9. the "parochialists." Each of these groups has its own particular image of a chemistry curriculum. The flipping back and forth from one camp to another camp makes it very difficult for educators to understand one another. As a result we often tend to "talk past each other" (Kuhn, 1970) for a period before anything meaningful is accomplished. Anyone who has been on a week-long chemistry education conference can certainly attest to the feeling of frustration that accompanies this "talking past."

The particular sub-cultures to which each of us belongs will depend upon our general cultural heritage, our chemistry-education heritage, our personal chemistry-education experiences, and our stage of conscious growth as chemistry educators. Since the latter

The particular sub-cultures to which each of us belongs will depend upon our general cultural heritage, our chemistry education heritage, our personal chemistry education experiences, and our stage of conscious growth as chemistry educators.

two (experiences and conscious growth) are something that we can all do something about, the emphasis in this paper will be placed there. However, before providing examples of experiences and growth as determinants of chemistry curricula, it is necessary to define the terms used above to classify the various chemistry-education subcultures.

The theorist is the chemistry-educator who demands that rigor, academic excellence and high level knowledge be emphasized in chemistry curricula.

The *"theorist"* is the chemistry-educator who demands that rigor, academic excellence, and high level knowledge should be emphasized in chemistry curricula. In the early 1960's this emphasis on theoretical knowledge and on the structure of a discipline (Schwab, 1962) gave rise to a concept of curriculum which has been referred to as "academic rationalism" (Eisner and Vallance, 1974). This theoretic view of chemistry curricula generally also takes the position in the nature-of-science debates that scientific objectivity can lead to final answers about nature. The theoretic view "sees" all theoretical knowledge as being equal and that, wherever you reside on Earth or in our universe, chemistry curricula (like chemistry knowledge and research) should be the same. (This view will be contrasted below with those of, for example, the applicists, pedagogists, epistemologists and reconstructionists.)

The *"empiricists"* argue that the emphasis in chemistry curricula should be placed on experiences and experimental work. "Action-learning" and "practical" are terms often employed by empiricists. "Practical" in this sense does not mean applied; "practical" means doing, experiencing and observing. Practical-theoretical curricula are just as acceptable to the empiricist as are practical-application curricula. For example, the empiricist does not really care whether the student goes to the laboratory to do a 'theoretical' sodium hydroxide-hydrochloric acid titration or to do an 'applied' sodium hydroxide-aspirin or household ammonia-hydrochloric acid titration. Also included among the empiricists might be those who would emphasize descriptive chemistry and also some who are followers of Piaget.

The *"applicist"* values applied knowledge, although not necessarily the practice of applying knowledge. The applicist wants the student to realize that there are uses (i.e. applications) associated with theoretical knowledge. Theoretical knowledge may or may not accompany the applicists' applied knowledge in the curriculum. Many of the pre-1960 chemistry textbooks emphasized applied knowledge, whereas in the 1960's textbooks tended to emphasize theoretical knowledge.

The *"processists"* also had their days in the sun during the 1960's. Actually the "emphases" (Roberts, 1980) as they emerged during the 1960's first went to the processes of science and of scientific enquiry and secondly to theoretical scientific knowledge. At the high school level, the major contribution resulting from this was the improvement in the level and quantity of theoretical knowledge and of laboratory work. In the view of many processists, the 1960's programs did not succeed very well in transmitting to students (or teachers) the scientific way of knowing. The success of the processists in lower-level (in terms of theory) courses and at the lower grade levels (e.g., SAPA and SCIS) has sustained the movement. Whether the processists will again become leaders at the high school level will probably depend upon a political coalition with the empiricists and epistemologists (see below).

The *"pedagogists"*, were among those who were responsible for the failures of the empirical and the process movements. The pedagogists' emphasis is on efficiency of learning. Teaching through experiences or by enquiry requires more time than teaching theoretical or applied knowledge. In this sense pedagogists determine what should not be taught. Besides process skills and experiences, the pedagogists either eliminated applied knowledge entirely (because of the "lack of time to find suitable applications to match with theoretical knowledge in the curriculum") or they eliminated some very theoretical topics (because these topics are "too abstract for most students in high school to learn"). On the additive side, the pedagogists added pedagogical models and theories to the curriculum either to supplement or replace "scientific" or "historical" models and theories. The pedagogists have never been officially recognized as a pressure group which determines the curriculum (Schwab, 1974) but, even though they are largely silent, they probably have the most powerful influence on curricula of any group (Fullan and Pomfret, 1977 and Roberts, 1980).

The "*reconstructionists*" would include such science educators as latterday Bruner (1971) and Schwab (1974), and Kilbourn (1980). Both Bruner and Schwab dramatically changed their science education emphases during the period between 1962 and 1971. By the 1970's, they were both calling for an 'action-learning' component of science education that would or could be carried on outside the school walls. To some extent their intent seemed to be social reconstruction. Kilbourn, by comparison, criticizes the mechanistic world view which is held by some science educators and is hidden in a number of chemistry curricula, and suggests that we at least be aware of our own world views.

The critical theorists among the reconstructionists demand that we ask the question "What is being taught besides chemistry, when chemistry is taught?" For example, what are we saying covertly to the girls, the poor, the gifted, and the majority and minority races in each country? Are we saying covertly that science is right, that science has the answers, that science is the only way of knowing (or seeing), that science is for boys, or that academic success in science is good (morally good)? The reconstructionists are asking, "In whose interest is this chemistry curriculum constructed?". They are asking us to examine our chemistry textbooks, and to ask the question "What is this textbook trying to do to or for the student?" This type of question is generally easier to answer when one looks outside one's own field of study. For example, we as science educators are more likely to identify the interests of business education authors as supporting a country's economic system; and of household education as supporting a country's social system.

The "*existentialists*" value relevant knowledge, self-knowledge, self-expression and self-actualization. The personal meanings which the students bring to and take away from the classroom are important to the existentialist. The emphasis on

Teaching through experiences or by inquiry requires more time than teaching theoretical or applied knowledge.

personal relevance appeared in the early 1970's in North America. This emphasis has been integrated with other emphases, such as applied and descriptive chemistry, and has been espoused in particular by low-level chemistry courses which attempt to attract more students to chemistry.

The *"epistemologists"* (including the sociology-of-knowledge types) form along with the reconstructionists, the most recent interest group to appear or reappear on the chemistry education scene. From general books with titles like *The Social Construction of Reality* (Berger and Luckman, 1966), we have gone to science-epistemology books like *The Structure of Scientific Revolutions* (Kuhn, 1970), and *The Dancing Wu Li Masters* (Zukav, 1979). Each of these books emphasizes that science is not the objective enterprise that we have pretended it to be. As Zukav (1979:30) writes:

> To observe something objectively means to see it as it would appear to an observer who has no prejudices about what he observes. The problem that went unnoticed for three centuries [i.e., until the "new physics" (e.g., quantum mechanics)] is that a person who carries such an atitude certainly is prejudiced. His prejudice is to be "objective" that is, to be without a preformed opinion. In fact, it is impossible to be without an opinion. An opinion is a point of view. The point of view that we can be without a point of view is a point of view.

Zukav's statement applies equally well to chemistry and to chemistry education. Indeed, the present attempts at classifying the standpoints held by chemistry educators should help us to recognize our own points of view.

The *"parochialists"* (whether in a national or provincial sense) are the only sub-culture group among chemistry educators that gets accused of having the only cultural influence on chemistry curricula. Their accusers forget, however, that no position taken by anyone on any aspect of chemistry or chemistry education really reflects a position of neutrality (see Zukav's quote above).

Each of the sub-cultures previously listed values something different in chemistry education, as is summarized in Table 1.

Table 1
A Classification of Chemistry-Education Sub-Cultures (Values)

A Theorist
- values theoretical knowledge
- values a theoretical way of knowing

An Empiricist
- values knowledge gained empirically
- values an empirical way of knowing
- values experience and experiencing

An Applicist
- values applied knowledge
- values gaining knowledge in applied contexts
- values applying theoretical knowledge

A Processist
- values knowledge of process skills
- values a scientific way of knowing
- values problem solving and problem posing

A Pedagogist
- values pedagogical knowledge
- values efficient ways of knowing

A Reconstructionist
- values social, economic and political knowledge
- values social action/reflection

An Existentialist
- values relevant and self-knowledge
- values attitudes and self-actualization

An Epistemologist
- values knowledge of the limits and validity of knowledge
- values identifying assumptions

A Parochialist
- values parochial (national or provincial) knowledge
- values a parochial way of doing things

The foregoing classification of what chemistry educators value is intended for the classification of the ideas presented and positions taken by people, not the people themselves. Although such a reconstruction can never claim to truly reflect actual ideas and positions, it can be useful in dialectical exchanges and should also help chemistry educators who use it to evolve new perspectives from those held by them now.

Another restriction that should be placed on the use of the above classification system relates to its use with every chemistry topic. Although in theory it should be possible to teach every chemistry topic with any one of the emphases mentioned, in practice this is difficult to accomplish. For example, quantum mechanics may be highly valued as a chemistry-education topic by the theorist, whilst an applicist, pedagogist, social reconstructionist, or parochialist may not rate quantum mechanics very highly. This, of course, is the reason why we have the wide range of different chemistry curricula and chemistry textbooks available today. The variety of emphasis placed on different values is healthy, but every curriculum developer and every author should be conscious of his values and identify them overtly in his work.

The variety of emphasis placed on different values is healthy, but every curriculum developer and every author should be conscious of his values and identify them in his work.

An Example of Sub-Culture Perspectives An example of custom tailoring the chemistry curriculum to the culture (or sub-cultures) is the ALCHEM chemistry program developed by a dozen teacher-authors (including this writer) from high schools in the Edmonton, Alberta, Canada region. The teacher-authors were all educated in a high-technology, highly affluent society and are all upwardly mobile into the middle class from more humble roots. Although there is a healthy mix of values and political persuasions within the group, the general cultural backgrounds of the teacher-authors are similar. The sub-cultural emphases (as defined by the nine types presented above) are, however, quite varied. The most commonly shared emphases are pedagogy and chemistry theory. All the authors are or were high school teachers of chemistry or chemistry-physics, with a strong background in chemistry theory from their university studies. As a result of these particular backgrounds, it is not surprising that initially the ALCHEM materials emphasized "easy-to-learn-from, rigorous chemistry". The common practice of excessively matching the level of the chemistry theory taught with the ability level of the students was, over a period of time, substantially broken by the ALCHEM authors by a mix of pedagogical and theoretical chemistry emphases.

What induced the ALCHEM group to put more emphasis on pedagogy was the particular (parochial) situation of chemistry education in Edmonton public schools. The situation was and still is that between 75 and 85 per cent of Grade 10 students, 65-75 per cent of Grade 11 students, and 55-65 per cent of Grade 12 students take a single-stream chemistry course. Thus, students cannot be slotted into two or three different levels of chemistry curricula. As a result the ALCHEM authors had to write classroom materials suitable for single-stream chemistry teaching (i.e., they had to produce curriculum materials which were custom tailored for the prevailing cultural situation).

For example, the ALCHEM teacher-authors developed for their tenth grade course a single, five-step method for writing equations for about fifteen types of electrochemical and acid-base reactions and a single definition format for seven types of chemical and intermolecular bonding. Also, a number of pedagogical (as opposed to historical) models and theories were developed (e.g., a 'restricted' quantum mechanical model of the atom and a 'restricted' Bronsted-Lowry theory of acids and bases).

Related to the pedagogical thrust was the empirical emphasis. Laboratory work, demonstrations and demonstration kits were developed in order to provide the student with experience of a large number of chemicals, and chemical reactions. The emphasis was primarily on experience and on what many call descriptive chemistry. For example, by the end of the first three units ALCHEM students have met over 30 elements, 30 compounds, and 30 chemical reactions in the laboratory.

Also interwoven into the early deliberations in the ALCHEM project (which started in 1973) was an existential component called "attitude toward science". One of the first solutions to the attitude problem which ALCHEM inherited was pedagogic: to make the materials easier to learn from and improve the success of the student in the course. In retrospect, these are a couple of the major successes of the ALCHEM project - students now are learning more and feel better about chemistry than was previously the case.

It is not uncommon in chemical education at the secondary school level that "good" students are given the theoretical chemistry, whilst "poor" students get the applied chemistry. In the ALCHEM situation, the classroom circumstances of having "good" and "poor" students together required us to integrate theoretical and applied chemistry. The attack on this problem taken by us was a pedagogic one. Instead of putting the applied chemistry into the textual materials, the teacher-authors put the applications (including consumer, environmental, industrial, historical, and descriptive chemistry) within the questions, laboratory work and demonstrations. Each question was given an appropriate context, in addition to its theoretical context.

The next stage within the ALCHEM project was a combination of the applicist's and the parochialist's perspectives for writing electives. Again the Alberta situation proved to be a help in this respect. The curriculum guidelines require 25-40 per cent of the classroom time to be spent on elective studies (i.e. materials other than the prescribed core). Fortunately for the growth of the ALCHEM chemical-education perspectives, there was a dearth of elective material that was presented in a context other than a theoretical one.

In response to this, the ALCHEM teacher-authors decided to develop applied-chemistry materials for elective studies. Written were: Alberta Chemical Industries, Analytical Chemistry (nonparochial), Nuclear Chemistry (with a CANDU emphasis), Metallurgy and Corrosion (with Canadian data), Ethylene and its Derivatives (with an Alberta emphasis), The Athabasca Tar Sands, and Foods and their Analogs (nonparochial).

From a social reconstructionist's perspective, the electives fall short by not discussing science-and-society issues. The public debates are missing from, for example, the

Nuclear Chemistry and The Athabasca Tar Sands units. However, the ALCHEM authors intended to include science-and-society issues in both the ALCHEM core and the ALCHEM elective materials. The expansion to science-and-society issues following the move from theoretical to applied knowledge, is a natural evolution within this particular project. This expansion of perspectives must, of course, be done carefully in order to achieve a satisfactory integration of theoretical, applied and societal knowledge in the chemistry curriculum. Any single emphasis would very quickly become boring and would certainly not provide the student with a comprehensive view of what chemistry is.

The ALCHEM materials, like most chemistry materials today, do not satisfy the epistemologist perspective within each of us. The limits, the validity and the assumptions associated with both chemistry and chemistry-education knowledge and ways of knowing are seldom discussed by authors and are even less often made explicit within chemistry materials. University departments of chemistry seldom require their students to study the philosophy of science and, hence, the students - once they have graduated - tend to be unaware of the limits of the scientific way of knowing. It is highly desirable that students should be exposed to some alternate ways of knowing (Aoki, 1979 and Aikenhead, 1981). The ALCHEM authors have been recently exposed to the point of view of this sub-culture and have developed some ideas for the writing of new materials. As perspectives grow, the chemistry materials should explicitly reflect these new perspectives (along with modifications to the old perspectives).

Conclusion The point of view has been presented here that chemistry curricula have always been tailored to a set of sub-cultures and always will be. Chemistry curricula, like all other forms of knowledge, are socially constructed and validated. The values of the social groups constructing curricula are just as important for determining "what is knowledge" and "what is an accepted way of knowing" for high school chemistry curricula as they are for high school social studies curricula. The values of these social groups should be made explicit to all students and teachers who use the curricula. A group's restricted model of a chemistry curriculum can then be expanded by teachers to suit the particular situations of the region or classroom. To assist chemistry educators who are either constructing curricula outside the classroom or reconstructing it inside the classroom, a restricted set of sub-cultures who display their values within chemistry curricula, has been identified above. This classification system should not be used to classify people but to classify values displayed by people. The ultimate goal for all of us is growth. As Byron so aptly put it "I am not that which I have been."

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Appendix A2

I

THE POTENTIAL OF A TEACHER-GENERATED FRAME OF REFERENCE

AS A

CURRICULUM RESEARCH AND DEVELOPMENT PERSPECTIVE

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The Potential of a Teacher-Generated Frame of Reference as a Curriculum Research and Development Perspective

Frank W. Jenkins and Heidi Kass

University of Alberta

Introduction

The theoretical traditions of educational research have to date allowed little place for the conventional wisdom of teachers. Classroom studies are generally conducted by outside observers, with the teacher's contribution rarely extended to the interpretation of the data from his particular frame of reference. Indeed, under the theoretic paradigm, the research problem is perceived as a generalized conceptualization independent of the particular classroom context, teacher, and researcher (Schubert, 1980). Since the goal is generalizability, the unique features and needs of particular situations are explicitly excluded from consideration. The resulting models are often viewed by classroom teachers as mere abstractions having little relationship to actual practice. Since the exemplars and applications are missing, the teacher is at a loss as to how to apply the generalization in his particular situation.

Models of curriculum design and curriculum implementation have also typically sought their constructs in areas other than the complexities of the classroom-in-use (Reid, 1979). The less than outstanding results of such an approach in the face of the realities of problems in curriculum design and implementation may have contributed to Schwab's well-known criticism (Schwab, 1970) of the field of curriculum. Reid (1979) presents a case for practical research into curriculum which is responsive to the realities of the classroom-in-use consistent with Schwab's emphasis (Schwab, 1969, 1971, 1973) upon the uniqueness of such problematic situations and their potential for practical enquiry. Envisaged are practical researchers who engage in an interactive process with the problematic situation--researchers who stress, among other skills, action, judgment, deliberation, and tactics (Schwab, 1975).

A change in the way of viewing the relationship between theory and practice appears to be emerging in the use of terms such as "practical enquiry" (Schwab, 1969), "practical reasoning" (Gauthier, 1963, and Reid, 1979), "group deliberation" (Schwab, 1973), "praxis," "action-reflection," and "mutualistic ends-means" (Werner, 1979, and Aoki, 1979), to characterize curriculum enquiry. Changes in the focus and activities of the curriculum researcher are set out and elaborated. The role and contribution of the classroom teacher in the practical reasoning context also warrants examination and possibly revision.

Purpose

The characteristics and unique contributions of the classroom teacher to educational research and development are discussed in terms of both his classroom-based frame of reference (pedagogical perspective of the classroom "insider") and the empirical data provided by the classroom-in-use situation <u>as perceived and interpreted by the classroom participants</u>. The potential of the view of the teacher-author as participant researcher, actively engaged in practical enquiry is illustrated with reference to a two-year high school chemistry program called ALCHEM. ALCHEM was initiated, developed, revised, and evaluated over a period of eight years almost exclusively by classroom teachers who were concurrently actively engaged in teaching. Five specific illustrations of how the dynamics of the deliberative research and development process became part of the classroom-in-use are described in order to explore the potential of such a view of the teacher's role in practical curriculum enquiry. (Classroom-in-use refers to the specific teaching/learning transactions of the teacher's normal classroom setting.)

Perspective

Examination of the classroom-in-use, whether it be for research or for curriculum development purposes has for the most part been done by outsiders, that is, people not themselves directly involved in the teaching/learning transactions being studied. A variety of predetermined coding schemes have been used, although recently ethnographic studies have increased in popularity (Guba, 1978).

Current naturalistic approaches (e.g., Reid and Walker, 1975; Stake and Easley, 1978; Wilson, 1979) may still be considered as part of the "outside observer" approach in that the classroom and its interactions remain the object of reconstruction and interpretation by someone other than the practitioner. Teacher participation in the research process, while sometimes extended to include a role as a source of data about perceptions of what is happening and why it is happening, remains at the information input level. Rarely does one encounter the teacher and outside researcher engaged in joint deliberation, with the teacher viewed as a full partner in all aspects of the research process (i.e., the "participant research" role.)

It may be argued that practical reasoning is by definition carried out by the practitioners in the setting being studied. The assumptions underlying the distinctions between the practitioner (or participant researcher) and the outside researcher require explication within the context of interactive deliberation. Differences may exist in both the unique contributions of each and in the perceived ends of the endeavor (improving practice vs insight and understanding as ends in themselves, for example). By virtue of being a participant in the classroom dynamics, the teacher brings to the research or curriculum development task a point of view which cannot be taken by the outsider.

Differences in fundamental frames of reference or assumptions about curriculum presented later in the paper illustrate some of the areas in which these differences may appear. Although it has been suggested that teachers tend to assume the frame of reference of the "outsider" fairly readily once they leave the classroom interaction itself (Keddie, 1971), it is by no means clear what influence such a conceptual shift (if indeed it exists) would have on the situational-interpretive process. In any event, the critical reflective orientations used by the classroom teacher would not only contribute to the purposes of the outside researcher by adding a different perspective on the task at hand, but could also result in a deepened understanding on the part of the teacher of his professional practices.

Guiding Questions

Teachers are typically involved in the curriculum process (Ben Peretz, 1980) as either (a) part of an external development group, or (b) as a "user-developer" (Connelly, 1972), adapting the externally produced material in his classroom. When the opportunity to do both simultaneously is present, as is the case in the ALCHEM project, the situation approximates that of the practical researcher (Schwab, 1969).

What, then, might some of the characteristics and unique contributions of the classroom teacher as curriculum developer/researcher be and how might the final product differ from that produced in situations where this type of involvement is not present? While the complexity of the question is recognized (e.g., its implications for the typical role of the classroom teacher will be discussed later) and is clearly beyond the scope of any one paper to address, some potentially useful starting points emerge.

The following questions have served to guide the analysis of this facet of the ALCHEM experience*.

1. What kinds of assumptions about the curriculum development/evaluation/implementation (CD/E/I) process are held by teacher-authors as participant researchers and how do these differ from the assumptions manifest in curriculum products developed in more conventional ways?

2. What specific practical reasoning contexts, skills, and tactics are required for CD/E/I practice by teacher-authors?

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*The ALCHEM curriculum group is still active. A more comprehensive analysis of various aspects of the ALCHEM experience is the topic of a forthcoming Ph.D. dissertation by F. Jenkins.

3. What unique characteristics (if any) are manifest in the curriculum products developed in the participant researcher context by teacher-authors and how important are these in the classroom?

4. What theories or models of curriculum are relevant to CD/E/I practice by teacher-authors?

Delimitations

It is in no way implied that every classroom teacher assume the role of participant researcher (or, more specifically, teacher-author) suggested here in addition to the already heavy demands placed on his professional attention and judgment by the complex interactions of the classroom. Indeed, it may well be that the combination of skills and desire to engage in such a demanding task is comparatively rare, at least at this writing. Again, it might be noted that, as a curriculum project, ALCHEM has many unique features, including the duration of the project, its voluntary nature, the characteristics of the materials produced, the process which yields these materials, and the contexts in which the content is embedded.

The extent to which the skills needed to engage productively in such endeavors can be isolated and developed in individuals may be a function of the level of professional growth of the teacher. Studies of teacher concerns (Fuller 1969; Kass and Wheeler, 1975) indicate that teachers may progress through a number of stages in their professional development, starting with concern over one's own classroom effectiveness and culminating in concern for the broader philosophical and curricular issues inherent in education. It may well be that the role of participant researcher is particularly appropriate as an avenue for deepening the professionally mature teacher's understanding of his own teaching practices. Involvement in the process itself may also enhance the progression of professional maturity to later stages. In any event, the critical-reflective stance described here may be one which some selected teachers and also outside researchers may find of professional value.

Data Source

Data and interpretations are based upon a retrospective analysis by a direct participant in the ALCHEM curriculum development process. Both stimulated recall and perusal of documents associated with the project were used. The archives of the many ALCHEM editions, classroom pilot notes, newsletters, correspondence, and implementation records over the past eight years are used as evidence to provide support for the claimed outcomes of this teacher approach. The current (since the project is still in existence) reflections on the curriculum materials development process by ALCHEM authors (including the participant author-researcher) are included. Emphasis in the analysis is placed on identifying the generalizable features of the curriculum materials development process.

The Evolution of the ALCHEM Project

ALCHEM is a two-year, high school chemistry, core-elective program originated, written, piloted, evaluated, implemented and repeatedly revised by a team of classroom teacher-authors. The ALCHEM project is of interest to the field of curriculum study because of the relatively uncommon long-term teacher control of all aspects of the program. The teachers were and are more than just members of a writing team or implementors of a program. As a result of eight years of intense writing, classroom use, and revisions, a classroom oriented perspective has been generated and employed by the group which questions many traditional views of curriculum and curriculum materials. Before examining some of the curricular challenges emanating from the ALCHEM project, a brief history of the project is presented below and summarized in Table 1.

The external view of the history of the ALCHEM project as presented in Table 1 is somewhat superficial in that it does not completely reflect the in-process environments and reasoning of the team. However, the long term commitment of the teacher-authors to the project does provide a sense of their deep feeling for the process and products. As the project grew in scope, so did the individual teacher-authors. This simultaneous growth was a result of the intense interactions of the teacher-authors with their students, their colleagues, the current ALCHEM materials, other textbooks, and other ALCHEM teacher-authors. There was a conscious search (or re-search) for different interpretations of the standard curriculum, in other words, the teachers became participant researchers.

As the project progressed over time the type of questions being asked changed from a stress on sequencing and increasing student achievement to a stress on critical examination of why certain topics were taught. The "why" questions also progressed (and still do) through a structure of the

TABLE I

ALCHEM Development

1973 — Initial survey, listing of objectives, topics and sequences

Period	(ALCHEM 10)	(ALCHEM 20)	(ALCHEM 30)	(ALCHEM Electives)
Summer 1	First Summer Writing (4 teacher-authors) → Piloting in Semester 1 (2 schools, 400 students)			
1974 / Summer 2	Rewriting for Semester 2 (5 schools, 750 students) → Piloting	ALCHEM 20 Started Second Summer Writing (7 teacher-authors) → Piloting		
1975 / Summer 3	In-process Revision Test-Item Bank Started → Piloting (5000 students)	In-process Revision → Piloting (2500 students)	ALCHEM 30 Started Third Summer Writing (9 teacher-authors) → Piloting (2500 students)	Electives Started Third Summer Writing (exploratory electives written; 2 now published 4 unpublished) → Piloting
1976 / Summer 4	In-process Revision (1 teacher-author released) → Second Major Revision → Piloting (12 500)	In-process Revision (1 teacher-author released) → First Major Revision → Piloting (5000) Test-Item Bank Started	In-process Revision → First Major Revision → Piloting (3000)	Piloting → Five Electives Written (all now published) Athabasca Tar Sands Rewritten → Piloting
1977 / Summer 5	In-process Revision → Individuals Rewriting → Alberta Education Adoption → Piloting	In-process Revision → Individuals Rewriting → Alberta Education Adoption → Piloting	In-process Revision → Individuals Rewriting → Alberta Education Adoption → Test-Item Bank Started	In-process Revision → Individuals Rewriting → Piloting & Revisions
1978 / Summer 6	Third Major Revision → Individuals Rewriting → First Printing by Publisher → Piloting (15 000)	Second Major Revision → Individuals Rewriting → First Printing by Publisher → Piloting (12 000)	Second Major Revision → Individuals Rewriting → First Printing by Publisher → Piloting (8 000)	Major Revisions → Individuals Rewriting → Alberta Education Adoption → Piloting & Revisions
1979 / Summer 7	In-process Revision → Inservice in PEI → Practical Lab Final Developed and Piloted	In-process Revision → Inservice in PEI → Practical Lab Final Developed and Piloted	In-process Revision → Inservice in PEI → Piloting	In-process Revisions → Piloting
1980 / Summer 8			Piloting	Piloting → Writing Environmental Chemistry Elective
1981	Developing a 3 Year Plan	Developing a 3 Year Plan	Developing a 3 Year Plan	Developing a 3 Year Plan
Summer 9, 10 & 11	Team Writing	Team Writing	Team Writing	Team Writing

discipline stage to a "why would anyone want to know that" stage and then to a knowledge and society or knowledge and self stage. These types of questions were not individually exclusive to Year 1 or Year 8 of the project, but as experience and confidence grew, there was a broadening of the perspective on what constituted an appropriate curriculum.

The situational contexts and typology of reasoning that the teacher-authors employed were and are extremely complex. With full recognition that the logic-in-use may have been superior to the reconstructed logic, an attempt can be made to reconstruct the situational contexts and types of reasoning in order to bring the process to consciousness in hopes of encouraging its growth. The situational contexts in which the teacher-authors found themselves were (1) individual, (2) group and (3) classroom. In the individual situation the teacher-author interacts with his experiences and thoughts, existing curriculum materials, and/or the curriculum materials he is currently writing. In the group situation the teacher-author must overtly or covertly defend his position against others and will very often gain another perspective on a topic. In the classroom everything the teacher-author believes in the individual and group situation is either modified or shattered, but seldom ratified.

The types of reasoning which accompany the situational contexts need to be studied, perhaps by the participant researchers themselves in cooperation with outside researchers. A variety of reasoning approaches ranging from nonproblematic acceptance through ends-means to situational interpretive and critically reflective reasoning have been described by Werner (1979) and Aoki (1979). What makes the teacher-author unique is the potential grounding of their reasoning in experience (practice). Some of the results of this practical reasoning by the ALCHEM teacher-authors are presented below.

Some Results of a Classroom Perspective

A large number of assumptions (at one time the list exceeded 75 items) can be identified as guiding principles employed by the ALCHEM teacher-authors. The large number of assumptions indicates the extreme complexity of the educational enterprise but at the same time indicates the power of the classroom situation as a site for resolving complex curriculum research questions. A very common set of statements made by the teacher-authors is: "We'll see how it works in the classroom"; "I don't know, let's try it"; "Maybe I can work something out in the classroom"; and again "Let's try it." There appears to be an underlying confidence expressed by the teacher-authors that in the midst of the classroom situation or following a classroom experience some insight will be gained with respect to the problem which cannot come from elsewhere.

Table 2 lists a few of the ALCHEM assumptions that may be used to illustrate how a classroom perspective can be used to challenge the prevailing views.

Some of the thinking behind each of the five areas noted above will be presented in turn. Again it may be noted that the assumptions themselves were not nearly as powerful or enduring as the deliberative process which produced them. The participants were themselves often pleasantly surprised by the productivity of the seemingly disjointed practical process. As

TABLE 2

Perspectives on Curriculum Issues

ALCHEM Assumptions (Paradigm A)	Alternate Assumptions (Paradigm B)
1. The emphasis within curriculum materials writing should be on student activities.	The emphasis within curriculum materials writing should be on textual material and teachers' guides.
2. The format of textbooks can be made to reflect a classroom perspective.	The format of textbooks is delimited by economics and expediency.
3. The structure of the discipline can be viewed and molded from a pedagogic perspective (practical reasoning).	The structure of the discipline is defined by its historical evolution and/or by the shared conceptions of subject matter specialists.
4. Pure and applied subject matter should and can be integrated within all facets of a program.	Pure and applied subject matter can and should only be integrated within certain facets of a program or by the teachers themselves.
5. Both pure and applied subject matter are appropriate for all students.	Pure and applied subject matter are for different types of students.

noted earlier, the sequencing of the assumptions reflects the development of the thinking of the group from concern with fairly immediate classroom issues e.g., suitable teaching activities to a broader theoretical and integrative perspective.

1. The emphasis within curriculum materials should be on student activities.

The emphasis from very early in the ALCHEM project was placed on producing curriculum materials which actively involved the students. There was and is a de-emphasis on textual material and teachers' guides and an increased stress on exercises, labs, and demonstrations. Initially this approach may have been attributed to reaction against the current emphasis in the prescribed textbooks. The increased student activity led to increased teacher interaction with students. The teacher-authors in their efforts to discover the meanings given to the curriculum constructs by the students were greatly assisted by the activity emphasis. Their initial interpretations of their classrooms led to the activity emphasis and in turn further interpretations led to and are still leading to continual revisions of the ALCHEM materials. As this process continues the authors as participant researchers are improving on their ability to perceive the meanings attributed to the curriculum materials by the students. A recognizable intermediate stage was evidenced by statements such as: "Is that for you or for your students?"; "Are you having trouble or are your students?"; and "Is that what you think or is that what your students think?". Later stages in the interpretative process are discussed below.

2. The format of textbooks can be made to reflect a classroom perspective.

The ALCHEM core curriculum materials are in loose-leaf format with the exercises, labs, and demonstrations interspersed in a manner appropriate for direct classroom use. Each higher level book begins with a review unit, each lab or demonstration is preceded by a pre-lab exercise and each unit is concluded by a separate overview exercise. Space is left to permit students to write in the materials and thus to make the book "their own." The assumed superiority of this format is both criterion based and value based. The participant researchers feel that the achievement of the students is increased by using this format. It is also important for students to make the book "their own," to take it home and to perceive that the subject matter is worth keeping. To produce academic books for average citizens which are regarded by the learners as worth keeping is a self-imposed challenge to the ALCHEM authors.

3. The structure of the discipline can be viewed and molded from a pedagogic perspective.

The ALCHEM teacher-authors have reshaped the conventional structure of introductory chemistry by omitting some time-honored topics, by integrating topics generally treated separately, and by re-interpreting or "reconstructing" some topics. Examples of ALCHEM omissions of conventional chemistry curricular material are gas laws, quantum mechanics, and equilibrium K-values. The main reasons for the omissions are pedagogic--these topics are abstract, allow for little lab work, and have very few applications in the further study of secondary school chemistry or within the citizen's world.

Examples of integrated topics are the treatment of states of matter within chemical formula and equation writing, chemical equilibrium within electrochemistry and acids-bases, and numerous normal core topics within the applied chemistry elective booklets (e.g., proteins, carbohydrates and fats within the Foods and their Analogs unit and electrochemistry within the Metallurgy and Corrosion unit).

Questioning whether a given topic should be isolated or integrated within another core topic or elective unit continues in ALCHEM today. The answers will initially remain based on past experience and ultimately will depend upon classroom trials where the criterion becomes whether or not it "works" in practice.

The above focus has over time led to a more fundamental questioning of conventional presentations of introductory chemistry. Initial challenges were posed within fairly standard pedagogical situations (e.g., the use of VSEPR rather than quantum mechanical ideas in stereochemistry, "molar mass" rather than "molecular weight" in stoichiometric computations, SI rather than British units, and IUPAC nomenclature rather than classical nomenclature). Pedagogical adaptations of chemical principles often used in classrooms but seldom present in textbooks (e.g., a modified Bohr model of the atom which uses energy levels but no orbits, an approach to the mole which evolves from molar mass through molar concentration to molar volume, molar heat, and molar charge, and a modified Arrhenius definition of an acid which employs the hydronium ion) were explicitly incorporated in the material. An historical treatment of a topic was considered secondary to its pedagogical requirements.

The realization that historical content is not always the most appropriate pedagogical content led to further challenges to prevailing treatments of secondary school chemistry. For example, in the ALCHEM "Chemical Bonding" unit all chemical and intermolecular bonding is defined conceptually beginning with the phrase "the simultaneous attraction of . . ." Not only are students capable of conceptualizing "simultaneous attractions," but definitions presented separately historically by several different chemists (and retained as such in textbooks) are now unified as slight variations of one definition. Thus the ALCHEM authors have, within this unit and while challenging the prevailing pedagogy and science of the bond definitions, in a sense led students to the leading edge of science by emphasizing predictions of the melting point, boiling point, and solubility of substances. At present the ALCHEM team is awaiting the verdict of the scientific community as to whether what is good pedagogy in these cases is also "good science." The criterion here implies acceptance by the appropriate scientific community (Kuhn, 1970). That pedagogues can contribute conceptually to a discipline may perhaps be an overstatement but it does illustrate the point that the ALCHEM teacher-authors are not "overawed," as Schwab would suggest, by "the discipline of the scholars"(1973:501) and may assist in the synthesis of the "normal science" aspects (Kuhn, 1970) of the discipline.

The pedagogic perspective of the ALCHEM team is described above from the contexts of omitting, integrating, and reconstructing a subject matter topic. Clearly such decisions need a very broad perspective both of the discipline and of the classroom situation. The ALCHEM experience demonstrates that teacher-authors are capable of adopting such broad perspectives, very likely generated by their participation in the classroom-in-use setting while writing.

4. Pure and applied subject matter should and can be integrated within all facets of a program.

Pure and applied knowledge (as conventionally viewed) each have their own proponents in the educational field. At various times in educational history the integration of pure and applied subject matter has been accomplished within the textual material, within applied elective units, or within the classroom by the teachers and students. The ALCHEM teacher-authors recognized that, if an applied context for the pure subject matter was to receive attention, the applications must appear in those parts of the curriculum materials where students pay the most attention; e.g., the exercises, sample problems, labs and demonstrations. To an insider the need for the applied context in the questions is fairly obvious. The motivation to commit oneself to the onerous task of providing hundreds or thousands of applied contexts for questions or of developing the generally more complex labs with an applied context could only come from seeing the reaction of students in the classroom. An outsider, without the classroom rewards or reinforcement, would be unlikely to persist in such a task.

It might also be argued that teacher-authors are much more likely to conceptualize actions such as placing every question into an matter topic. Clearly such decisions need a very broad

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The above rejection of the conscious or unconscious matching by curriculum writers of certain types of students with certain types of subject matter (rather than with levels of subject matter) indicates a critically reflective stance taken by the authors. However, this stance would all be for naught if the teacher-authors could not find a means to accomplish their end, or if the interpretation of the pilot materials in the classroom indicated that the students would prefer to be typed and matched. There is obviously a very complex mixture of types of practical reasoning used by teacher-authors to answer questions such as that of integration of pure and applied subject matter for all students.

Discussion

The ALCHEM teacher-authors feel as Aoki (1979:17):

> "that for too long 'thought' and 'practice' have been set apart, an act which has tended to invite reified 'thought' on the one hand, and a-theoretical utilitarian practice on the other. For too long we have not been aware that second order thoughts were being 'applied' to the first order social world of practice. . . . Insight into possibilities of contextualizing 'thought' and 'practice' within a new framework wherein the relatedness of the situational interpretative and the critically reflective orientations may lead us further along the way." (emphasis added)

The ALCHEM teacher-authors have provided evidence of a working reciprocal interaction between action and thought such that, if the word "application" is to be used in this context, it must fit as well to the paradigm of practice into theory as to theory into practice. A teacher-generated frame of reference needs to challenge the outsiders' frame of reference to the point that titles such as "What Research Says to the

Science Teacher" (Rowe, 1978) are complemented by "What Participant Researchers Say to Research and to the Classroom."

The unique format of the ALCHEM materials, the major conventional chemistry omissions, the integration of pure and applied chemistry and the pedagogic approach taken to many topics in the material illustrate some of the outcomes of the practical deliberative process as applied to CD/E/I by the team of teacher-authors. The foregoing descriptions have addressed some of the considerations inherent in the first three guiding questions (p. 5). That the implications are heavily embedded in a particular situational context is not inconsistent with the premises of practical enquiry (Schwab, 1969). Some lines of curriculum inquiry suggested by the ALCHEM experience are presented here as areas suitable for research by participant researchers.

With respect to question 4, it is clear that theories which separate curriculum implementation and curriculum development (Reid, 1975) and view a curriculum as a "given" to be "marketed" are not consistent with the practice of teacher-authors writing curriculum within the classroom-in-use context. Views of curriculum development as primarily a linear working out of the details once the pre-eminent objectives have been identified are also inconsistent with what occurred in the ALCHEM context. The objectives, and the relationships among the objectives were subject to major modification as the project developed, as were most other parts of the undertaking. The search for more appropriate models could well be a cooperative endeavor between classroom "insiders" and "outsiders."

As the necessary perspectives, skills and pilot materials evolved, a realization of confidence in the process itself emerged in the group.

What the specific nature of the ultimate product would be was, and to some degree still remains, an open question since the work is continuing. Perhaps an iterative model of the curriculum process would better reflect the dynamics of such groups. Obviously a fairly stable curriculum product needs to emerge at reasonable intervals in order to yield specific types of classroom feedback and to give the teacher-authors time to reflect upon the directions in which they are heading. The continuing voluntary viability of the group reflects the attraction which the CD/E/I perspective holds for mature, exper'enced, classroom-oriented teachers. In a sense it might be said that teachers derive satisfaction from the products but become "hooked" on the process. The deepened awareness and involvement of the teacher as a participant researcher in the classroom-in-use setting opens creative and stimulating avenues for professional growth not readily apparent elsewhere and thus the process itself warrants further study.

It is not suggested that the existing, primarily university-based community of educational researchers be replaced by classroom-oriented teacher researchers. Teachers have other things to do, namely, the teaching of students. Various models for cooperative research endeavor need to be developed and tested in practice which use the "insider" perspective as an important element. The ALCHEM team did not operate in a vacuum, at various points in the project consulting extensively with people in industry and in the university setting. However, the interpretations placed upon these interactions and the paths followed as a consequence of these interactions were those of the ALCHEM authors as classroom "insiders," not of external agencies or decision-makers.

The significance of the perspective of the classroom-in-use added by classroom teachers to educational research and development is not restricted to curriculum materials development/evaluation. The classroom teacher through the classroom-in-use can help to identify research problems in many areas and in some cases carry out those aspects of the research especially suited to participant-researchers. As a cooperating teacher supervising student teachers, classroom teachers can also assist university personnel with developing and applying specific practicum curricula. The potential of such an approach cannot at this point be specified by predetermined ends or hypotheses, but must be accepted on the basis of confidence in the process generated by successful applications such as ALCHEM. Other current examples can no doubt be identified and future examples are expected.

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Appendix A3

DEVELOPING CHEMISTRY CURRICULUM MATERIALS:

A MULTI-PERSPECTIVE APPROACH

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DEVELOPING CHEMISTRY CURRICULUM MATERIALS: A MULTI-PERSPECTIVE APPROACH

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The University of Alberta

Since the appearance of Kuhn's widely-read essay on "The Structure of Scientific Revolutions" (1970), there has been increasing recognition of the subtle, yet powerful influences of human subjective and value orientations upon the creation of scientific knowledge and on how the scientific enterprise is viewed, both by its practitioners and by its spectators. Although less well known, Ravetz (1970) remarkable account of the characteristics of contemporary science as a human, social activity and the problems suggested by fundamental changes in perspective upon the nature of its endeavors, offers much that should be thought about seriously by those of us in science education. The incompatibility of the picture of science presented in school science courses with the messages received by students from other sources, whether they be the popular media or books like Zukav's "The Dancing Wu-Li Masters" (1970) has not escaped the more reflective and well-informed of our students (the less perservering or capable having "tuned out" and "opted out" some time ago). To ignore the characteristics of contemporary science with curricular presentations of essentially a nineteenth-century picture, often implicit, of the nature of science is to perpetuate the notion that science is abstract, esoteric, and really has nothing to do with us.

From the perspective of the classroom observer, any school science, including chemistry, can more often than not be described as a body of knowledge which in some sense exists "out there" for which the main job of the student is to assimilate those particular bits and pieces, problems, and examples, which are set out in the curriculum of the day (Stake and Easley, 1978, Weiss, 1978). The job of interpretation, of what the concept, fact, etc. means or counts for within some conceptual framework or view of knowledge is either left to the student or discussed in terms of a small number of carefully pre-selected examples or situations which reflect (and in the absence of alternative interpretations, reinforce) the implicit preferred orientation to knowledge presented in the textbook. This orientation, if the widely used chemistry textbooks such as CHEM Study and its progeny, Metcalfe, etc. are any indication, tends to be almost exclusively theoretical, with the development of the field portrayed as proceeding in an orderly and linear way to the current organization of standardized facts and principles. It is generally assumed by both teachers and students that any interpretations of the concepts brought to bear on classroom discussion conform closely in their contextual elements to those presented in the text and that any deviations represent incomplete or faulty understanding. That science consists of right answers is only one of the notions which is perpetuated in this way. In many instances it may not even be considered appropriate to ask how, if at all, the concept can "work" in other contexts or what, if anything, the concept means to the student within his personal framework for knowledge. The point made by Weisskopf (1976) with respect to physics also applies to chemistry, namely that it is considered inhuman by many students because of its abstract and symbolic concepts which deal with matters under conditions far removed from the human environment and direct human experience.

It may be argued that the domain of chemistry is itself somewhat farther removed from the direct, everyday experience of the student than are the phenomena of physics and biology. Indeed, many of the concepts encountered in the introductory stages (eg., atom, nucleus) have no perceptible instances (Herron et al., 1977) and necessitate the use of "pseudoexamples" to reveal their attributes. Since students rarely conceptualize the world in chemical terms on their own, both the concrete referents for chemical phenomena and the concepts to describe them need to be presented in the classroom. In an important sense, the science of chemistry is itself generated or "created" for the student within the context of the teaching-learning relationship and it is the specific classroom interpretations of the subject that form the basis of most of the student's understanding of chemistry - not only of its formalisms and textbook examples but in the sense of the development of a coherent picture of the nature of scientific matters - its concepts, phenomena, practical and social context and how these "work" in the world. It may even be argued (Mishler, 1979) that lack of understanding of conceptual material resides not in unfamiliarity with their denotative meanings or definitions, but with a lack of familiarity with the universe in which the concepts are interpreted. In the absence of other "reality checks", the images conveyed by chemistry curriculum materials, and of how the teacher chooses to bring them to life within the partciular context of his or her classroom become pre-eminent. Students cannot deal with abstractions alone. The "context stripping" that often accompanies the design of curriculum materials, leaving only an emphasis on their logical and theoretical characteristics may do much to contribute to the anti-theory, anti-science, and anti-research attitudes found among students.

It is increasingly recognized in the curriculum field that the many varieties of knowledge and value perspectives associated with each interact both at the explicit and implicit normative levels in any given curriculum and that these messages are communicated to the student. Often such impressions outlast the recollections of specific facts and principles which, once tested, can be safely forgotten. These messages inform students and teachers how they are expected to think about the subject, about what kinds of knowledge are to be preferred, and to what kinds of contexts the substantive and methodological aspects of the subject can be expected to apply. A partial listing of possible normative perspectives on the nature of knowledge in science which can be applied to chemistry might include:

a) theoretical - values theoretical knowledge and theoretical ways of knowing
- seeks ever greater inclusiveness and predictive power in theory

b) empirical - values knowledge gained by empirical means: observations, experimentation, measurement, etc.
- seeks data

c) applicational - values practical and instrumental knowledge and the gaining of knowledge in applied contexts
- seeks ways of using knowledge, functional knowledge

d) methodological - values the processes and methods of gaining knowledge
- seeks problems to solve, criteria for reliability and generalizability

e) epistemological - values knowledge of the limits and validity of knowledge claims
- seeks to identify underlying assumptions of knowledge claims

f) <u>social reconstructionist</u> - values social, political and economic components of knowledge, social action/reflection

- seeks emancipatory change, understanding of socio-political contexts and uses of knowledge

g) <u>psychological</u> - values knowledge meaningful to the individual as an active participant in construction these meanings

- seeks relevant knowledge, personal knowledge

h) <u>pedagogical</u> - values effective and efficient ways of transmitting knowledge

- seeks to develop literacy, standardization of knowledge

The reader can identify other perspectives as well. Each represents a different starting point for approaching the nature of science and the place of chemistry in it and can lead to curricula which are very different from each other.

The prevasiveness of normative elements about the ~~nature of science~~ in chemistry textbooks has been made explicit by Factor and Kooser (1981) who assert:

> ... in scientific texts there are explicit and also tacit normative assertations which cover the full range of personal and public dilemmas confronting contemporary society. To some this will seem obvious and the only puzzles will be why authors and teachers do not see that their most important teaching vehicle includes evaluative opinion as well as descriptive fact. To others it is not at all obvious that texts carry moral messages or normative prejudices (p. 1).

They proceed to support this contention by identifying such value judgements in a comprehensive listing of currently available chemistry textbooks designed for college science non-majors. These cover a range of social, political, and economic issues which include a chemistry component as well as the impressions of the nature of science and scientific method. A similar kind of analysis is also much needed for existing high school chemistry textbooks and should be an explicit element in future curriculum development and evaluation endeavors.

Recommendations by Connelly (1972) that a curriculum present a sufficiently clear exposition of its epistemological basis to permit a clear choice among alternatives support Walker's (1971) suggestion that the "platform" of the curriculum writers be set out as an explicit part of the curriculum material. The teacher can then choose from among the available perspectives and implement that particular view in a way appropriate to the characteristics of the class. The variety of theoretical, applied, environmental, and practical chemistry curricula which are currently in existence attest to the viability of this approach.

Another approach is also possible. It should be pointed out that just as it is possible for an individual to hold a variety of perspectives on the nature of knowledge, including knowledge in the scientific and technological realm, curriculum and instruction can also reflect a multiplicity of perspectives within a coherent organizational framework. No one perspective, no matter how well developed is adequate in reflecting the plurality of perspectives which can be used in relation to the subject. Ineeed, it could be argued that study of no one single science subject or specialization is a sufficient vehicle for promoting an awareness of science. We live in a pluralistic world, with numerous alternatives for approaching it, and learning to cope with it (Toffler, 1980) and students need to be taught how to examine matters from a number of alternative perspectives. The linear, cumulative, top-down ways of thinking and of representing science are declining in usefulness in the present contexts and, at some level, our high school students are aware of this.

A more immediate practical problem is the boredom that quickly sets in when only one perspective is emphasized, whether it be societal, historical, theoretical, or whatever. No one perspective can be clearly designated as the "correct" one. All are right and all are wrong at the same time, but all are useful in that they represent different ways of viewing the subject and different starting points for inquiry. Students can be taught how to approach chemistry as well as other areas of knowledge with this type of orientation in order to think in an integrated, holistic way about the nature of science. Such perspectives are not mutually exclusive, but interact in many subtle ways.

Can this be done within the framework of a single curriculum? Can this be done to produce a coherent, integrative approach, or will the product be piecemeal, fragmented, and lacking in academic rigor? Clearly this is a question that cannot be answered in simplistic terms. Various alternative ways of approaching a multi-perspective curriculum organization will need to be devised, implemented and assessed. The view that since knowledge is relative it does not matter what we teach is not what is being said here. Obviously, it does matter, but what and how to teach those aspects of science, chemistry to be precise, that reflect the current nature and import of the field in ways that are meaningful to more than the college-bound in the area requires innovation and exploration.

What are some of the curricular questions accompanying the design of a multi-perspective approach and what would these materials look like? A partial listing might include:

1. Whose perspectives and what perspectives should prevail?
2. Why are we, or should we be, doing this?
3. Why bother with the value/contextual dimensions?
4. What is required to make a course multi-perspective?
5. What are some specific ways to make a course multi-perspective?
6. What would the textbook and other instructional materials look like?
7. What would the classroom teaching and evaluation look like?
8. What kinds of contributions can the student make to developing his own world view?

One approach which is meeting with acceptance among chemistry teachers in Canada and elsewhere is reflected in the ALCHEM chemistry program. ALCHEM is a two year, high school chemistry core-elective program originated, written piloted, evaluated, and repeatedly revised by a team of chemistry classroom teacher authors. The ALCHEM project is of interest to the field of curriculum study because of the relatively uncommon long-term teacher control of all aspects of the program. The teachers were and are more than just members of a writing team or implementers of a program designed by someone else. As a result of nine years of intense writing, classroom use, and revisions, a classroom-oriented approach has been generated and used by the group which questions many of the traditional views of curriculum and curriculum materials. One of these approaches is tne evolution of a multi-perspective approach to knowledge in chemistry.

Contextual Referencing

Within the framework of the subject matter of chemistry, what steps can be taken to develop a multi-perspective approach? One alternative is to rely on the teacher to provide a range of practical and interpretive contexts as a part of the instruction. While this is sometimes done in practice, there is a tendency for teachers, pressured to prepare students for college-level work, to omit such "peripheral" matters. Such a response is not unusual if one considers that the teacher's own training in chemistry was very likely from a theoretical perspective alone.

Another consideration is the sometimes held notion that a theoretical context is appropriate for the better students and that applied science is suitable for the poorer students. The assumption that intellectually superior students are bored by applied contexts and the poorer students are bored by theory is not supported by the ALCHEM experience. In a program in which both theoretical and applied chemistry are part of the core and optional units, although with a somewhat different emphasis, the better students are not only motivated by the applied contexts, but challenged as well. Since the materials are flexible and contain a wide range of choices, theory is introduced in a pedagogically appropriate way for the less capable students as well. In this way, the teacher and students <u>together</u> begin to see the interrelationships in pure and applied chemistry.

Rather than relying on the teacher to provide most of the context from his own background and experience, the ALCHEM materials present the chemical concepts and applications embedded in a variety of contextual frameworks from which teachers can choose the ones they prefer to discuss. For example, chemical facts such as the two specified below can be referenced to a variety of contexts:

1. The chemical formula for table salt is NaCl.

   This fact can be referenced to:

   a) Salt is the major spice used by North Americans
   b) Salt is used to produce hydrogen, chlorine, sodium hydroxide, and sodium
   c) The salt content of many processed food is very high
   d) Aspects of health such as high blood pressure
   e) ...

2. The solubility of table salt is 5.3 mol/L.

   This fact can be referenced to:

   a) Theoretical constructs such as what factors affect solubility
   b) Experimental constructs such as the visual impression of the quantity of salt that represents 5.3 mol
   c) Industrial applications such as solution-mining, pulp and paper
   d) Historical connections eg., desalinition of water
   e) ...

Similar contexts can be devised for principles, theories, chemical processes; etc. The Appendix contains additional examples of contextual referencing and the reader can readily supply his own.

The potential of such an approach to a multi-contextual curriculum is further enhanced by the advent of microcomputer technology in schools in that a wide variety of contextual referents can be made readily available to teachers for inclusion in tests, work sheets, etc. The teacher can literally custom-tailor the chemistry course to the particular class at a given point in time. The possibilities are at present being developed further by the ALCHEM group.

What do the students think of all this? Preliminary indications are that such an approach is very well received. Teachers report that students are pleased and reassured to learn explicitly within the sanctions of "official" schooling that there are different varieties of knowledge and that different value-perspectives on a situation can lead to somewhat different interpretations in the sciences as well. This seems to reinforce something that many of them have already sensed. Identifying and analyzing the epistemological and value perspectives taken in the instructional material becomes an interesting and enjoyable part of the classroom activity. There is no evidence that spending time on such matters detracts from the more traditional learning of chemical facts and principles. If anything, there seems to be an increase in self-confidence when students become aware that, as one student put it, "Scientists have trouble with science too." Science is more likely to be viewed as a challenging and exciting form of human exploration rather than a monolithic accumulation of facts and principles. One survey of student response to the ALCHEM approach re-revealed a change from 54 per cent to 90 per cent disagreement with the statement "Scientific developments are distant from my everyday life" for students in the early stages and the latter stages of the program. Other questions revealed similar changes in attitude from an earlier view of "Science is important, but not to me" or "Science is difficult to understand" to "I would like to find out more about ..." and "It is important to be kept informed about science."

If students are to comprehend even some aspects of the complex relationships between science, technology, society, and their own lives, we cannot deal with science, including chemistry, from a single vantage-point alone. Contextual referencing in a multi-perspective approach represents one way of approaching a plurality of perspectives in a coherent way and in helping the student toward a presonally meaningful synthesis of some of the subject-matter of school science. Clearly much more work is required in both curriculum development and testing in the classrooms for the potential of such an approach to be assessed. This of necessity includes an examination of society and knowledge itself. The process is continuing.

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Appendix A4

NORMATIVE PERSPECTIVES ON THE NATURE OF CURRICULAR KNOWLEDGE IN CHEMISTRY

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Introduction

The subtle yet powerful influences of human value orientations on the nature and creation of scientific knowledge have been widely discussed since the appearance of Kuhn's essay on "The Structure of Scientific Revolutions" (Kuhn, 1970). How the scientific enterprise is viewed by its practitioners, its students and teachers, and its spectators is a product of exposure to many such messages. Often these messages are implicit rather than overt, but they nevertheless influence the value positions about the nature and worth of different kinds of scientific knowledge. If fundamentally incompatible, such perspectives serve to alienate the various groups from each other.

Messages about the relative worth of different perspectives on the nature of scientific knowledge may also be inconsistent with each other. As with the science they present, science curricula are also not neutral with respect to type of knowledge valued. The incompatibility of the picture of science presented in school science courses with impressions received from other sources e.g., popular media, books, and periodicals, has not escaped the more reflective and well-informed of our students. Curricular presentations of an essentially nineteenth-century picture of science as abstract, objective, and theory-driven ignore many of the characteristics of the contemporary scientific enterprise.

Perhaps as a reaction to earlier aggregations of descriptive detail, the science curricula of the 1960's gave particular value to theoretical knowledge. Numerous current curricula place high value on empirical and applicational knowledge. The pervasiveness of normative elements about the nature of science in science textbooks has been made explicit by Factor and Kooser (1981) who assert:

> ... in scientific texts there are explicit and also tacit normative assertations which cover the full range of personal and public dilemmas confronting contemporary society. To some this will seem obvious and the only puzzles will be why authors and teachers do not see that their most important teaching vehicle includes evaluative opinion as well as descriptive fact. To

> others it is not at all obvious that texts carry moral messages or normative prejudices (p. 1).

While different textbooks in a field may reflect somewhat different dominant perspectives on the nature of knowledge in the field, it must be remembered that the student is typically exposed to only <u>one</u> of these.

High school represents the last of formalized science study for approximately four out of five young persons. From the perspective of the classroom observer, any school science can more often than not be described as a body of knowledge which in some sense exists "out there" for which the main job of the student is to assimilate those particular bits and pieces, problems, and examples which are set out in the curriculum of the day (Stake and Easley, 1978; Weiss, 1978). The task of <u>interpretation</u>, of what the concept or fact means or counts for within some conceptual framework or view of knowledge is either left to the student or discussed in terms of a small number of carefully pre-selected examples or situations which reflect and, in the absence of alternative interpretations, reinforce the implicit preferred orientation to knowledge presented by text book and/or teacher. This orientation, if widely used textbooks are any indication, tends to be almost exclusively theoretical, with the development of the field portrayed as proceeding in an orderly and linear way to the current organization of standardized facts and principles (Ravetz, 1971).

The particular normative orientation to knowledge taken in a science course also determines the definition of educational success or failure in the subject. It is generally assumed by both teachers and students that interpretations of the concepts brought to bear on classroom discussion and assignments conform closely in their contextual elements to those which are presented in the textbook. Deviations are taken to represent incomplete or faulty understanding. In many instances it may not even be considered appropriate to ask how, if at all, the concept can "work" in other contexts or what, if anything, the concept means to the student within his or her personal framework for knowledge. Physics in particular tends to focus on abstract and symbolic concepts which deal with matters under conditions far removed from the human environment and direct human experience. Hence it is often considered inhuman by students (Weisskopf, 1976). The tendency for introductory chemistry textbooks to replace descriptive chemistry with physical chemistry and abstract chemical theory has also been viewed with reservation by the ACS General Chemistry Subcommittee (1972).

The purpose of the present discussion is to identify a number of possible normative perspectives which can be taken on curricular knowledge in science and to consider some of the normative characteristics of each. Areas of potential confusion for both students and teachers are outlined with reference to how such pespectives may manifest themselves in chemistry.

The Nature of the Chemical Sciences

Chemistry is chosen for discussion for a number of reasons, the most influential in the current context being that it is often treated pedagogically as if it were physics. Perhaps this is not unexpected, given the current physical chemistry orientation of introductory chemistry courses. The converse may also be valid — that the pre-eminent intellectual worth placed upon theoretical knowledge within the 20th century scientific community has itself served to orient the selection of those ideas judged important enough to be transmitted via chemistry courses strongly toward the theoretical-abstract i.e., physical chemistry concepts. Physical chemistry is relatively amenable to being taught as if it were physics, and hence the many aspects of contemporary chemistry which are not easily seen to be "like physics" are de-emphasized, distorted, or ignored.

While a detailed philosphical treatment is beyond the scope of this discussion, some of the major properties of chemistry as a branch of scientific knowledge which set it apart from what is usually viewed a physics may be useful. Spice (1975) takes the view that the chemistry-physics distinction is itself largely an historical artifact, preferring a categorization along the lines of nuclear physics and molecular science. Hammond and Nyholm (1971) maintain that the classical organization of inorganic, organic, and physical chemistry which largely determines how chemistry is taught is increasingly irrelevant to what is actually done in chemistry. Hammond and Nyholm also describe chemists, in contrast to physicists, as working on molecular rather than atomic systems, on molecular transformations and structures rather than on phenomena associated with simple substances only. Reorganization of chemistry along the lines of structure, dynamics, and synthesis is suggested, as is subdivision into: structure and properties of pure substances, chemical transformations, and chemistry of complex systems. While maintaining that directed explorations in chemistry are grounded in theoretical pictures, Hammond and Nyholm go on to state:

> ... We must recognize that the focus of attention on a single model may seriously inhibit chemical advances. It has been said, and not without a grain of truth, that the factor which distinguishes a chemist from a physicist is that the former argues from 100 weak facts, whereas the latter argues from one strong fact. Without pausing to comment critically on the risks involved in placing too much reliance on one so-called "strong fact," we must concede that chemistry may be a less straightforward subject than physics. The ultimate molecular properties are inferred from indirect measurements, so evidence from many different sources is essential. The emphasis on a single model, may, in fact, distract an investigator from achieving his goal of building better models for molecular behavior.

Any pedagogical structure which is imposed should not create obstacles to learning. Rigid interpretations which may lead to isolation of areas of chemistry from one another are seen as negative. Hammond and Nyholm thus recommend that introductory chemistry should expose the students to some of the interesting problems studied by chemists today and the likely nature of future problems. Mathematical rigor and "good science" are not necessarily synonymous. Elegant mathematical development of a poor theory may make it worse and at the same time stifle intellectual initiative.

How, then, can knowledge in science be viewed in order to present to learners a coherent portrayal of its interactions in a complex and context-embedded science like chemistry? The section which follows will present a set of nine knowledge types and some of the different epistemological goals and values which may be ascribed to each. Subsequent sections will articulate their influences on what impressions students and teachers may generate about the nature of the subject, the kinds of learnings which are valued, and the kinds of intellectual problems which may emerge when different types of knowledge are inadequately differentiated.

Normative Perspectives on Knowledge in Science

Table I presents a set of possible normative perspectives on the nature of knowledge in science. Each perspective, although interacting with one or more others, informs students and teachers about how they are expected to think about the subject, about what kinds of knowledge are to be preferred, and to what kinds of contexts the substantive and methodological aspects of the subject can be expected to apply.

One can ask for each perspective: What kind of knowledge is produced, and how is it valued?

A. Theoretical Knowledge

If current textbooks are any indication, this is the kind of knowledge valued above all else in the sciences. Indeed, Popper asserts "The empirical sciences are systems of theories" (Popper, 1959). What is meant by theory, and where does theory development begin relative to human experiences and observations (Bradley, 1975) are questions not often addressed in school chemistry courses.

Perhaps in part because theory in chemistry is not nearly as extensively examined in its philosophical foundations as is theory in physics, the complex roles and functions of different kinds of theory in chemistry can become troublesome to students. Part of the puzzlement may be attributed to the tendency for chemistry textbooks to ignore such problems - to present chemical theory as clear-cut and self-evident in its properties as a kind of chemical knowledge.

TABLE I

POSSIBLE NORMATIVE PERSPECTIVES ON THE NATURE OF KNOWLEDGE IN SCIENCE

A)	THEORETICAL	- Values theoretical knowledge and theoretical ways of knowing. - Seeks ever greater inclusiveness and predictive power in theory.
B)	EMPIRICAL	- Values knowledge gained by empirical means: observations, experimentation, measurement, etc. - Seeks data.
C)	APPLICATIONAL	- Values practical and instrumental knowledge and the gaining of knowledge in applied contexts. - Seeks ways of using knowledge, functional knowledge.
D)	METHODOLOGICAL	- Values the processes and methods of gaining knowledge. - Seeks problems to solve, criteria for reliability and generalizability.
E)	EPISTEMOLOGICAL	- Values knowledge of the limits and validity of knowledge claims - Seeks to identify underlying assumptions of knowledge claims.
F)	SOCIAL RECONSTRUCTIONIST	- Values social, political and economic components of knowledge, social action/reflection. - Seeks emancipatory change, understanding of socio-political contexts and uses of knowledge.
G)	PSYCHOLOGICAL	- Values knowledge meaningful to the individual as an active participant in constructing these meanings. - Seeks relevant knowledge, personal knowledge.
H)	PEDAGOGICAL	- Values effective and efficient ways of transmitting knowledge. - Seeks to develop literacy, standardization of knowledge.
I)	HISTORICAL	- Values developmental characteristics of knowledge over time. - Seeks retrospective understanding of the origin and impact of ideas.

Examination of chemistry textbooks reveals at least ten different ways in which the idea of "theory" is involved. Each is considered in turn.

1. "Grand" Theory - This kind of theory e.g., structure of matter, atomic theory, thermodynamics, is essentially physics. The context in which the ideas and relationships are used in chemistry differs from its uses in physics both in scale and in the relationships of the results to other kinds of chemical knowledge. The desirable attributes of such theory are often implicitly accepted as the same as in physics i.e., ever greater inclusiveness and predictive power. Individual descriptive contexts are stripped to yield mathematical and symbolic representations. Questions having to do with the functions and desirable attributes of such theory within chemistry and its purposes as basic explanatory notions within the corpus of chemical science are usually left unexamined in presentation of such theory.

2. Theory as key constructs (or concepts) e.g., chemical bond, chemical activity, ion, acid, etc.

Fensham's discussion of the properties of chemical concepts in terms of intention and extension (Fensham, 1975) is useful here. This is the level at which much of what is conventionally viewed as chemistry is grounded both in its pattern of inquiry and its substantive outcomes. This is also the level at which theoretical ambiguities e.g., what is a chemical bond? and conventions e.g., reduction potentials, compound the task of attaching some kind of chemical meaning to the theoretical terms.

3. Theory as prediction/explanation of observation e.g., acid-base theories, types of reaction mechanisms. Much of laboratory work (the laboratory experiment itself may be viewed as a kind of theoretical entity) is directed at such a notion of theory. Patterns of observations provide meaning both in the sense of "extension" i.e., the set of objects or events the term denotes, and "intention' i.e., the property or characteristic which is the criterial attribute. Fensham's discussion of the concept "acid" (Fensham, 1975 p. 201) is a good illustration of this type of theory in chemistry.

The basic assumption in many chemistry courses is that the students know what chemical phenomena are - that they understand the nature of chemical reality. Chemistry curriculum merely provides the explanations. Inability of students to adequately differentiate these kinds of theoretical terms from the other kinds of words used in chemistry may be attributed to insufficient experience with the content-specific, knowledge-rich nature of problem solving in chemistry.

4. Theory as revealed in principles e.g., Avogadro's hypothesis, the "mole concept". Terms such as principle, hypothesis, theory, and law are often used loosely and perhaps even interchangeably in chemical discourse. While it may be

clear to the textbook writer or teacher what these terms mean, the student may not be able to quickly distinguish this type of theoretical statement from others.

5. Theories as idealizations e.g., ideal gas law, Nernst equation.

Relationships such as the above, which are not universals but idealized reconstructions that come complete with assumptions and limiting conditions hold a particular place in chemistry. It seems worthwhile to make the point that the Nernst equation is not the same kind of logical or, indeed, practical entity as w = ctz where w is the number of grams of silver plated out on a teapot as a function of the current time and electrochemical equivalent of silver.

6. Theories as models e.g., electron pair repulsion theory.

Correlation between a priori theory and experimental results forms an integral part of chemistry. However, the value of simple and easily used models for appropriate tasks e.g., use of the above model to predict shapes of selected molecules, needs to be noted. Such model building helps a great deal in stimulating new experiments. The transient character of many such models is an important aspect of the interaction between theory and experiment in chemistry .

7. Theoretical vs. measured.

The variety of meanings taken by the quantitative aspects of chemistry include chemical "theory" e.g., coordination numbers, electronegativity, spectroscopy. The idea of the "theoretical" value of "x" as an expectation and the notion of error of measurement are fundamental in describing much of chemical behavior. Students may find the idea that chemical reactions do not occur in the exact stoichiometric ratios indicated by the equation either intriguing or distressing, depending on their understanding of the characteristics and complexities of chemical "theory".

8. Theoretical vs. practical e.g., Why are some chemical systems of more "interest" than others? How do varieties of chemical theory interact in a "real" problem ? A situation created in a theoretical sense may/may not have a counterpart in physical reality.

9. Theoretical vs. applied.

Distinctions between pure and applied chemistry e.g., lab scale vs. chemical engineering scale, and constraints of "real life" situations e.g., biochemical systems may in themselves be areas of research.

10. Theoretical as abstract.

Chemistry employs a kind of "logical algebra" which forms a basis for communication of ideas e.g., chemical symbolism, stereochemistry. The multiple meanings associated with the symbolism, what is interchangeable in practice and what is not, may be apparent through use as much as by memorizing the formal definitions.

The above relatively lengthy treatment of chemical theory is intended as illustrative of the broad knowledge category of "theoretical" knowledge. Consideration of the sense in which each may be viewed as normative within the discipline, within the curriculum, and within instruction is beyond the scope of the present discussion. Theory also interacts with other varieties of knowledge in a reciprocal manner (Bateson, 1979).

B. Empirical Knowledge

Here we consider the nature and value placed upon knowledge gained by observation, experiment, and measurement. What constitutes chemical data, and on what criteria does one judge its worth? How do the varieties of chemical data pertain to chemical theory?

The chemistry teacher, like the chemist, may experience certain chemical phenomena over and over again in the course of his or her chemistry lessons. The student, on the other hand, may experience the same phenomenon only once, if at all. The complexity of separating out the "scientific observation" from the undifferentiated mass of sense data which the student assimilates is, it is suggested, severely underestimated. It is also crucial to developing a sense of what is meant by scientific data. As an illustration, it may be difficult for students to understand that even though one can calculate the mass of an electron from e/m and the Millikan oil drop experiment, it is quite another thing to treat it conceptually in the same way as, say, the molar mass of sulfur.

Several kinds of chemical data may be identified:

1. results of key experiments in theory building and theory validation e.g., Rutherford's alpha scattering, Stern-Gerlach experiment. As pointed out by Kuhn (1970) part of the value of such data lies in the historical and/or standardized knowledge realm. Any examplar or instance is not suitable here. It needs to be the particular one in order to be part of the "shared paradigm" of chemistry.

2. key experiments or observations with implications for theory revision e.g., experiments that have yielded the unexpected - ferrocene, the xylenes, the so-called "inert" gases.

3. normal science - the mass production of chemical knowledge. The results turn out more or less as expected and any of a range of exemplars will do.

4. tricky practical/applied problems e.g., catalysis. Not all common or well-documented chemical observations have well-documented explanations.

5. data related to the development and availability of specific instrumentation e.g., spectroscopic techniques, computers.

The value placed on data, particularly data experienced by the student is highly problematic in chemistry curricula. In addition to the subtle and complex interrelationships with theoretical knowledge, the everyday language of description used in conjunction with chemical data conveys its own set of images. The widespread use of particular adjectives to denote colors is a case in point. Chlorine gas is "greenish-yellow", litmus is "red" while phenolphthalein is "pink" etc. The student's sense perceptions of the colors may be quite different from the formalized descriptions which are learned.

C. Applicational knowledge

This type of knowledge places high value on the practical usefulness of knowledge in real contexts and its worth is often contrasted with theoretical knowledge in this regard. The translation of theoretical knowledge to a form suitable for solving particular problems or meeting particular goals may itself be complex. Practical problems typically involve interactions among a much larger number of variables than found in theory-directed problem solving situations. After virtual disappearance in many of the science curricula of the 1960's and 1970's, applied chemistry is slowly being re-introduced in a number of recent school textbooks.

D. Methodological or procedural knowledge

The knowledge inherent in mastery of the techniques and procedures employed in a branch of science is an intergral part of that field. Such knowledge is at best only partially described by phrases such as "the scientific method" or "the process of science". As an illustration, the procedural knowledge inherent in knowing how and when to do a redox titration is not the same as knowledge of the methods of science. As noted earlier, problem-solving in chemistry tends to be more content-specific than in physics and the resulting solutions more localized in their range of application. Casting chemical problems into forms which are potentially solveable and establishing appropriate criteria for reliability and generalizability are a function of ingenuity and practical skill as much as they are application of broad algorithms. When one examines what chemists do, the listing of procedures and/or techniques is relatively brief (Fensham, 1984).

For the novice, the language used in conjunction with chemical procedure may invoke its own ambiguities e.g., "... is treated with an excess of...". which need to be treated explicitly in chemistry instruction.

The above four varieties of knowledge together form the group which has dominated the sciences and science curricula to date. The five kinds of knowledge to be enumerated in the sections which follow are more recent in their emergence as curriculum-related perspectives to be taken on knowledge in science. Given the very large amount of knowledge in each of the above four types which is available today relative to the amount that can be included in any one curriculum, the value of the kinds of knowledge now outlined may also reside in their usefulness in providing starting points for establishing selection criteria for such inclusion.

E. Epistemological Knowledge Perspective

The present discussion may be viewed as an exercise in epistemological knowledge. The goal is to identify underlying assumptions of knowledge claims and to develop understanding of the range of applicability, limits, and validity of that which is presented as knowledge in a field. Matters to be considered include what constitutes logic in chemical reasoning, what are the varieties of chemical argument e.g., symbolic, mathematical, reaction mechanisms, and how are these assesed? The need for this type of knowledge to be made explicit in science teaching is stressed by Desautels (1982), who refers to it as a critical view of knowledge.

In the realm, of chemistry, students can easily leave their high school courses with impressions such as: all chemical reactions occur very quickly, all chemical reactions go to completion, all acids are liquids, and other assorted misconceptions. Teachers tend to present only positive exemplars i.e. instances where a particular concept applies. Negative exemplars, also necessary for concept formation (Bruner, Goodnow and Austin, 1956) are rarely noted. It is therefore not surprising that students leave instruction in chemistry with little idea of the range of applicability of the concepts and theories they have learned.

It can be argued that skill in applying epistemological judgments to scientific presentations may be <u>the</u> crucial skill in science-related reasoning for the average person to acquire. As citizens, social issues having scientific components confront us with increasing regularity. How is one to assess the relative merits of competing scientific positions? Science courses which explicitly deal with such critical reasoning within the context of the other varieties of knowledge presented can develop such skills in students, incidentally also giving the student a more authentic view of the development of the field.

Not all theoretical propositions within chemistry have equal "value" in adding to our understanding of the chemistry of matter. Accounts of attempts to improve this understanding and the relative success and failure of various ideas can do much to provide the student with insight into chemistry as a human activity. In one sense all the other perspectives may be viewed as varieties of epistemological perspective.

F. Social Reconstruction Perspective

Understanding of the socio-political contexts and uses of scientific knowledge is often mentioned in the context of scientific literacy. As with epistemological perspectives, evaluative dimensions are salient here. Social, political and economic components of chemical knowledge e.g. areas of inquiry to be developed or closed, scientific research which is classified and/or developed with the support of the military, the ethics of nerve gases, and a host of other issues of the uses and abuses of scientific knowledge, warrant examination. The idea of neutral, value-free knowledge is increasingly seen as a myth. Contemporary chemistry courses need to acquaint learners with some of the current (and historical) dilemmmas which have a chemistry component. This should not be left entirely to the social studies courses.

G. Psychological Perspective

All of us - including students and scientists - participate in constructing our ideas about the world. This perspective on knowledge values the personal meanings and interpretations held by persons as a result of their participation in the process of construction. Personal relevance and the ability to use the ideas in interpreting specific situations, making decisions, and solving problems are viewed as outcomes of such knowledge. Termed the generative learning model (Osborne and Wittrock, 1985) and based broadly on constructivist theory, the nature of personal science knowledge frameworks and alternative conceptions or explanations are currently active areas of research (White and Tisher, 1986). While the extent of individual capacity to assimilate and compartmentalize inconsistent information has been noted by teachers as well as researchers, its effects on the ability of individuals to integrate such pieces is not well understood. Perhaps what should be studied are persons who have performed such integration in a functionally productive way i.e. the nature of scientific "talent" or scientific-intuition as an adjunct to identifying and describing the various personal conceptions which the population at large may hold.

What attracts individuals to a given field? What are the characteristics of productive collaborations and how do centers for a particular line of research develop? What factors influence intellectual commitment to a particular theory or problem area? How is the "business" of science e.g. patents, publication, organization of the research team, carried out and are there differences here in the pure and applied areas?

H. Pedagogic Perspective

The codification, standardization and transmission of scientific knowledge involves modifications along the way (Ravetz, 1971). The major elements may be portrayed as:

research data → research paper → research review → textbook → ccurriculum

Criteria for selection and interpretation operate at each step. What is included, what is omitted, and what is emphasized is a function of the orientation of the person toward the other varieties of knowledge enumerated here. The relative influence of the other perspectives may result in curricula with somewhat different emphases for the training of research chemists, applied chemists, chemical engineers, other chemistry-related occupations e.g. pharmacy, food sciences, or chemistry teachers. How the context in which one learns chemistry (pure chemistry, engineering, applied courses, honors thesis, general education, etc.) influences how one presents the key ideas to others - one's choice of sequence, examples, and language used - may be a useful extension of teacher background variables, more often than not presented only as numbers of courses.

Some preferred pedagogic approaches and modifications may also evolve as a result of teaching experience. It is widely accepted that some ideas e.g. acid/base theory are introduced in an historical context while others e.g. reaction mechanisms are rarely treated in this manner. Some ideas e.g. "diagrams" of atoms appear in chemistry textbooks primarily as pedagogic rather than scientific entities. It might be helpful to point out to the learner when such pedagogic simplification and generalization is taking place and the purposes that it serves. The same might be said for the analogies and metaphors which are introduced as aids to description and understanding. Appreciation of the power of a good model or metaphor is an important element in scientific thinking.

Psychological and pedagogic perspectives on knowledge are often interrelated and the psychological can at times act as a barrier to the pedagogic. The portrayal of molecular geometry on the printed page is a common example of such a problem in chemistry teaching. Despite one's best efforts, stereochemistry becomes distorted and its perceived relationship to the chemical behavior of these entities vague and inconclusive. Are there key problems and examples which are essential to the development of chemical understanding and if so, what might these be?

H. Historical Perspective

The history of chemistry is usually portrayed as originating in alchemy. While such an historical emphasis might intrigue the learner, it fails to give account of the extensive applied chemical knowledge that has existed in human society since ancient times e.g. preserving of foods, fermentation, dyes, medicines, the making of paper, cloth, glass, pottery and numerous other items. Chemistry has been and to a significant extent remains today a practical science. It is also in this context that problem-solving in chemistry is referred to as a knowledge-rich task.

Understanding of some key concepts in chemistry and the language used in conjunction with these concepts e.g. acid, oxidation, and ion may be enhanced by tracing through their historic roots. The conceptual anomalies created by chemical terminology in particular seem to call for such treatment in instances where the current usage of the term has departed widely from its historic origins. Oxidation-reduction is among the most problematic areas in this regard for many learners.

A Multi-Perspective Approach to Curriculum

The above represents a brief exposition of some of the perspectives that may be taken on knowledge in science. Other possibilities are not ruled out. Each perspective involves value judgments about the kind of knowledge it encompasses. Factor and Kooser (1981) have identified such value judgments in a comprehensive listing of currently available chemistry textbooks designed for college science non-majors. These cover a range of social, political, and economic issues which include a chemistry component as well as the impressions of the nature of science and scientific method. A similar kind of analysis is also much needed for existing high school chemistry textbooks.

Recommendations by Connelly (1972) that a curriculum present a sufficiently clear exposition of its epistemological basis to permit a clear choice among alternatives support Walker's (1971) suggestion that the "platform" of the curriculum writers be set out as an explicit part of the curriculum material. The teacher can then choose from among the available perspectives and implement that particular view in a way appropriate to the characteristics of the class. The variety of theoretical, applied, environmental, and practical chemistry curricula which are currently in existence attest to the viability of this approach.

Another approach is also possible. It should be pointed out that just as it is possible for an individual to hold a variety of perspectives on the nature of knowledge, including knowledge in the scientific and technological realm, curriculum and instruction can also reflect a multiplicity of perspectives within a coherent organizational framework. No one perspective, no matter how well developed, is adequate in reflecting the plurality of perspectives which can be used in relation to the subject. Indeed, it could be argued that study of one single science subject or specialization is itself not a sufficient vehicle for promoting an awareness of science. We live in a pluralistic world, with numerous alternatives for approaching it and learning to cope with it and students need to be taught how to examine matters from a number of alternative perspectives. The linear, cumulative, top-down ways of thinking and of representing science are declining in usefulness in the present human context and, at some level, our high school students are aware of this.

A more immediate practical problem is the boredom that quickly sets in when only one perspective is emphasized, whether it be societal, historical, theoretical, or whatever. No one perspective can be clearly designated as the "correct" one. All are right and all are wrong at the same time, but all are useful in that they represent different ways of viewing the subject and different starting points for inquiry. Students can be taught how to approach chemistry as well as other areas of science with this type of orientation in order to think in an integrated, holistic way about the nature of science. Such perspectives are not mutually exclusive, but interact in many subtle ways.

Can this be done within the framework of a single curriculum? Can this be done to produce a coherent integrated course, or will the product be piecemeal, fragmented, and lacking in academic rigor? Clearly this is a question that cannot be answered in simplistic terms. Various alternative ways of approaching a multi-perspective curriculum organization will need to be devised, implemented and assessed. The view that since knowledge is relative hence it does not matter what we teach is <u>not</u> what is being said here. Obviously, it does matter, but what and how to teach those aspects of science that reflect the current nature and importance of the field in ways that are meaningful to more than the college-bound in the area requires innovation and exploration.

What are some of the curricular questions accompanying the design of a multi-perspective approach and what would these materials look like? A partial listing of such questions might include:

A. Value-Related Questions

1. Why should value/contextual dimensions be incorporated?

2. What perspectives and whose perspective should prevail?

3. What contribution does the student make in developing his/her own world view?

4. What contribution does the teacher make in response to local and situational demands?

B. Applied-Instrumental Questions

1. What are some specific ways to make a course multi-perspective?

2. What would the textbook and other instructional materials look like?

3. What would the laboratory and course assignments look like?

4. What would the classroom teaching and evaluation look like?

One approach which is meeting with acceptance among chemistry teachers in Canada and elsewhere is reflected in the ALCHEM chemistry program (Jenkins et. al, 1981). ALCHEM is a two year high school chemistry core-elective program which was written, piloted, evaluated, and repeatedly revised by a team of chemistry classroom teacher-authors. The ALCHEM project is of interest to the field of curriculum study because of the relatively uncommon long-term teacher control of all aspects of the program. The teachers were and are more than just members of a writing team or implementers of a program designed by someone else. As a result of over ten years of intense writing, classroom use, and revision, a classroom-oriented approach has been generated and used by the group which questions many of the traditional views of curriculum and curriculum materials. One of its approaches is the evolution of a multi-perspective approach to knowledge in chemistry and the design of teaching methods to implement this approach in the classroom.

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APPENDIX B

Appendix B1

ALCHEM Description

The content and format of the ALCHEM materials are unique in at least three ways: a) applied and descriptive chemistry are integrated with chemistry theory: b) the academic level of the chemistry content is kept at a university entrance level even though the context for the chemistry content is applied and descriptive chemistry, and c) the three student core books consist of pages which can be inserted into student loose leaf binders. In its present form there are three core books and seven elective units in the ALCHEM program. The core books are called ALCHEM 10, ALCHEM 20, and ALCHEM 30, and can be used as the basis of two half-courses and one full course, respectively, or with two full courses. Each core book contains the following features: statements of behavioral objectives, explanations of chemical concepts and principles, information about the sources and uses of chemicals, student exercises, sample solutions, outlines for teacher demonstrations, laboratory exercises, and a special edition of the periodic table. The core books are divided into units that cover specific topics. Within each unit, student laboratory work, teacher demonstrations, and student exercises are integrated with the textual material. Teachers' guides are available for each of the core books. The elective units are titled, Foods and Their Analogs, Athabasca Tar Sands, Analytical Chemistry, Nuclear Chemistry, Metallurgy and Corrosion, Ethylene and Its Derivatives, and Alberta Chemical Industries. In addition, a test item bank, a data sheet, and four wall charts have been produced to supplement the ALCHEM texts. The textual materials were written and edited by a group of teacher-authors, The Author Group, Inc.

ALCHEM 30

Unit L Topics: Energy (L1-L34)
- L1 Objectives, Introduction (phase, chemical and nuclear changes)
- L5 Biography: James Prescott Joule (1818-1889)
- L6 Heat Lost = Heat Gained
- L7 Measurement of Energy Change
- L10 Phase Changes; Molar Heat of Phase Change
- L12 Lab L1 - Molar Heat of a Phase Change
- L15 Chemical Change
- L16 Molar Heat of Chemical Reactions
- L17 Lab L2 - Molar Heat of a Chemical Change
- L20 Representing Energy Changes
- L22 Predicitng Heats of Reaction (from molar heats of formation)
- L30 Comparing Phase, Chemical and Nuclear Changes
- L32 Overview

STSC Chemistry Project

1. Project Objectives

Goals and Results

The following goals (numbered) and anticipated results (lettered) have been developed by our Group over the past three years.

1. To present, in a manner suitable to the sophistication of our high school students, the widespread use of technology in our Canadian society, and the nature of technological development as a scientific endeavor.

   a. All questions in the student curriculum materials will be in a context of the nature of science, the nature of technology, and/or technological examples of the theoretical or empirical content being studied. The students will see an emphasis placed on examples of Canadian technology and Canadian technological development (as a process). The students will see the science presented in a less sterile, more contextual manner.
   b. Students will be asked to differentiate between a theoretical and an empirical way of knowing (way of gaining knowledge), to be aware of the interaction between these two ways of knowing, and to recognize that either way of knowing may lead the scientific endeavor.
   c. Students will be asked to apply the theoretical and empirical knowledge and ways of knowing learning towards the prediction of solutions of problems set in a "real" context.
   d. The curriculum materials will lead the students through a series of technologies [illegible] illustrate the nature of technological development. Examples of the development of chemical processes (e.g., the chlor-alkali process, the Hall-Herault process, and the polyethylene production) will be presented as the context for the content line being presented in each unit or chapter of the textbook.
   e. Example test items and tests will be available to teachers to illustrate how test items can be written in science, technology and society contexts. Sterile (acontextual) questions are now the norm. A national STS test (i.e., a competition) may result from this initiative.

2. To present in simple fashion the nature of the scientific endeavour and to present the similarities and differences between science, technology and other ways of knowing about our world and of problem solving.

   a. One core unit at each of three levels of chemistry will integrate into the content textual material, questions, examples, experiments, and demonstrations a nature of science emphasis.
   b. Students will be able to use a simple model to list the attributes of [illegible]table scientific theory (e.g., it explains, predicts, and is simpler than competin[illegible]es) and compare these attributes to a law or generalization (which predicts but do[illegible] explain).
   c. Students will experience the process of falsifying various scientific theories and laws as they progress through their chemistry course. They will be going to the laboratory to falsify or verify the predictions that they have made based upon the current theory or law that they are using. If they falsify the theory then the theory will have to be made less restricted or the restrictions will have to be made conscious for the continued use of the falsified theory.
   d. Students should have a better feel for the way in which the scientific endeavour "progresses", and for the wealth of evidence in support of most scientific ideas. For example, the VSEPR theory of Canadian chemist, Ron Gillespie will be used to show the acceptance of a theory and its superiority over other theories or empirical rules.

3. To foster an understanding of the inter-relationship between science, technology and society in societal issues.

   a. Students will learn to classify perspectives taken in a STS issue. Our Group has modified a scheme developed by Glen Aikenhead in his text Science: A Way of Knowing, whereby perspectives on an issue are classified as aesthetic, ecological, economic, emotional, ethical, legal, militaristic, mystical, political, scientific, social, and technical.

b. Suggestions and examples for the use of STS videotapes, magazine articles and newspaper articles in the classroom will be provided for teachers. For example, the videotape series "Renewable Society", "Dimensions in Science", and "Connections" will be recommended. Students will be asked to classify the perspectives presented within the media and to identify the major perspective taken and the perspectives not presented.

c. Students will be asked to write answers to questions concerning the importance of scientific literacy within a technological society (i.e. the importance of the "scientific" and "technical" perspectives on major issues in a technological society).

d. The curriculum materials will ask questions which will help them gain an appreciation for the need for social responsibility by scientists and engineers and for informed debate by citizens and politicians.

e. Students will be asked questions which will lead to an understanding of the language of uncertainty or certainty used by scientists and engineers when addressing STS issues.

4. To increase the students' ability to communicate in a scientific manner, expressing the appropriate uncertainty and appealing when necessary to the nature of science and technology as justification for acceptance or rejection of an idea, theory or law.

a. the curriculum materials will be written in an exemplary way to illustrate the language of science and engineering (e.g. "Use the Stoichiometric laws to predict ...", "The scientific community currently supports the explanation that ...", "There is evidence to suggest that ...", and "Empirically it can be shown that ...".

b. Students will be asked to underline the scientific language in provided articles describing scientific and technological developments. (e.g. we have used an article written by Canadian chemist, Ron Gillespie in defense of the VSEPR theory in this manner and all indications are that students can complete this exercise well).

c. Students will be asked to rewrite (add phrases to) a given article that has the qualifications and expressions of uncertainty removed and compare their revision to the original.

d. From the beginning of the course students will have to use a system of communicating the uncertainty of quantitative measurements and predictions (e.g., significant digits and expression of uncertainties). The sophistication of this system will be increased as the course progresses (e.g., the gradual introduction of terms such as "precision", "accuracy", "reliability", "validity", and "systematic error").

e. At the upper level of the course exercises will be provided that will ask students to compare the way in which general citizens, scientists and engineers communicate, and how communication problems may arise as a result of the differences.

5. To facilitate the students' ability to employ specific scientific skills (both natural science and technologically oriented) in a problem solving environment.

a. The curriculum materials will be written requiring the students to employ a wide variety of scientific problem solving skills, as identified by research as being skills used by scientists and engineers in their work (e.g., problem defining, seeking information, hypothesizing, designing experiments, establishing procedures, observing and interpreting data).

b. Students will be asked to complete laboratory work in an increasingly independent manner (e.g., they will increasingly be responsible for the design of experimental work and research).

c. Students will be asked to identify and display such scientific attitudes as have been identified by research (e.g., honesty, open-mindedness, objectivity, suspended judgment, respect for evidence, willingness to change, critical mindedness, and questioning attitude).

d. The curriculum materials will attempt to ask students (1984-05) to identify and display the skills and attitudes of engineers at work. (What the Science Council Science Education Study (1984-05) suggests no textbook which they analyzed has done before).

e. The curriculum materials will provide a Canadian context for illustrating the work of scientists and engineers.

Science in Society Issues

Quantitative Predictions in Chemistry

D

Nature of Technology

STSC Reference Materials

Overview of Emphases

Contents

Instructions

- Study these outlines. At this stage everyone should be intimately familiar with all aspects of all emphases.
- Keep these summaries handy as you revise/develop units. They are a required reference.
- Ensure that the objectives indicated are being met in appropriate units of each of STSC CHEMISTRY 20 and 30.
- The attached summaries should also be used to generate student objectives for the beginning of an STSC unit.

STSC 20/30 General Guidelines for Exercises

1. A lot of "cleaning up" was done on the format in STSC 10. Refer to your copy of the 10 materials to be consistent in our approach; e.g., stoichiometry examples.
2. Use whole or part page dealing with a single context and preface with an introductory paragraph.
3. Use 1-2 sentence context within a exercise question and a 1 sentence context within a test question. Separate context by a space (1/2 line) from the actual question.
4. Use more qualitative questions that require a written English sentence answer.
5. Use given evidence/information to meet scientific skill objectives regarding corresponding to the titles of lab outline.
6. Include scientific skills practice within exercises. Ask for the written and quantitative prediction (STSC format) rather than just quantitative prediction. Ask for procedure rather than the steps; e.g., preparation of solution. Ask for identification of variables.
7. Use diploma exams as guide for questions.

STSC 10	STSC 20	STSC 30	
✓			**Definition of Science°** (new) Science is the study of the natural world in an attempt to describe, explain and predict natural products and processes.
✓			**Scientific Knowledge**

Types (p. A5)	Communicated by (pp. A5,A21)	Characteristics (pp. A5,A21)
empirical	statements, tables, graphs empirical definitions generalizations scientific laws	- describe/classify observations, predict new observations, simple (easily understood
theoretical	theories, models, analogies statements theoretical definitions	- explain current evidence, predict new observations simple (easily understood)

STSC 10	STSC 20	STSC 30	
✓			**Scientific Ways of Knowing** 1. empirical - knowing from experience or experiment (See Scientific Skills) - knowing from predictions from laws or generalizations 2. theoretical - knowing from explanations from theories - knowing from predictions from theories 3. empirical/theoretical - knowing by combining theories, laws, generalizations and/or experience (TLGE) 4. other ways - memorizing knowledge - referencing knowledge - being given knowledge
✓			**Stating the Limitations of Scientific Knowledge** 1. Expressing the certainty A. using scientific language (appeal to evidence; expressing uncertainty) B. using quantitative certainty (significant digits) C. using a number of types of ways of knowing
✓			2. Recognizing the life cycle of TLGE
✓			3. Acknowledging alternate perspectives (e.g., social)
		✓	4. Stating assumptions and restrictions (See Scientific Skills.) A. assumptions - presuppositions that can not or are not tested. B. restrictions - contexts within which the TLGE works
		✓	5. Acknowledging the reductionism in scientific knowledge
	✓		**Ways of Testing Scientific Knowledge** 1. Attempting to verify predictions from TLGE by repeating procedures from previous experiments (See Scientific Skills.)
		✓	2. Attempting to falsify predictions from TLGE by devising new problems and experimental designs (see Popper)
	✓		3. Evaluating the logic of explanations made by theories
		✓	4. Attempting a social acceptance of scientific knowledge within the scientific community (see Kuhn)
			Scientific Attitudes (See Scientific Communication.)
			Scientific Skills (See separate outline.)

STSC 10	STSC 20	STSC 30	
			Clarify Problems
		✓	1. Recognize discrepant events and possible relationship to subject matter.
✓			2. Identify specific possible variables.
	✓		3. Identify possible relationship among variables based on theory, law or generalization.
		✓	4. Formulate problem to test prediction of theory, law or generalization.
		✓	5. Formulate problem to test unexpected event not predicted by theory, law or generalization.
		✓	6. Formulate problem to test event not explained by current theory.
		✓	7. Distinguish relevant from irrelevant information.
		✓	8. State assumptions and/or restrictions.
		✓	9. Collect background information.
			Design Experiments
✓			1. Choose general method for solving a problem.
✓	✓		2. Determine techniques appropriate to the problem.
✓			3. State manipulated and responding variables.
✓			4. State controlled variables.
		✓	5. Identify controls.
		✓	6. Choose appropriate intervals for the manipulated variable.
			Make Predictions
✓			1. Use the format "According to ... [TLGE] . . [prediction]" to structure predictions.
	✓		2. Use manipulated (if) and responding variables (then) whenever appropriate.
✓			3. Predict qualitative answer to problem based on empirical or theoretical knowledge.
✓			4. Communicate prediction calculation for quantitative predictions.
			Write Procedures (c/w Materials and Tables of Evidence)
✓			1. Choose specific equipment, reagents and techniques. (Materials)
✓			2. List quantity and size of all materials. (Materials)
	✓		3. Prepare labelled diagrams to summarize equipment or to clarify apparatus.
✓			4. Design appropriate tables of evidence and lists to collect anticipated evidence. (Evidence)
	✓		5. Descirbe the purpose of a procedural step.
✓			6. Number each individual step in an appropriate sequence.
✓			7. State safety and waste disposal steps.
✓			8. State common techniques as single general step.
	✓	✓	9. Determine an appropriate number of trials (i.e., repetitions).
✓			10. State quantities and precision for all measures.

STSC 10	STSC 20	STSC 30	Skill
			Collect Evidence
✓			1. Observe and record all evidence in a clear, complete and appropriate form.
✓	✓	✓	2. Observe and record all unusual, unexpected or questionable evidence.
✓			3. Record evidence honestly using appropriate units, certainty and precision.
✓			4. Distinguish between observation and interpretation.
✓			5. Observe and record evidence in quantitative terms whenever appropriate.
	✓		6. Repeat observations and measurements for questionable evidence.
		✓	7. Adjust procedures where they are found to be inadequate.
✓			8. Estimate quantities where precise measure is not possible or necessary.
			Analyze Evidence
✓			1. Classify and order evidence to identify trends.
✓			2. Design charts or tables to reorganize evidence.
✓	✓	✓	3. Select and apply suitable mathematical treatments.
✓			4. Use appropriate units and calculation rules (certainty and precision).
	✓		5. Present evidence in neat, labelled graphs whenever appropriate.
✓			6. Write empirical definitions.
		✓	7. Produce "best fit" lines for graphs.
	✓		8. Determine best averages in the case of multiple trials.
✓			9. Determine accuracy (percent error) of empirically determined values.
		✓	10. Identify anomalies in evidence obtained.
		✓	11. Decide whether some contrary evidence collected should be ignored or not.
			Evaluate Experiment
✓			1. Answer the problem statement using the analysis of the evidence.
✓			2. Evaluate the prediction by indicating whether the evidence supports or conflicts. A. Display honesty and use scientific language to reflect appropriate level of certainty.
	✓		B. Recognize acceptable accuracy.
✓	✓	✓	3. Evaluate the TLGE used for the prediction as supporting or conflicting in terms of the empirical or theoretical knowledge used. A. Suggest whether the empirical or theoretical knowledge used to make prediction needs to be restricted, revised or replaced.
		✓	4. Evaluate the experimental design considering variables, precision, completeness and equipment. A. Indicate limitations and source of errors (random and/or systematic).
		✓	B. Suggest improved design and procedure.
		✓	C. Suggest additional problems to investigate.
		✓	5. Suggest new TLG to replace a falsified TLG.
✓	✓	✓	**Problem Solving**

STSC 10	STSC 20	STSC 30	
			Comparing Science and Technology
✓			1. Define science and technology. Science is the study of the natural world in an attempt to describe, explain and predict natural products and processes. Technology is the study, production or use of a ~~man-made~~ product or process.
✓ D1			2. Identify five contrasting key words comparing science and technology.
✓ D2			3. Classify scientific and technological questions or statements.
Q	✓		**Characteristics of a Technology** Acceptable to the Engineering Community • economic (profitable if produced; least expensive if used) • works (fulfills its function, reliable, relatively maintainance free) • simple (easily used or produced)
			Categories of Technological Understanding
✓	✓	✓	1. Technological Information of Interest (e.g., Space Shuttle)
✓	✓	✓	2. Technological Products
	✓	✓	3. Technological Processes (See Technological Skills.)
✓	✓	✓	4. Technological Communication (See Communication.)
✓	✓	✓	5. Technological Skills (See separate outline.)
✓	✓	✓	6. Technology-Science Interdependence
	✓	✓	7. Technology and Societal Change
✓	✓	✓	8. Technological Design Problem Solving (See Technological Skills)
			Technological Products
✓	✓	✓	1. Memorize uses of certain chemicals (• in STSC 10).
✓	✓	✓	2. Identify users of industrial products - consumer - commercial - industrial
			Technology-Science Interdependence
✓			1. technology leading science
✓			2. science leading technology
		✓	3. science/technology dialectic
			Technology and Societal Change
	✓		1. Classify perspectives on a technology. (Use the perspectives outline on the Science in Society Issues sheet.)
		✓	2. Identify/write positive and negative statements on perspectives on a technology.

STSC 10	STSC 20	STSC 30	
			General Technological Skills
✓	✓	✓	1. Use a calculator correctly and efficiently.
✓			2. Use appropriate safety apparatus (clothing, goggles, eyewash apparatus, fire extinguishers and waste disposal equipment).
✓	✓		3. Read instruments to the limit of their precision.
✓			4. Handle instruments in a manner that will avoid damage to them.
✓			5. Read instruments to avoid errors due to parallax.
			Laboratory Equipment Identify major parts, describe accepted procedure and demonstrate technological skill in the operation of the following laboratory equipment.
✓			1. laboratory burners
✓			2. centigram balances
✓			3. conductivity apparatus
	✓		4. volumetric flask
	✓		5. delivery pipet
		✓	6. graduated pipet
	✓		7. buret
		✓	8. voltmeter (multimeter)
		✓	9. pH meter
		✓	10. calorimeter
			Laboratory Procedures Describe and demonstrate the accepted procedure for each of the following techniques.
✓			1. shaking a stoppered test tube
✓			2. transferring a solid
✓			3. obtaining a specific mass of a chemical
✓			4. filtering a precipitate
✓			5. testing for the presence of water, oxygen, hydrogen, carbon dioxide, acids and molecular substances
	✓		6. testing for saturated and unsaturated hydrocarbons, polar and nonpolar liquids
	✓		7. preparing a standard solution from a solid
	✓		8. preparing a standard solution from a concentrated reagent
	✓	✓	9. titrating to determine the concentration of an acid/base or OA/RA.
			Technological Processes Draw a diagram of and/or describe the technological process in important industrial applications.
	✓		1. solution mining (sodium chloride, sodium sulfate)
	✓		2. contact process (Solvay, sour gas plant, sulfuric acid production)
		✓	3. electrolytic refining (copper, magnesium, aluminum, chlorine)
		✓	4. reduction refining (iron, copper, phosphorus, aniline)
	✓		5. distillation
			Technological Problem Solving
✓			6. trial and error
	✓		7. empirical knowledge
		✓	8. integrated empirical/theoretical

Teacher References

SISCON - Ingredients for a Successful Technology (Invention)

1. market pull
2. scientific knowledge
3. technological research (experiments, prototypes, inspiration)
4. invention push
5. patents

The Technology Connection by CommCept
When studying a technology keep in mind:

1. materials
2. energy
3. tools and techniques
4. capital
5. labor
6. knowledge
7. organization of work
8. values and attitudes
9. change
10. impact

Issue ______________________________ Name ______________________

1. Aesthetic

2. Ecological

3. Economic

4. Emotional

5. Ethical

6. Legal

7. Militaristic

8. Mystical

9. Political

10. Scientific

11. Social

12. Technical

Issue Perspectives

10	20	30	Perspective	Meaning
|	|	|	ecological.	relationship between living things and the environment
|	|	|	economic	production, distribution and consumption of wealth
|	|	|	political.	government and affairs of state
|	|	|	scientific	researching, explaining and predicting natural phenomena
↓	|	|	technological . . .	development and use of machines, instruments and processes
	|	|	ethical.	questions of right and wrong; moral conduct or duty
	|	|	legal	laws; constitutional rights
	↓	|	social.	dealing with relations of humans, community and society
		|	aesthetic	sensitive to beauty; artistic; good taste
		|	emotional	strong feelings (as opposed to reason); excitement
		|	militaristic.	war and aggression
		↓	mystical.	spiritual meaning; mysterious (unexplained and nontestable)

STSC 10/20/30 Objectives

10	20	30	Objective
|	|	|	1. Classify given single sentences.
|	|	|	2. Recognize definition of each perspective.
↓	|	|	3. Exhibit tolerance for the perspective(s) of other people.
	|	|	4. Classify and underline perspective phrases in each sentence in a short paragraph.
	↓	|	5. Evaluate a technology from a multiperspective approach.
		|	6. Define any one of twelve perspectives.
		|	7. Collect phrases and/or sentences that reflect twelve perspectives.
		|	8. Write short statements illustrating a given perspective.
		↓	9. Recognize the need for a multiperspective view of an issue.

<u>Note:</u> Union of Concerned Scientists; Physicians for Social Responsibity; certain scientists (Bohr, Einstein, Suzuki) as sources of examples of certain perspectives.

Scientific & Technological Communication

STSC 10	STSC 20	STSC 30	
			Attitudes
✓	✓	✓	1. Appeal to the nature of science and technology.
✓			2. Realize the need for international communication.
✓			3. Value preciseness and conciseness.
✓			4. Question unsupported statements.
✓			5. Communicate honestly.
		✓	6. Recognize restrictions.
	✓		**Language (Talk)** 1. Identify/classify scientific language (e.g., Gillespie article).
✓	✓	✓	2. Use nature of science terms (e.g., theoretical, evidence).
✓	✓	✓	3. Use nature of technology terms (e.g., high and low tech.).
✓	✓	✓	4. Use science terms (e.g., element, stoichiometry, solute, oxidizing agent).
✓	✓	✓	5. Use technology terms (e.g., buret, filter system, bubble caps).
✓			6. Express uncertainty or tentativeness of scientific knowledge.
✓			7. Appeal to evidence.
✓			8. Translate international chemical formulas into IUPAC English names.
✓			9. Translate quantity, unit and numeric symbols into English.
		✓	10. Analyze nature of language (media; public versus private among scientists).
✓			**Communication Systems** 1. List three characteristics of scientific communication systems. • international (meaning of symbols) • precise (restricted to specific phenomena) • simple (easily understood)
		✓	2. Recognize anomalies to the three characteristics. • classical/systematic systems in use (e.g., acid nomenclature) • duplication of terms largely due to social characteristics of scientific community (galvanic cell/voltaic cell/electrochemical cell; dissociation/reaction with water; heat of reaction/enthalpy)
✓			3. Recognize and use examples of communication systems. • IUPAC chemical symbols, nomenclature and quantity symbols • SI units and unit symbols • mathematical expressions • quantitative certainty (significant digits) and precision (place value) • perspectives on social issues
✓			4. List kinds and characteristics of definitions. • empirical definitions (in terms of chemical and physical properties)
✓			• theoretical definitions (in terms of theoretical entities and processes)
		✓	• arbitrary definitions (in terms of conventions established)
✓			**Process Skills** 1. Use scientific process skill words (e.g., predict, analyze, evaluate).
✓	✓		2. Use technological process skill words (e.g., titrate, filter).
✓			3. Order data concisely and clearly in tabular form.
✓			4. Present organized written reports on laboratory activities.
✓	✓	✓	**Problem Solving Situations** 1. Apply all of the above categories appropriate to communicating logical solutions to scientific and technological problems.
		✓	2. Differentiate between communication used in scientific and technological problem solving.

Appendix B5

Scientific Language in the Classroom

Scientific language in the classroom may appear in a variety of contexts. Scientific language may involve:

1. precise scientific content words such as *work, reaction, element, energy, and stoichiometry*.
2. a description of the nature of the scientific enterprise including words such as *theoretical, empirical, restricted, predict, explain, falsify, and verify*.
3. an appeal to the evidence that supports or conflicts with a prediction made by a theory, law or generalization.
4. an expression of uncertainty using phases such as *according to the Law of ....*
5. scientific process words such as *predict, infer, interpret, hypothesize, observe, and describe*.
6. technological application words such a *hardware, microchip, lazer, IC, fuel cell, and LCD*.
7. technological process words such as *fractional distillation, coking, refining, in-situ, and retrofit*.

The list could increase significantly as one takes a less restricted view of what science and in particular science education encompasses. For purposes of this workshop the discussion of scientific language will be restricted to an attempt to increase the use of scientific language in the classroom in the areas of *nature of science, appeal to evidence, and expression of uncertainty*.

The following is a list of phrases and sentences taken from three classroom lessons taped within a two day period of time. The list is quite restricted and should be expanded upon as more and more observations are made.

Sample Scientific Language from the Classroom

1. We went into the lab to test the predictions ....
2. ... which ultimately becomes a test of the generalization used to make the prediction.
3. ... we are going to have to reject the generalization ... falsify the generalization.
4. ... the generalization that we had in Chemistry 10 was too restricted to accurately make the predictions that we want to make here.
5. Previously you had made the prediction that ... and there was not any question that the ...
6. Assuming that ....
7. ... to determine whether the predictions were valid or not.
8. Using the generalization that ... you can predict ....
9. We have made the assumption that there are no restrictions to those generalizations.
10. We are going to move from a given way of knowing ... to ....
11. You know from experience that ....
12. .... we're moving to a more empirical way of knowing ....
13. .... and then we are going to come up with a generalization ....
14. Generalizing from the empirical data ...
15. .... then move towards a more theoretical way of knowing ...
16. ... the two major attributes of a theory ... explain ... and predict.
17. We are not going to be able to predict from (this) theory ... the theory will only be able to explain ....
18. That's as far as we are going to go in Chemistry 30.

Scientific Communication

The following represent phrases which are commonly used within scientific communication. These particular phrases were taken from "Science 84" and "Discover" magazines. The phrases could be categorized as expressions of uncertainty and as appeals to evidence. Use the list as a checklist to evaluate the extent of scientific talk within a research paper, magazine or newspaper article, film or video tape. Underline these type of phrases within the article or research paper.

.... We see no evidence of ...
.... How can we explain that if we don't invoke the theory of ...?
.... We don't have any reason to believe that ...
.... A review of a long line of evidence shows that ...
.... One would predict that ... but in fact ...
.... The current explanation is that ...
.... There is a preponderance of evidence to support the belief that ...
.... It is now well established that ...
.... Internationally it is pretty well accepted, allow there are various belief systems in operation, that ...
.... This model is holding up very well. A lot more people are using it now.
.... One can generalize that ...
.... You shouldn't make the assumption that ...
.... The present model ...
.... We have considerable evidence that ...
.... The follow-up study confirmed that ...
.... It is assumed that ...
.... We believe that ...
.... This evidence is beautiful in that it ...
.... We were able to predict which of the ...
.... What ties it together - what integrates it - is ...
.... New technology is necessary to provide evidence for the theory that ...
.... According to this theory ...
.... Another suggestion is that ...
.... Other scientists think that ...
.... The science of [whatever] is so empirical that ...
.... Until now we have more or less had to speculate about the ...
.... The data seems to show that ...
.... Using measurements from [whatever], we inferred that ...
.... This view is based on ...
.... We believe these could be ...
.... Physicists are convinced that ...
.... In a series of experiments ...
.... Another [whatever] hunt has ended in success at ...
.... The measurement should help scientists pin down ...
.... The scientists found that the measurement was [so many] times [greater or less] than predicted.
.... Its now possible to [do whatever] with enough physics that people believe in to ...
.... A Canadian group reports that it has found ...
.... The discovery might enable scientists to ...
.... [The scientist] has found new evidence that ...
.... The [whatever] look suspicious, as if ...
.... The ..., he concludes, may have ...
.... [The scientist] observed the ... for two years and discovered that ...
.... They combed the scientific literature for data or the ...
.... They selected ... for more detailed research.
.... In his opinion the inference that ... is inescapable.
.... Despite the unknowns and uncertainty, many scientists would welcome the challenge of ...
.... Scientists are learning to predict ...
.... Reserchers have recently established that ...
.... The ... predicts that ...
.... What sets off ... still mystifies reserchers.
.... As research continues ...
.... Still other scientists think that ...
...... may explain why ...
.... Even as scientists unravel the ..., they remain unsure about ...
.... Scientists are less sure about ...
.... There is not a shred of evidence to support the hypothesis that ...

APPENDIX C

Early Classification Schemes

Classification of Sentence

The classification of elements into metals and nonmetals in Lab A1 was based on qualitative properties. Further and more detailed classification requires quantitative properties. In 1817 a German chemist, Johann Doebereiner (1780–1849), identified several groups of three elements which had similar chemical properties. In these groups, called <u>triads</u>, the atomic mass of one element was equal to the average mass of the other two. Historically, triads are important as they were the first examples of groups of elements which had similar properties.

— K Ped W / K Emp W_L
— K Emp W_L
— His K / Nat K / Emp K_L
— Com K / Emp K_L
— His K / Emp K_L

In 1864, John Newlands (1838–1908), an English chemist, arranged the elements in increasing order of atomic masses. Newlands noted that various properties repeated themselves with every eighth element. This is the first example of a <u>periodic law</u>. *When elements are arranged in order of increasing atomic mass, chemical properties repeat themselves at regular intervals.* Unfortunately, Newlands referred to this observation as the Law of Octaves—an analogy to the octave scale in music. Since there is no logical connection between music and chemistry, Newlands was ridiculed by many of his peers and his periodic law was not accepted by the scientific community.

— His K / Nat K / Emp K_L
— Emp K_L
— Com K
— Emp K_L
— ? / Com K / Epi K_S
— K Epi W / Epi K_S / Epi° K_S

Mendeleyev's Periodic Law

In 1869 the Russian chemist, Mendeleyev, published a scientific paper in which he reported an observation similar to the one stated by Newlands five years earlier. Mendeleyev arranged the sixty-three known elements into a table with horizontal rows corresponding to groups of elements with similar chemical properties. Mendeleyev called this analysis the <u>periodic table</u> of the elements and it is the basis for the modern classification of elements.

— His K / Nat K / K Com W / Emp
— K Emp W_L
— Com K / His K
— Emp K_L
— Emp K_E x5

Table A3
Mendeleyev's Periodic Table

	↓ Periods ↓					
				Ti = 50	Zr = 90	? = 180
				V = 51	Nb = 94	Ta = 182
				Cr = 52	Mo = 96	W = 186
				Mn = 55	Rh = 104.4	Pt = 197.4
				Fe = 56	Ru = 104.4	Ir = 198
→	H = 1			Ni = Co = 59	Pd = 106.6	Os = 199
				Cu = 63.4	Ag = 108	Hg = 200
G		Be = 9.4	Mg = 24	Zn = 65.2	Cd = 112	
r		B = 11	Al = 27.4	? = 68	Ur = 116	Au = 197?
o		C = 12	Si = 28	? = 72	Sn = 118	
u		N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
p		O = 16	S = 32	Se = 79.4	Te = 128?	
s		F = 19	Cl = 35.3	Br = 80	I = 127	
	Li = 7	Na = 23	K = 39	Rb = 85.4	Cs = 138	Tl = 204
→			Ca = 40	Sr = 87.6	Ba = 137	Pb = 207
			? = 45	Ce = 92		
			?Er = 56	La = 94		
			?Yt = 60	Di = 95		
			?In = 75.4	Th = 118?		

Communicating Theoretical Knowledge

As indicated throughout this unit, most empirical knowledge comes from observation. *Theoretical knowledge*, however, comes from trying to explain these observations. Theoretical knowledge is communicated with theories, models and analogies.

- A theory is an idea that attempts to explain natural or technological events. A major goal of scientific research is to test theories and scientific laws. This testing is done by using a theory to make a prediction and then gathering empirical evidence to compare with the prediction. This empirical evidence either ***supports*** or ***conflicts with*** the prediction, and ultimately, the theory.
- A model is a mental or physical picture which allows the scientist to communicate a theory in a more concrete way. For example, Dalton pictured atoms as featureless spheres. The simpler the model, the more likely the theory will be accepted. Scientists often suggest that the more complex the model or theory, the further the theory is from reality.
- An analogy is often used to make a model easier to remember. For example, the analogy of a billiard ball is useful when discussing the Dalton Model of the Atom.

Theories, and their associated models, are accepted by the scientific community if they have the following characteristics. The test of a theory is based on these characteristics. Acceptable theories

- explain current observations
- predict new observations
- are simple (easily understood)

Greek Theories of Matter

In the 5th century BC, an ***atomic theory of matter*** was proposed by the Greek philosophers Leucippus and Democritus. Substances were envisioned as being composed of very small units called atoms. These atoms could not be subdivided into anything simpler. Atoms, although invisible, were pictured as geometric shapes (e.g., pyramids and cubes) which fit together to make up all substances. Although this atomic theory received some initial acceptance, it was replaced in the 4th century BC by the element theory of Aristotle.

Aristotle's theory pictured all substances on Earth as mixtures of four elements—earth, air, fire and water. Aristotle's disciples used this theory to predict that substances could be changed into other substances by altering the proportion of each element in a mixture. The element theory led the alchemists to predict that lead could be converted into gold. Thousands of tests of this prediction failed.

Classification of Sentence

Scientific Communication

Epi K_c – / KEpi W_c – / Epi K_c or KEpi W_c –

There are many communication systems in use within the scientific community. Systems acceptable to the scientific community share certain common characteristics. These systems are

- international (meaning and symbols)
- social (commonly accepted agreement)
- precise (restricted to specific situations)
- simple (easily understood)

IUPAC Inorganic Nomenclature

Com K or KEpi W_c – / Nat K/KEpi W_c – / KEpi W_c – / Ped K_p/KEpi W_c/His K – / KPed W_R – / KPed W_R –

The International Union of Pure and Applied Chemistry (IUPAC) is the governing body for scientific communication. The representation in this organization is international and includes scientists from government, universities and industry. In addition to the main organization, several important subcommittees exist dealing with specific areas of chemistry. The nomenclature of inorganic chemistry used in STSC CHEMISTRY is the United States presentation (published in 1960) of the IUPAC Inorganic Rules. The most convenient reference for these rules is the CRC Handbook of Chemistry and Physics. The following IUPAC rules are some of the rules used to this point in STSC CHEMISTRY.

KCom W – / Epi K_c – 1.11. The elements should have the [international] symbols given in the following table. It is desirable that the names should differ as little as possible among the different languages, but as complete uniformity is hard to achieve . . .

KCom W – 2.15. In formulas the electropositive constituent (cation) should always be placed first; e.g., KCl, $CaSO_4$.

KCom W – 2.21. The name of the electropositive constituent will not be modified (see 2.2531).

KCom W – 2.252. The proportions of the constituents also may be indicated indirectly by Stock's system, that is, by Roman numerals . . . placed in parentheses immediately following the name.

Epi K_c – 2.253. The following systems are in use but are not recommended.

KCom W – 2.2531. The system of indicating valence [ion charge] by means of the suffixes -ous and -ic added to the root of the name of the cation may be retained for elements exhibiting not more than two valences. (Epi K_c)

KCom W/KPed W_R/Com K – 2.3. Certain well-established trivial names for oxo acids (Section 5) (KPed W_R) and for hydrogen compounds (water, ammonia (Com K), hydrazine) are still acceptable.

KCom W/Com K – 3.21. The names for monatomic anions shall consist of the name (sometimes abbreviated) of the element, with the termination -ide. [E.g., chloride (Com K) ion]

KCom W – 3.223. The names for other polyatomic anions shall consist of the name of the central atom with the termination -ate, . . .

Epi K_c/KCom W – 6. Among salts particularly, there persist many old names which are bad and misleading, and the Commission wishes to emphasize that any which do not conform to these Rules should be discarded.

KCom W/Com K – 6.2. [Salts Containing Acid Hydrogen] Names are formed by adding the word hydrogen, immediately in front of the name of the anion. [E.g., sodium hydrogen carbonate]

Science in Society

Our western society is increasingly dependent on advances in science and technology. The affluence of our society is expressed by the multitude of technological devices that surround us in our everyday lives. The technological applications of metal, paper, plastic, glass and wood are evidence of our manipulation of natural substances found on our planet.

Thousands of new scientific discoveries and technological advances are made each year. Our society embraces higher and higher technology. We look for *technological fixes* for our problems. The problems needing fixes are both natural (e.g., medical) and technological (e.g., acid rain).

Deciding how to use science and technology for the benefit of all life on our planet is very complex. Many perspectives can be taken on any science-in-society issue. At this point in STSC Chemistry we restrict the classification of perspectives to five—economic, ecological, political, scientific and technological. There is a general agreement within the community of scholars who study science-in-society issues that a multi-perspective approach to any issue is preferred to a single perspective.

Exercise

1. (Discussion) List six science-in-society issues.

2. (Discussion) List the perspectives to be taken on science-in-society issues at this point in STSC Chemistry.

Chemical Equations

A chemical reaction equation is an internationally-accepted method of communicating a chemical reaction. Chemical equations are usually based on empirical evidence, but they may also represent a prediction from a theory, law, or generalization.

> A chemical equation must communicate with international symbols the correct formula and state for each reactant and product.

By convention of the chemistry community the chemicals which react (the reactants) are written on the left side of the equation and the chemicals which are produced by the reaction (the products) are written on the right side. The change from reactants to products is indicated by an arrow pointing to the right ($\longrightarrow$). This arrow is translated as, "react to produce" or "react to form".

Many of the chemical reactions studied in this unit were placed in a context of a science-in-society issue. In addition to the scientific perspective of an issue, other perspectives such as ecological, economic, political and technological were considered. For each of the following questions, use the information presented to classify one or more perspectives.

34. The combustion of sulfur-containing fuels produces sulfur dioxide. The emission of this substance into the atmosphere creates international problems since weather patterns cross national borders. Assume the sulfur reacts in its elemental form.

Reaction type ________________ Perspective(s) ________________

Balanced equation ________________________________

English translation ________________________________

____

____

35. One process used extensively in the Alberta natural gas industry to remove sulfur compounds is the Claus Converter. One step of this method involves the reaction of hydrogen sulfide with air (oxygen).

Reaction type ________________ Perspective(s) ________________

Balanced equation ________________________________

English translation ________________________________

____

____

36. Empirical studies by scientists have shown that sulfur trioxide in the air reacts with rainwater to produce sulfuric acid. This reaction has serious environmental implications for Canada.

Reaction type ________________ Perspective(s) ________________

Balanced equation ________________________________

English translation ________________________________

____

____

37. The repair costs are enormous when sulfuric acid in acid rain erodes limestone, $CaCO_{3(s)}$, buildings and statues.

Reaction type ________________ Perspective(s) ________________

Balanced equation ________________________________

English translation ________________________________

____

____

Science and Technology

In the last unit you used a list of five perspectives to classify statements that are made on a science-in-society issue. Besides classifying ecological, economic and political statements, you also classified scientific and technological statements. This multi-perspective view of world issues can help promote tolerance and understanding. Issues in modern society are becoming more complex. An informed electorate is indispensible to the maintainence of a democratic society. In STSC CHEMISTRY you are required to recognize the existence of alternate perspectives. Of these perspectives you are required to be particularly knowledgeable about scientific and technological perspectives.

Technological fix refers to the habit of our society to expect technological solutions to our problems.

Science and technology are closely related activities. Initially, you have to exaggerate the differences in order to define the terms. Later you can look at the complex interactions between science and technology.

Technology	Science
• studies *man-made* products and processes	• studies *natural* products and processes
• is more *empirical* in nature	• is more *theoretical* in nature
• emphasizes *methods* and materials	• emphasizes *ideas*
• is valued for how well it *works*	• is valued for how well it *explains*
• is often *local* in development and use	• is often *international* in scope

I&I Technological Inventions

1838 Charles Fenerty developed the world's first usable newsprint made from wood pulp.
1854 Nova Scotian Abraham Gesner invented kerosene oil.
1874 Alexander Graham Bell invented the telephone.
1915 Dr. Cluny McPherson designed a gas mask for World War I soldiers.
1928 Dr. Archibald Huntsman invented the process for freezing fish commercially.
1930's James Hillier and Albert Prebus invented the first commercial electron microscope.
1951 Atomic Energy of Canada developed the cobalt-bomb for cancer treatment.
1971 Dr. James Guillet invented degradable plastics.
1981 The Space Shuttle's Canadarm was designed and built in Canada.

I&I Scientific Achievements

- Doctors Banting and Best discovered insulin.
- Hans Selye discovered the whole area of biological effects of stress.
- Gerhard Hertzberg, Canada's only living Nobel laureate, studies electronic properties of molecules.
- Murray Barr of London, Ontario discovered the sex chromatin used in mandatory sex tests on female Olympic athletes.
- Tuzo Wilson developed the modern theory of plate tectonics at the University of Toronto.
- Brenda Milner at McGill University discovered specific function-related regions of the brain.
- Neil Bartlett at the University of British Columbia revolutionized chemistry by his research on noble gas compounds.
- Canadian Henry Taube, working in the USA, was a recent Nobel Prize winner for his work in inorganic chemistry.

The Canadian accomplishments listed above appeared in Royal Bank Reporter, Winter '85/86. Only a few of the many inventions and achievements are listed.

Technology-Science Interdependence

PedKp / EpiKT — EpiKT — EpiKT — EpiKT

It has only been in this century that pure research has produced new technology.

All too often, discussions of technology assume that technology is just the application of principles that are discovered by scientific activity. In fact, more often technology leads science, and develops long before science provides theoretical understanding of why a process or device works. Perhaps more importantly, the development of technology often provides the scientific problems that lead to the advancement of science.

PedKR / KEpiWT — EpiKT / HisK — KEmpWT / KEmpWT — PedKR — TecK / SocK

As an example of science advancing technology, consider the incandescent light bulb. The electrical theory for how the bulb works was well-established when Thomas Edison (1847–1931) decided to develop a *useful* bulb. He used a trial and error approach until he found a durable, inexpensive material for the bulb filament. Edison's life makes fascinating reading. He may be the most creative technologist the world has ever seen.

PedKR / EpiKT — KTecW / TecK / HisK — HisK / EpiKT / EpiKS — ✓ EpiKT / EpiKS

A good example of technology advancing science is the whole field of ceramics. Mankind has been using stone, clay and glass materials since before recorded history. Only recently, however, have scientists begun to understand the incredibly complex chemistry of ceramics. New materials will undoubtedly come from this understanding.

HisK / RecK — KEpiWT — KEpiWT — KEpiWT

The change in human society that has occurred in the last few centuries reflects an amazing accumulation of knowledge—both technological and scientific. The reason for this abrupt increase has to do with the *interdependence* of science and technology. Applied separately, neither science nor technology seems to be very productive. When applied together a cyclical process develops where science advances technology, which advances science, which advances . . .

Exercise

1. Use key words or phrases to list the five differences between science and technology. — EpiWS / EpiWT

Classify each of the following questions as a *scientific* or a *technological* question. (S or T) — KPedWp / PedWp

Example What can a nail be coated with to stop corrosion? __T__ — KPedWp / EmpWT / EpiKT

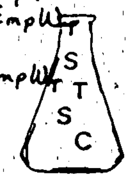
What chemical reactions go on in the corrosion of iron? __S__ — KPedWp / EmpWS - TheW / EpiKS

2. What is an accepted explanation for the chemical formula of water, H_2O? ____ — TheW / EpiWS
3. What process is necessary to continuously produce nylon thread? ____ — EmpWT / EpiWT
4. Why is a copper(II) sulfate solution blue? ____ — TheW / EpiWS
5. Can the Space Shuttle be redesigned to achieve a safer and better operation? ____ — EmpWT / EpiWT

Familiarity with technology and the terms applied to it is becoming a more important part of our present society. — ComK / SocK

6. (Discussion) Explain the meaning of the following technological language—technological fix, user friendly and hard, soft, high and low technology. — ComW x 6

STSC Context



LAB D1

Lab D1 deals with an important metallurgical reaction. The decomposition of copper ore is one step in the industrial refining of copper metal. Predicting the quantity of copper that can be produced from copper ore is a very realistic concern when building a smelter or mining a body of ore. Metallurgical engineers take prediction methods very seriously.

Predicting the mass of a substance that will be involved in a reaction is a complex process involving considerable theoretical and empirical knowledge.

The purpose of Lab D1 is to demonstrate the need for scientific theory, communication skills and technological skills to successfully predict quantities of substance in chemical reactions.

Background Knowledge

The chemical, $Cu(OH)_2 \cdot CuCO_{3(s)}$, used in Lab D1 is known by three different names.

- The systematic name is *copper(II) hydroxide carbonate.*
- The specialized name used by geologists to communicate the identity of this substance is *malachite*. Geological nomenclature of <u>minerals</u> must be memorized when studying geology. The chemical composition cannot be determined from the name of the mineral.
- A common name for this chemical is *basic copper carbonate.*

The systematic (IUPAC) nomenclature has the advantage that the formula of the substance can be determined from the name.

Copper(II) hydroxide carbonate is a <u>double salt</u> with a chemical formula written as $Cu(OH)_2 \cdot CuCO_{3(s)}$. Empirical studies show that strong heating decomposes this substance forming copper(II) oxide, carbon dioxide and water vapor.

Read the following sections of the STSC Reference Materials—Predicting, Using a Laboratory Burner, Using a Laboratory Balance, Transferring a Solid.

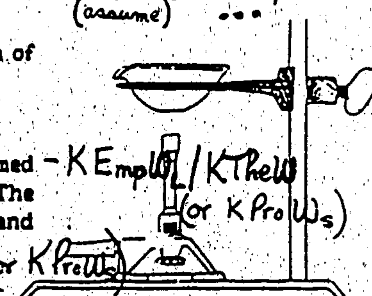
Assumptions and Restrictions

When predicting the mass of solid product obtained in this reaction, assume that *all* of the reactant is converted into products.

Problem

What is the mass of copper(II) oxide formed in the decomposition of a measured sample of malachite?

Experimental Design



A prediction will be made (theoretically) of the mass of product formed when a measured mass of malachite is decomposed by heating. The actual mass of product will then be measured (found empirically) and the two masses will be compared.

Complete the sections checked below.

Problem	Exp. Design	Prediction	Materials	Procedure	Evidence	Analysis	Evaluation
		✓			✓	✓	discussion

Prediction

* K TheW / K EmpWL / TheW / EmpWL

KEmpWL / EmpWL — 1. Predict a balanced chemical equation for the reaction. Include state of matter subscripts. (or KProWS / ProWS x 2)

*repeat — 2. Predict whether the mass of solid product formed will be more than or less than the mass of reactant used. (or KProWS / ProW)

*repeat — 3. Predict the mass of product that will be formed. Make the prediction after you have calculated the mass of malachite (after Procedure 3). (or KProWS / ProW)

KPedWP / KPedWP

1. At best, your third prediction will be a guess.
2. The prediction may not be very accurate. The purpose
3. of Lab D1 is to show you the need for a method to make accurate predictions.

1. EptKS
2. EptKS
3. KPedWP

EmpKE x5

Materials

- evaporating dish (or crucible)
- laboratory burner
- bottle or vial of malachite reagent
- laboratory scoop or plastic spoon
- small ring stand
- glass stirring rod
- centigram balance

Procedure

* K ProWT / KComW / ProWT / ComW — 1. Measure and record the mass of an evaporating dish to 0.01 g.

KProWT / ProWT — 2. Transfer a small sample (approximately one teaspoonful) of malachite into the evaporating dish.

*repeat — 3. Measure and record the total mass of the malachite sample and evaporating dish to 0.01 g.

KProWT / ProWT / EmpKE — 4. Using a laboratory burner adjusted to the hottest flame, heat the sample until the color changes from green to black.

KProWT / ProWT — Use a stirring rod to mix the contents while heating.

KProWT / ProWT — When the color change is *complete*, turn off the burner.

KPedW / KProWS / ProWS / KProWS / ProWS — While the sample is cooling, calculate the mass of malachite used (Analysis 1) and predict the mass of solid product formed.

KProWS / KProWT / KComW / ProWT / ComW — 5. After the dish is cool enough to hold, measure and record the mass of the evaporating dish and product to 0.01 g.

Analysis

*All of the evidence gathered would be classified as ProK.

KProWS / ProWS — 1. Calculate the mass of malachite in your sample.

KPedWR — 2. Refer to the Prediction section of the lab. Record the mass of product that you predicted would form.

KComW —

KProWS / ProWS — 3. Using the evidence from the experiment, calculate the mass of product that actually formed.

KProWS / ProWS — 4. Calculate the following ratio. $\frac{\text{mass of product obtained}}{\text{mass of reactant used}} = ?$

KProWS / ProWS — 5. Compare your value for the ratio with the value obtained by other students.

KProWS / ProWS — If your teacher records values from the class on the chalkboard, calculate a class average value, and state whether you think your value is acceptable

KProWS / ProWS — in comparison to the average.

Appendix C2

```
1 REM "TRUE" RANDOM NUMBER GENERATOR
2 REM FROM "ALL ABOUT APPLESOFT"
3 REM ELIMINATES DOS INTERFERENCE WITH RND
5 PR#1
6 PRINT "RANDOM NUMBERS BETWEEN 1 AND 132"
7 PRINT:PRINT"1986-07-12"
10 GOSUB 50100
20 FOR I = 1 TO 2000: GOSUB 5000
21 RN = RN * 1000
22 IF RN < 133 THEN PRINT INT(RN),
23 NEXT I
25 END
50000 19 = INT(RND(1)*100):RN = R8(19): GOSUB 50300:R8(19)=R9: RETURN
50100 DIM R8(99):K7 = 2 ^ 20: K8 = 566387:K9 = 2^ 10 + 3
501110 19 = RND (-(PEEK(78) + 256 * PEEK (79))): FOR 19 = 0 TO 99:
GOSUB 50300:R8(I9) = R9: NEXT : RETURN
50300 K8 = (K9 * K8) - INT ((K9*K8)/K7) * K7:R9 = K8/K7:RETURN
51000 END
```

Key to STSCP and K-KW-W Reliability Instruments

RDM.	REF.	K-KW-W	RDM.	REF.	K-KW-W	RDM.	REF.	K-KW-W	RDM.	REF.	K-KW-W
1.	34	K Sci W	34.	23	Sci W	67.	44	Sci W	100.	123	K Ped W
2.	2	Sci K	35.	78	Soc K	68.	106	K Com W	101.	6	Sci W
3.	10	K Sci W	36.	37	Sci W	69.	57	K Tec W	102.	111	K Com W
4.	54	K Tec W	37.	91	Soc K	70.	66	Tec W	103.	121	Ped K
5.	124	K Ped W	38.	68	Soc K	71.	24	Sci W	104.	89	Soc W
6.	77	Soc W	39.	12	Sci W	72.	86	Soc K	105.	55	Tec K
7.	133	Com W	40.	38	Sci W	73.	88	K Soc W	106.	42	K Sci W
8.	33	K Sci W	41.	14	Sci K	74.	16	K Sci W	107.	109	Com K
9.	28	K Sci W	42.	18	Sci W	75.	40	Sci K	108.	110	Com K
10.	3	K Sci W	43.	61	Tec K	76.	116	Ped K	109.	75	K Soc W
11.	56	Tec K	44.	70	K Soc W	77.	128	Ped K	110.	101	Soc W
12.	97	Soc K	45.	9	K Sci W	78.	102	Soc W	111.	96	Soc W
13.	30	Sci W	46.	131	Ped W	79.	58	K Tec W	112.	100	K Soc W
14.	47	K Tec W	47.	114	Com W	80.	84	Soc W	113.	107	Com W
15.	76	K Soc W	48.	35	•K Sci W	81.	22	K Sci W	114.	105	K Com W
16.	69	K Soc W	49.	73	Soc K	82.	92	Soc K	115.	93	K Soc W
17.	8	Sci K	50.	27	K Sci W	83.	17	Sci W	116.	56	Tec W
18.	71	Soc W	51.	82	K Soc W	84.	104	Com K	117.	63	K Tec W
19.	112	K Com W	52.	120	Ped W	85.	95	Soc W	118.	25	Sci K
20.	125	Ped W	53.	11	Sci W	86.	45	Tec K	119.	4	K Sci W
21.	60	Tec W	54.	119	Ped W	87.	85	Soc K	120.	52	Tec K
22.	94	K Soc W	55.	13	Sci K	88.	129	K Ped W	121.	103	Com K
23.	48	K Tec W	56.	21	K Sci W	89.	69	Soc K	122.	98	Soc K
24.	80	Soc K	57.	46	Tec K	90.	26	Sci K	123.	51	Tec K
25.	5	Sci W	58.	81	K Soc W	91.	117	K Ped W	124.	50	Tec W
26.	15	K Sci W	59.	99	K Soc W	92.	108	Com W	125.	72	Soc W
27.	43	Sci W	60.	13	Ped W	93.	1	Sci K	126.	59	Tec W
28.	79	Soc K	61.	127	Ped K	94.	74	Soc K	127.	90	Soc W
29.	122	Ped K	62.	130	K Ped W	95.	53	K Tec W	128.	62	Tec K
30.	31	Sci K	63.	32	Sci K	96.	87	K Soc W	129.	115	Ped K
31.	39	Sci K	64.	7	Sci K	97.	83	Soc W	130.	126	Ped W
32.	64	K Tec W	65.	20	Sci K	98.	19	Sci K	131.	29	Sci W
33.	41	K Sci W	66.	119	K Ped W	99.	36	•K Sci W	132.	49	Tec W

• K Sci W-Sci W

STSC Categories - Validation Instrument Name

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19. epistemological (the way that systems of communication get accepted by the scientific and engineering community)

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21. pedagogical reference (includes the identification of common ways of knowing including referenced, memorized and given ways of knowing something in science and technology)
22. epistemological (knowledge about the limitations and validity of pedagogical knowledge)

STSC Categories – Validation Instrument Name

Examples to be Validated

1. The evaluation at the conclusion of this laboratory exercise should include five elements—an answer to the stated problem; an evaluation of the prediction; an evaluation of the theory, law, generalization or experience (TLGE) used to make the predictionx;an evaluation of the experimental design; and an attempt, if necessary, to restrict, revise or replace the TLGE.
3. From experience people know the characteristics of the three states of matter of water.
5. To develop an understanding of the concept of phase and temperature changes requires a combination of ways of knowing including the time honored memorized, referenced, and given ways of knowing.
7. Comment on the necessity for using a system of significant digits when communicating values in the scientific community.
9. The states of matter in this reaction in a water environment may be predicted from solubility generalizations, while the solubility might be explained by molecular polarity or hydrogen bonding.
11. In a laboratory simulation, a student found that the best container for water in a passive-solar greenhouse was a polyethylene container painted flat-black.
13. Use the theory of conservation of atoms and solubility generalizations to write a balanced chemical equation including states of matter for the reaction of potassium metal with water.
15. To make the gas furnace more efficient the Canadian solution was to improve the heat exchanger to the point that combustion water vapor condensed.
17. The mass of ice used in the experimental determination of the molar heat of fusion of water was 15.04 g.
19. When analyzing the language used in scientific communication, the language should reflect the nature of science by appealing to the evidence that supports or conflicts with a prediction made by a theory, law or generalization.
21. Describe the process you should employ in the school laboratory to prepare an aqueous primary standard solution from a solid solute.
23. Water may be used to mine sodium sulfate (salt cake) from the bottom of lakes.
25. Explain the relative boiling points of water and hydrogen sulfide.
27. State the restrictions and ~~assumptions associated~~ with the Bronsted-Lowry Theory of acids and bases as employed within this last section covered in the textbook.
29. From referencing the periodic table, the boiling point of oxygen is -183°C.
31. The VSEPR Theory is accepted by the scientific community because the theory is able to explain and predict the shape and/or polarity of molecules, such as the water molecule.
33. The criteria that should be used to judge a theory which is acceptable to the scientific community is the ability of the theory to explain existing effects (e.g., the polarity of the water molecule), and to predict future effects (e.g., the bond angle of the water molecule).
35. Describe how the Canadian inventors of the high-efficiency (condensing), gas furnace were <u>originally</u> able to extract heat from the combustion water vapor.

37. Politicians in Ontario have been forced by electorate interest-groups to take a stance on the acid-rain issue.

39. Describe the effect of adding water vapor to a gas mixture in an experiment similar to that done by Raoult or Dalton.

41. One way of explaining the boiling point of water relative to hydrogen sulfide was to invent the theory of hydrogen bonding.

43. Upon analyzing Charles Hall's search for a nonaqueous solvent for alumina it is apparent that the search is an example of a systematic trial and error approach to technological problem solving.

45. The bond angle of the hydrogen-oxygen-hydrogen bond in water can be determined by the X-ray analysis of ice.

47. Why is the SI system of units and symbols superior or inferior to the English system of measurement?

49. Ron Gillespie of McMaster University in Hamilton co-developed the VSEPR theory of stereochemistry.

51. In the video series and book, Connections, James Burke presents an alternate view of historical analysis by relating technological advances to historical "progress".

53. Describe the behavior of water upon freezing in a large lake.

55. The observation that small bugs can walk on water can be explained by creating the concept of intermolecular forces.

57. The hot-water process for extracting oil from tar-sands has proven to be the most acceptable process yet invented.

59. The restricted perspectives taken on an issue by an individual or group can be analyzed from written or oral communication by classifying each sentence into perspectives (e.g., aesthetic, ecological, economic, emotional, ethical, legal, militaristic, mystical, political, scientific, social, and technological).

61. Classroom experience with the teaching/learning of phase change phenomena indicates that people have trouble integrating the phase change (temperature versus time) curve of water with the potential energy versus time graph of water. This empirical knowledge from the classroom is supported by formal educational research, but still needs some theoretical structure to explain why this is so. Perhaps the reason lies in the variety of different kinds of knowledge and different ways of knowing which are almost randomly thrown at people trying to make sense of the topic.

63. The student interpretation of the disappearance of the ice from the sidewalk was that the ice sublimed.

65. From the law of equilibrium, the predicted hydronium ion concentration in the solution is 2.4 mmol/L.

67. Why did Arrhenius have such great difficulty in getting his Theory of Ionic Dissociation accepted by the scientific community?

69. When titrating in the school laboratory, you should rinse all equipment with water both before and after use.

71. Use a conservation law to predict the volume of water that must be added to 10 mL of concentrated sulfuric acid in order to dilute the concentrated acid to 0.75 mol/L.

73. To treat an eye threatened by chemicals, flush the eye with water for at least 15 min.

75. The scientists expressed uncertainty because of the lack of evidence and because of a skeptical scientific attitude.

77. For pedagogic convenience it is appropriate to invent the hydronium ion to represent a hydrated proton.

79. When designing a low-energy, passive-solar home for your school project, a water wall should be located to the south-west or west in order to store solar heat during the part of the day when excess heat is entering the home.

81. The Le Chatelier Principle may be used to predict the shift in equilibrium when sodium hydroxide is added to water.

83. How would you start to explain the observation that snow flakes come in many, many shapes?

85. Write a critical appraisal of why, although the technology exists to divert water from Northern Alberta to Southern Alberta, the current provincial government is being very cautious in its proposals on this issue.

87. The eye may be damaged to a greater extent by basic solutions than by acidic solutions.

89. Western societies are reliant on high technology for food, shelter and recreation.

91. When approaching a unit of subject matter the number of curriculum emphases is usually restricted to one or two.

93. The oxygen atom in the water molecule is surrounded by two lone pairs of electrons and two bonding electrons.

95. The technician reads the water flow-rate from the meter by making sure that the error due to parallax is kept to a minimum.

97. Discuss how the water wheel may have influenced the development of the cottage industries in Britain during the industrial revolution.

99. Obtain about a mole (one heaping tablespoonful) of ice and add it to the styrofoam calorimeter containing 100 mL of water at about 30°C.

101. Predict the shape of the water molecule.

103. From memory, the equilibrium constant for water at SATP is 1.01×10^{-14} mol^2/L^2.

105. The volume of water measured by the student using a pipet was 10.0 mL.

107. The IUPAC rule for communicating the name of a chemical hydrate has not received wide acceptance by the international community of chemists.

109. To predict the shape of molecules, Canadian Ron Gillespie used VSEPR Theory.

111. Why do you think tar sands plants are allowed to continue to allegedly spoil the fishing grounds of the native population on the Athabasca River in Northern Alberta?

113. Read out loud the following chemical equation for the decomposition of water—do not read the symbols literally, translate the international symbols into English words.

STSC Categories – Validation Instrument Name

115. A reconstructional or critical approach to social issues requires one to identify the interests (e.g., political, economic and social) and presuppositions of the principal actors who are in positions of power or who want to be in positions of power.

117. When judging any new technique which is acceptable to the engineering community, the technology must be economic, it must work reliably, and it must be simpler than the competition.

119. The stereochemical shape of the water molecule may be predicted by VSEPR theory. Draw a Lewis Model of the water molecule and then apply the theoretical rule that four groups of electrons will repel one another to form a tetrahedral distribution of electrons around the oxygen atom.

121. The chemical formula for sodium sulfate decahydrate is internationally communicated as $Na_2SO_4 \cdot 10H_2O_{(s)}$.

123. The technician determined the pH of the rain water to be 5.68.

125. Try to stand back from your society and interpret the effect of removing technology from your everyday life pattern.

127. What environmental effects might be expected when a large hydroelectric dam is built.

129. The purpose of this laboratory work is to gain a better appreciation of the importance of water as a "universal" solvent.

131. Predict (from Le Chatelier's Principle or the Equilibrium Law) and explain (from collision-rate theory) the shift in equilibrium when a strong base is added to a water sample.

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Examples to be Validated

2. The water molecule contains two polar covalent bonds.
4. The chemical engineer tests the quality of the water leaving the plant by using conductivity and photometric measurements.

6. Use the VSEPR Theory, co-developed by Candian Ron Gillespie, to predict, as he originally would have, the shape of the water molecule.

8. The experimental design of the experiment should state the manipulated, responding and controlled variables along with a summary of the procedure being used.

10. The Lewis Molecular Theory may be used to explain the empirical formula for water, H_2O, by using electron dot models of oxygen and hydrogen atoms.

12. The overt perspective taken on the acid rain issue by the President of the United States appears to be primarily scientific (i.e., more research needs to be done because scientists are uncertain as to the sources of the acid rain). The question remains as to whether the President understands that the nature of the scientific perspective on an issue requires the expression of uncertainty rather than dogmatic or absolute answers.

14. Water may be electrolytically decomposed in a Hoffman apparatus by employing a catalytic-electrolyte such as sodium sulfate.

16. A sociologist gathers evidence to answer a stated sociological problem by using one or more of three techniques—interviews, questionnaires or observation.

18. Take 15 min from your day and observe and interpret the dependence of your family on science and technology.

20. Use the CRC Handbook of Chemistry and Physics to reference the [ionization constant for water at 50°C in order to perform the following prediction.]

22. Scientific and technological knowledge and attitudes are just a couple of the many forms of knowledge and attitudes necessary to becoming informed on a science-in-society issue.

24. The first heavy-water moderated and cooled nuclear reactor in the world was built in the early 1950's.

26. Experience with states of matter may be combined with the theory of conservation of atoms to write a balanced chemical equation for the electrolytic decomposition of water.

28. H. Urey is credited with discovering heavy water at Columbia University in 1931.

30. The students observed that the water rose the highest in the smallest diameter capillary tube.

32. The process by which a new technology is developed by engineers or technicians is usually very empirical and involves a systematic trial-and-error approach.

34. Use solubility generalizations to predict whether the following ionic compounds have high or low solubility.

36. What interpretation may be put on the above observations of aqueous solutions?

38. We, in our modern society, tend to look for technological fixes for our problems.

40. Design and perform a laboratory experiment to determine the molar heat of fusion of ice.

42. Knowing from experience the state of matter of water at SATP, use stereochemistry and intermolecular force theory to explain this observation.

44. A sociologist may use the technique of "walking in someone elses shoes" or may "step back" from society in making more subjective or objective observations, respectively.

46. What ways of knowing the chemical formula and state of matter at room temperature of water were used by you in your last chemistry education course?

48. Add 15.0 mL of water to the solid solute and stir the mixture until the solute is all dissolved.

50. The shift in equilibrium in the water solution may be predicted by using the Le Chatelier Principle and explained using collision and rate of reaction theories.

52. What kinds of questions should be expected on the test for this unit?

54. What was the purpose of going into the laboratory to determine the molar heat of water?

56. The amount of heat gained by water in a calorimeter can be predicted by multiplying the volume times the volumetric heat capacity times the change in temperature.

58. When Jacob Bronowski investigated the history of a scientific idea (i.e., in The Ascent of Man), he used an approach of relating the scientific and social presuppositions of the era to one another.

60. How do generalizations and theories of learning get to be accepted by the science-education community?

62. The way to test any theories or generalizations of teaching and learning is to gather evidence in the classroom situation.

64. Water is a colorless liquid at room conditions.

66. When reading a laboratory assignment be sure to differenciate between the purpose of a laboratory exercise and the problem to be answered by the experiment.

68. SI Metric Rules suggest that the mass of water should be communicated as 12.7 g, using all symbols, rather than a combination of symbols and abbreviations or words such as in 12.7 gm. or 12.7 grams.

70. Describe the life cycle of a technological device from the time that it is invented to the time it is discarded or replaced by a competing device.

72. Lake water containing phosphates from detergents may becomed clogged with weeds and algae whose growth is promoted by the fertilizer effect of the phosphates.

74. Research chemists are able to use sophisticated equipment to obtain the conductivity and pH of water, and then use a theory of equilibrium to explain this evidence.

76. The purpose of the test will be to test chemisty content as well as STSC types of questions.

78. Further classify the issue perspective statements that you have found by indicating whether or not the statements are positive or negative statements relative to the resolution on the issue being debated.

80. Discuss how the concept of earth, air, fire and water as the elements of all things influenced the history of both science and society in the middle ages.

82. The rapid use of energy resources by our "me generation" will likely gain us a very ignominious reputation in the history of Earth.

84. The predicted molar heat of fusion of water from this experimental design should be communicated with three significant digits.

86. A water-wall may be used to store solar energy absorbed by the wall in a passive-solar home.

88. When analyzing pedagogic ways of knowing look for given, referenced and memorized ways of knowing.

90. The 42 MJ of heat predicted from heat laws for the phase change of water may be explained as an increase in chemical potential energy.

92. Predict the mass of water reacted and communicate your problem solving technique by communicating the formula with international quantity symbols, substituting with accepted significant digits and unit symbols, and communicating the prediction with accepted certainty and units.

94. The high-efficiency (95–98 % efficient) condensing gas furnace, now being marketted by an American firm, was originally developed by a Canadian in Manitoba.

96. The effect of PCBs on humans must be extrapolated from experiments on small animals or by doing health studies on humans exposed to PCBs.

98. The product of the hydronium and the hydroxide ion molar concentrations in any water sample at SATP is a constant—K_w—equal to 1.01×10^{-14} mol^2/L^2.

100. When a specific heat capacity other than for water is required in a quantitative prediction, the heat capacity will be given in the problem or must be referenced from a table of heat capacities provided.

102. When analyzing a system of communication acceptable to the scientific community, the communication system should be simple and precise and should express the uncertainty or tentativeness of science.

104. Determine the effect on various kinds of soil by their buffering of acid rain.

106. When a theory cannot predict accurately, it should either be restricted to predicting within a restricted situation, or revised such that it is able to predict more accurately, or replaced with a new theory that is able to predict accurately.

108. The rule for communicating significant digits that requires scientific notation is not as acceptable now that the simpler method of using SI prefixes is available.

110. Analyze the perspectives taken on the nuclear war issue in the article by the nuclear disarmament group and compare this to your analysis of the previous article by the pro-nuclear group.

112. There are positive and negative statements that can be classified on any science-in-society issue from any of twelve or more perspectives on an issue.

114. Instead of calling $H_2O_{(l)}$, hydrogen oxide, the scientific community prefers to call this substance "water".

116. What are the attributes of a process for the electrochemical production of electricity from water that would make the process acceptable to the engineering community?

118. The increase in the average kinetic energy of the water molecules was predicted by the laws of thermodynamics to be 368 kJ.

120. The chemical engineer adjusted the flow rate to 500 L/s to increase the efficiency of the process for removing bromine from sea water.

122. A fired environment official who has signed a pact of secrecy is put into an awkward position. For social, ethical and environmental reasons she might want to speak-up. However, the political party that fired her has a legal right to stop her from speaking in public about the controversy over which she was fired.

124. Design an industrial process to extract sodium sulfate from the bottom of a lake.

126. What accepted technique would you employ for using the solar photometer so that reflection off of water or snow does not get measured as part of the total solar radiation.

128. The bottom-line test of a technological process for the electrolytic decomposition of water by photoelectricity that was used by the engineers was the cost efficiency of the process.

130. From memory, what is the H–O–H bond angle in water?

132. Suggest changes to the Hoffman apparatus that would be necessary to the industrial production of hydrogen fuel from water on a large scale.

Ways of Knowing Frank Jenkins

Knowledge and Ways of Knowing

Students often ask the epistemological question, "How am I supposed to know that?" They want to know the procedure or the way of knowing required to them. Textbooks often give knowledge to and require knowledge of students without letting students know the various ways in which the knowledge is produced. Before students can be let in on the epistomological aspects of textbook, a study of statements and questions used in science education needs to be undertaken. This particular study has gathered evidence to suggest that all statements and questions in science education textbooks can be classified into three categories.

A. kinds of knowledge. Knowledge is given to people in the form of theoretorical (The K), empirical (Emp K), process (Pro K), epistemological (Epi K), and/or other kinds of knowledge. This cannot be procedural knowledge, it must be knowledge resulting from a procedure.

B. knowledge of a way of knowing. Knowledge is given to people as procedural knowledge in terms of how to obtain various kinds of knowledge. Procedural knowledge may appear as rules, steps and/or examples.

C. ways of knowing. Action is required of people to answer questions, discuss, debate, and problem solve. A way of knowing uses knowledge of a way of knowing (a procedure) to produce knowledge.)

Statements given to people through science-education textbooks can be classified as either kinds of knowledge or knowledge of a way of knowing. When a classroom or laboratory exercise requires a person to respond a way of knowing is required of that person. (Students produce knowledge as a result of this way of knowing, but this knowledge is usually judged for correctness rather than being classified.)

Examples

Within a technology emphasis (context) a technological process skill (Pro K) subcategory of knowledge appears. Technological process skill knowledge is produced by using a process way of knowing (Pro W) guided by knowledge of that way of knowing (K Pro W_T).

1.	Pro K_T - (given)	The student measured the percent transmittance of the water sample to be 94 %.
2.	K Pro W_T - (given)	The percent transmittance of light through a water sample may be measured by using a photometer or calorimeter.
3.	Pro W_T - (required)	Determine the clarity of a water sample and express the trasmittance as a percent reading.

Instructions

Please classify the following statements and questions as knowledge (K), knowledge of a way of knowing (KW) or a way of knowing (W) by placing the appropriate symbol in the margin.

Validating Examples of K-KW-W Categories Name

Instructions for Validating Knowledge and Ways of Knowing

The following sixty-six statements and questions are to be categorized into knowledge, knowledge of a way of knowing, and way of knowing categories. There is an equal number of each of these categories. Write *K* for knowledge, *KW* for knowledge of a way of knowing, or *W* for way of knowing in the margin to the left of each statement or question. If you have a close second choice, indicate the second choice as well; e.g., *K/KW*. You may wish to write comments on the validation sheet. You will be given the key and an opportunity to discuss your answers at a later time. Please provide your name at the top of the page.

Kinds of Knowledge Dimension

The kinds of knowledge dimension has been found by this empirical study to have three components—kinds of knowledge (K), knowledge of a way of knowing (K Way K), and way of knowing (Way K).

1. The *knowledge*, K, subcategory is knowledge *given to people* by the authors of the written materials.
2. The *knowledge of a way of knowing* subcategory includes knowledge *given to people* concerning how to use a particular way of knowing. This procedural knowledge should be very specific and should allow the person to then adopt that way of knowing to a certain extent. Examples, rules and procedures in textbooks provide knowledge of a way of knowing. This subcategory answers the question, "What do I do to get the answer?"
3. The *way of knowing* subcategory is usually a question, problem or task *required of people*. A way of knowing is required of a person in order for this person to complete the assignment. This subcategory answers the question, "What way of knowing am I supposed to use to get the answer?"

When tough classifications are encountered the relationships among K, K Way K and Way K should be reviewed to assist in the classification.

Examples to be Classified as K, KW or W

1. The evaluation at the conclusion of this laboratory exercise should include five elements—an answer to the stated problem; an evaluation of the prediction; an evaluation of the theory, law, generalization or experience (TLGE) used to make the predictionx;an evaluation of the experimental design; and an attempt, if necessary, to restrict, revise or replace the TLGE.

3. From experience people know the characteristics of the three states of matter of water.

5. To develop an understanding of the concept of phase and temperature changes requires a combination of ways of knowing including the time honored memorized, referenced, and given ways of knowing.

7. Comment on the necessity for using a system of significant digits when communicating values in the scientific community.

9. The states of matter in this reaction in a water environment may be predicted from solubility generalizations, while the solubility might be explained by molecular polarity or hydrogen bonding.

11. In a laboratory simulation, a student found that the best container for water in a passive-solar greenhouse was a polyethylene container painted flat-black.

Validating Examples of K-KW-W Categories   Name

13. Use the theory of conservation of atoms and solubility generalizations to write a balanced chemical equation including states of matter for the reaction of potassium metal with water.
15. To make the gas furnace more efficient the Canadian solution was to improve the heat exchanger to the point that combustion water vapor condensed.
17. The mass of ice used in the experimental determination of the molar heat of fusion of water was 15.04 g.
19. When analyzing the language used in scientific communication, the language should reflect the nature of science by appealing to the evidence that supports or conflicts with a prediction made by a theory, law or generalization.
21. Describe the process you should employ in the school laboratory to prepare an aqueous primary standard solution from a solid solute.
23. Water may be used to mine sodium sulfate (salt cake) from the bottom of lakes.
25. Explain the relative boiling points of water and hydrogen sulfide.
27. State the restrictions and assumptions associated with the Bronsted-Lowry Theory of acids and bases as employed within this last section covered in the textbook.
29. From referencing the periodic table, the boiling point of oxygen is −183°C.
31. The VSEPR Theory is accepted by the scientific community because the theory is able to explain and predict the shape and/or polarity of molecules, such as the water molecule.
33. The criteria that should be used to judge a theory which is acceptable to the scientific community is the ability of the theory to explain existing effects (e.g., the polarity of the water molecule), and to predict future effects (e.g., the bond angle of the water molecule).
35. Describe how the Canadian inventors of the high-efficiency (condensing), gas furnace were <u>originally</u> able to extract heat from the combustion water vapor.
37. Politicians in Ontario have been forced by electorate interest-groups to take a stance on the acid-rain issue.
39. Describe the effect of adding water vapor to a gas mixture in an experiment similar to that done by Raoult or Dalton.
41. One way of explaining the boiling point of water relative to hydrogen sulfide was to invent the theory of hydrogen bonding.
43. Upon analyzing Charles Hall's search for a nonaqueous solvent for alumina it is apparent that the search is an example of a systematic trial and error approach to technological problem solving.
45. The bond angle of the hydrogen-oxygen-hydrogen bond in water can be determined by the X-ray analysis of ice.
47. Why is the SI system of units and symbols superior or inferior to the English system of measurement?
49. Ron Gillespie of McMaster University in Hamilton co-developed the VSEPR theory of stereochemistry.

Validating Examples of K-KW-W Categories Name

51. In the video series and book, Connections, James Burke presents an alternate view of historical analysis by relating technological advances to historical "progress".

53. Describe the behavior of water upon freezing in a large lake.

55. The observation that small bugs can walk on water can be explained by creating the concept of intermolecular forces.

57. The hot-water process for extracting oil from tar-sands has proven to be the most acceptable process yet invented.

59. The restricted perspectives taken on an issue by an individual or group can be analyzed from written or oral communication by classifying each sentence into perspectives (e.g., aesthetic, ecological, economic, emotional, ethical, legal, militaristic, mystical, political, scientific, social, and technological).

61. Classroom experience with the teaching/learning of phase change phenomena indicates that people have trouble integrating the phase change (temperature versus time) curve of water with the potential energy versus time graph of water. This empirical knowledge from the classroom is supported by formal educational research, but still needs some theoretical structure to explain why this is so. Perhaps the reason lies in the variety of different kinds of knowledge and different ways of knowing which are almost randomly thrown at people trying to make sense of the topic.

63. The student interpretation of the disappearance of the ice from the sidewalk was that the ice sublimed.

65. From the law of equilibrium, the predicted hydronium ion concentration in the solution is 2.4 mmol/L.

67. Why did Arrhenius have such great difficulty in getting his Theory of Ionic Dissociation accepted by the scientific community?

69. When titrating in the school laboratory, you should rinse all equipment with water both before and after use.

71. Use a conservation law to predict the volume of water that must be added to 10 mL of concentrated sulfuric acid in order to dilute the concentrated acid to 0.75 mol/L.

73. To treat an eye threatened by chemicals, flush the eye with water for at least 15 min.

75. The scientists expressed uncertainty because of the lack of evidence and because of a skeptical scientific attitude.

77. For pedagogic convenience it is appropriate to invent the hydronium ion to represent a hydrated proton.

79. When designing a low-energy, passive-solar home for your school project, a water wall should be located to the south-west or west in order to store solar heat during the part of the day when excess heat is entering the home.

81. The Le Chatelier Principle may be used to predict the shift in equilibrium when sodium hydroxide is added to water.

83. How would you start to explain the observation that snow flakes come in many, many shapes?

Validating Examples of K-KW-W Categories   Name

85. Write a critical appraisal of why, although the technology exists to divert water from Northern Alberta to Southern Alberta, the current provincial government is being very cautious in its proposals on this issue.

87. The eye may be damaged to a greater extent by basic solutions than by acidic solutions.

89. Western societies are reliant on high technology for food, shelter and recreation.

91. When approaching a unit of subject matter the number of curriculum emphases is usually restricted to one or two.

93. The oxygen atom in the water molecule is surrounded by two lone pairs of electrons and two bonding electrons.

95. The technician reads the water flow-rate from the meter by making sure that the error due to parallax is kept to a minimum.

97. Discuss how the water wheel may have influenced the development of the cottage industries in Britain during the industrial revolution.

99. Obtain about a mole (one heaping tablespoonful) of ice and add it to the styrofoam calorimeter containing 100 mL of water at about 30°C.

101. Predict the shape of the water molecule.

103. From memory, the equilibrium constant for water at SATP is 1.01×10^{-14} mol^2/L^2.

105. The volume of water measured by the student using a pipet was 10.0 mL.

107. The IUPAC rule for communicating the name of a chemical hydrate has not received wide acceptance by the international community of chemists.

109. To predict the shape of molecules, Canadian Ron Gillespie used VSEPR Theory.

111. Why do you think tar sands plants are allowed to continue to allegedly spoil the fishing grounds of the native population on the Athabasca River in Northern Alberta?

113. Read out loud the following chemical equation for the decomposition of water—do not read the symbols literally, translate the international symbols into English words.

115. A reconstructional or critical approach to social issues requires one to identify the interests (e.g., political, economic and social) and presuppositions of the principal actors who are in positions of power or who want to be in positions of power.

117. When judging any new technique which is acceptable to the engineering community, the technology must be economic, it must work reliably, and it must be simpler than the competition.

119. The stereochemical shape of the water molecule may be predicted by VSEPR theory. Draw a Lewis Model of the water molecule and then apply the theoretical rule that four groups of electrons will repel one another to form a tetrahedral distribution of electrons around the oxygen atom.

121. The chemical formula for sodium sulfate decahydrate is internationally communicated as $Na_2SO_4 \cdot 10H_2O_{(s)}$.

123. The technician determined the pH of the rain water to be 5.68.

125. Try to stand back from your society and interpret the effect of removing technology from your everyday life pattern.

127. What environmental effects might be expected when a large hydroelectric dam is built.

129. The purpose of this laboratory work is to gain a better appreciation of the importance of water as a "universal" solvent.

131. Predict (from Le Chatelier's Principle or the Equilibrium Law) and explain (from collision-rate theory) the shift in equilibrium when a strong base is added to a water sample.

Validating Examples of K-KW-W Categories **Name**

Instructions for Validating Knowledge and Ways of Knowing

The following sixty-six statements and questions are to be categorized into knowledge, knowledge of a way of knowing, and way of knowing categories. There is an equal number of each of these categories. Write *K* for knowledge, *KW* for knowledge of a way of knowing, or *W* for way of knowing in the margin to the left of each statement or question. If you have a close second choice, indicate the second choice as well; e.g., *K/KW*. You may wish to write comments on the validation sheet. You will be given the key and an opportunity to discuss your answers at a later time. Please provide your name at the top of the page.

Kinds of Knowledge Dimension

The kinds of knowledge dimension has been found by this empirical study to have three components—kinds of knowledge (K), knowledge of a way of knowing (K Way K), and way of knowing (Way K).

1. The *knowledge*, K, subcategory is knowledge *given to people* by the authors of the written materials.
2. The *knowledge of a way of knowing* subcategory includes knowledge *given to people* concerning how to use a particular way of knowing. This procedural knowledge should be very specific and should allow the person to then adopt that way of knowing to a certain extent. Examples, rules and procedures in textbooks provide knowledge of a way of knowing. This subcategory answers the question, "What do I do to get the answer?"
3. The *way of knowing* subcategory is usually a question, problem or task *required of people*. A way of knowing is required of a person in order for this person to complete the assignment. This subcategory answers the question, "What way of knowing am I supposed to use to get the answer?"

When tough classifications are encountered the relationships among K, K Way K and Way K should be reviewed to assist in the classification.

Examples to be Classified as K, KW or W

2. The water molecule contains two polar covalent bonds.
4. The chemical engineer tests the quality of the water leaving the plant by using conductivity and photometric measurements..
6. Use the VSEPR Theory, co-developed by Candian Ron Gillespie, to predict, as he originally would have, the shape of the water molecule.
8. The experimental design of the experiment should state the manipulated, responding and controlled variables along with a summary of the procedure being used.
10. The Lewis Molecular Theory may be used to explain the empirical formula for water, H_2O, by using electron dot models of oxygen and hydrogen atoms.
12. The overt perspective taken on the acid rain issue by the President of the United States appears to be primarily scientific (i.e., more research needs to be done because scientists are uncertain as to the sources of the acid rain). The question remains as to whether the President understands that the nature of the scientific perspective on an issue requires the expression of uncertainty rather than dogmatic or absolute answers.

Validating Examples of K-KW-W Categories Name

14. Water may be electrolytically decomposed in a Hoffman apparatus by employing a catalytic-electrolyte such as sodium sulfate.

16. A sociologist gathers evidence to answer a stated sociological problem by using one or more of three techniques—interviews, questionnaires or observation.

18. Take 15 min from your day and observe and interpret the dependence of your family on science and technology.

20. Use the CRC Handbook of Chemistry and Physics to reference the [ionization constant for water at 50°C in order to perform the following prediction.]

22. Scientific and technological knowledge and attitudes are just a couple of the many forms of knowledge and attitudes necessary to becoming informed on a science-in-society issue.

24. The first heavy-water moderated and cooled nuclear reactor in the world was built in the early 1950's.

26. Experience with states of matter may be combined with the theory of conservation of atoms to write a balanced chemical equation for the electrolytic decomposition of water.

28. H. Urey is credited with discovering heavy water at Columbia University in 1931.

30. The students observed that the water rose the highest in the smallest diameter capillary tube.

32. The process by which a new technology is developed by engineers or technicians is usually very empirical and involves a systematic trial-and-error approach.

34. Use solubility generalizations to predict whether the following ionic compounds have high or low solubility.

36. What interpretation may be put on the above observations of aqueous solutions?

38. We, in our modern society, tend to look for technological fixes for our problems.

40. Design and perform a laboratory experiment to determine the molar heat of fusion of ice.

42. Knowing from experience the state of matter of water at SATP, use stereochemistry and intermolecular force theory to explain this observation.

44. A sociologist may use the technique of "walking in someone elses shoes" or may "step back" from society in making more subjective or objective observations, respectively.

46. What ways of knowing the chemical formula and state of matter at room temperature of water were used by you in your last chemistry education course?

48. Add 15.0 mL of water to the solid solute and stir the mixture until the solute is all dissolved.

50. The shift in equilibrium in the water solution may be predicted by using the Le Chatelier Principle and explained using collision and rate of reaction theories.

52. What kinds of questions should be expected on the test for this unit?

54. What was the purpose of going into the laboratory to determine the molar heat of water?

56. The amount of heat gained by water in a calorimeter can be predicted by multiplying the volume times the volumetric heat capacity times the change in temperature.

Validating Examples of K-KW-W Categories Name

58. When Jacob Bronowski investigated the history of a scientific idea (i.e., in The Ascent of Man), he used an approach of relating the scientific and social presuppositions of the era to one another.

60. How do generalizations and theories of learning get to be accepted by the science-education community?

62. The way to test any theories or generalizations of teaching and learning is to gather evidence in the classroom situation.

64. Water is a colorless liquid at room conditions.

66. When reading a laboratory assignment be sure to differenciate between the purpose of a laboratory exercise and the problem to be answered by the experiment.

68. SI Metric Rules suggest that the mass of water should be communicated as 12.7 g, using all symbols, rather than a combination of symbols and abbreviations or words such as in 12.7 gm. or 12.7 grams.

70. Describe the life cycle of a technological device from the time that it is invented to the time it is discarded or replaced by a competing device.

72. Lake water containing phosphates from detergents may becomed clogged with weeds and algae whose growth is promoted by the fertilizer effect of the phosphates.

74. Research chemists are able to use sophisticated equipment to obtain the conductivity and pH of water, and then use a theory of equilibrium to explain this evidence.

76. The purpose of the test will be to test chemisty content as well as STSC types of questions.

78. Further classify the issue perspective statements that you have found by indicating whether or not the statements are positive or negative statements relative to the resolution on the issue being debated.

80. Discuss how the concept of earth, air, fire and water as the elements of all things influenced the history of both science and society in the middle ages.

82. The rapid use of energy resources by our "me generation" will likely gain us a very ignominious reputation in the history of Earth.

84. The predicted molar heat of fusion of water from this experimental design should be communicated with three significant digits.

86. A water-wall may be used to store solar energy absorbed by the wall in a passive-solar home.

88. When analyzing pedagogic ways of knowing look for given, referenced and memorized ways of knowing.

90. The 42 MJ of heat predicted from heat laws for the phase change of water may be explained as an increase in chemical potential energy.

92. Predict the mass of water reacted and communicate your problem solving technique by communicating the formula with international quantity symbols, substituting with accepted significant digits and unit symbols, and communicating the prediction with accepted certainty and units.

Validating Examples of K-KW-W Categories Name

94. The high-efficiency (95-98 % efficient) condensing gas furnace, now being marketted by an American firm, was originally developed by a Canadian in Manitoba.

96. The effect of PCBs on humans must be extrapolated from experiments on small animals or by doing health studies on humans exposed to PCBs.

98. The product of the hydronium and the hydroxide ion molar concentrations in any water sample at SATP is a constant—K_W—equal to 1.01×10^{-14} mol^2/L^2.

100. When a specific heat capacity other than for water is required in a quantitative prediction, the heat capacity will be given in the problem or must be referenced from a table of heat capacities provided.

102. When analyzing a system of communication acceptable to the scientific community, the communication system should be simple and precise and should express the uncertainty or tentativeness of science.

104. Determine the effect on various kinds of soil by their buffering of acid rain.

106. When a theory cannot predict accurately, it should either be restricted to predicting within a restricted situation, or revised such that it is able to predict more accurately, or replaced with a new theory that is able to predict accurately.

108. The rule for communicating significant digits that requires scientific notation is not as acceptable now that the simpler method of using SI prefixes is available.

110. Analyze the perspectives taken on the nuclear war issue in the article by the nuclear disarmament group and compare this to your analysis of the previous article by the pro-nuclear group.

112. There are positive and negative statements that can be classified on any science-in-society issue from any of twelve or more perspectives on an issue.

114. Instead of calling $H_2O_{(l)}$, hydrogen oxide, the scientific community prefers to call this substance "water".

116. What are the attributes of a process for the electrochemical production of electricity from water that would make the process acceptable to the engineering community?

118. The increase in the average kinetic energy of the water molecules was predicted by the laws of thermodynamics to be 368 kJ.

120. The chemical engineer adjusted the flow rate to 500 L/s to increase the efficiency of the process for removing bromine from sea water.

122. A fired environment official who has signed a pact of secrecy is put into an awkward position. For social, ethical and environmental reasons she might want to speak-up. However, the political party that fired her has a legal right to stop her from speaking in public about the controversy over which she was fired.

124. Design an industrial process to extract sodium sulfate from the bottom of a lake.

126. What accepted technique would you employ for using the solar photometer so that reflection off of water or snow does not get measured as part of the total solar radiation.

128. The bottom-line test of a technological process for the electrolytic decomposition of water by photoelectricity that was used by the engineers was the cost efficiency of the process.

130. From memory, what is the H-O-H bond angle in water?

132. Suggest changes to the Hoffman apparatus that would be necessary to the industrial production of hydrogen fuel from water on a large scale.

Appendix C8

Validation of STSC Classification System Name

STSC Classification

The STSC classification system was developed from the classification of kinds of knowledge presented within chemistry classroom materials. This classification divides chemistry education knowledge into five categories - science, technology, society, communication and pedagogy. From your experience in chemistry education please comment on the appropriateness or usefulness of this classification scheme.

1. Describes accurately:

2. Guides future work:

3. Simplicity/complexity:

4. Restrictions and assumptions:

The Knowledge and Ways of Knowing. Triad

The second dimension STSC classification matrix involves the triadic classification of given statements and required activities. The given knowledge is divided into two classes — knowledge and knowledge of a way of knowing. The third class is the way of knowing actively used to complete the paper and pencil or laboratory activity. From your experience in chemistry education please comment on the appropriateness or usefulness of this classification scheme.

5. Describes accurately:

6. Guides future work:

7. Simplicity/complexity:

8. Restrictions and assumptions:

Appendix C9

A Classification of Scientific Knowledge and Ways of Knowing Name

STSC—The Nature of Science Emphasis

A nature of science emphasis includes various knowledge and knowledge of scientific ways of knowing components given to people and scientific ways of knowing components required of people. The nature of science emphasis is defined by eight substantive categories including

1. theoretical knowledge,
2. empirical (experience or experimental) knowledge,
3. linked experiential-empirical knowledge and theoretical knowledge,
4. empirical (law or generalization) knowledge,
5. combined generalized-empirical knowledge and theoretical knowledge,
6. scientific process skill knowledge,
7. scientific epistemology knowledge,
8. scientific context or perspective knowledge.

Each of these knowledge components (except the last) has a corresponding knowledge of a way of knowing and a way of knowing component associated with it for a total of twenty-two components.

The components have been derived from the literature, from the experience and intuition of the researcher, and from the research itself. The original three components, theoretical, empirical, and scientific process skills, were expanded upon by the researcher during the pilot application of the classification scheme to Unit L—"Energy" of the ALCHEM materials (1975 and 1982 editions). The empirical category was split at that time to include knowledge that was derived directly from experience and experiment versus predicted from laws and generalizations. It was later found necessary to differentiate the "experience and experiment" of a third person from that of a first person in a science-education situation. The latter came to be classified as part of the scientific process category. Activities that are to include the person directly in scientific laboratory work, as part of his or her science education, should be classified as scientific process work. Descriptions of scientific work outside of the science-education context should be classified as empirical or theoretical work, as appropriate. The epistemology category was found to be necessary in each of the STSC emphases. Epistemological statements speak to the validity, nature and origin of knowledge. In the scientific context, epistemology speaks to the acceptable attributes of scientific theories, laws, generalizations, and experiential "facts", and to the way in which scientific knowledge gets accepted in the scientific community.

Each of the Nature of Science categories and sub-categories are defined and examples are provided below. An attempt has been made in the examples to relate the content to the chemical—water.

A Classification of Scientific Knowledge and Ways of Knowing Name

The Theoretical Category

1. The K (theoretical knowledge) includes specific theoretical knowledge *given* to a person. Theoretical knowledge generally includes knowledge that is not directly observable or measurable; e.g., atoms, molecules, bonds, and intermolecular forces. Knowledge of a theory or knowledge which results from a theoretical way of knowing (i.e., the use of a theory) fits into this category.

E.g., The oxygen atom in the water molecule is surrounded by two lone pairs of electrons and two bonding electrons.
E.g., The water molecule contains two polar covalent bonds.

2. K The W (knowledge of a theoretical way of knowing) is specific knowledge given to a person about a theoretical way of knowing; i.e., how a theory may be used to explain or predict a particular phenomena.

E.g., The Lewis Molecular Theory may be used to explain the empirical formula for water, H_2O, by using electron dot models of oxygen and hydrogen atoms.
E.g., The stereochemical shape of the water molecule may be predicted by VSEPR theory. Draw a Lewis Model of the water molecule and then apply the theoretical rule that four groups of electrons will repel one another to form a tetrahedral distribution of electrons around the oxygen atom.

3. The W (a theoretical way of knowing) is required of a person. The person must use knowledge of a theory to explain or predict some phenomena or effect.

E.g., Explain the relative boiling points of water and hydrogen sulfide.
E.g., Predict the shape of the water molecule.

The Empirical (Experience) Category

4. Emp K_E (experiential-empirical knowledge) is knowledge given to a person, based upon the experience or experiment of someone else. The empirical knowledge usually appears as qualitative or quantitive descriptions of a phenomena.

E.g., Water is a colorless liquid at room conditions.

E.g., The mass of ice used in the experimental determination of the molar heat of fusion of water was 15.04 g.

5. K Emp W_E (knowledge of an empirical way of knowing related to experience or experiment) is knowledge given to people relative to how to obtain this kind of knowledge. To differentiate this category from K Pro W (knowledge of a process way of knowing) K Emp W is restricted to a third person type of involvement, whereas K Pro W is specific to the person (usually in the science-education laboratory).

E.g., The bond angle of the hydrogen-oxygen-hydrogen bond in water can be determined by the X-ray analysis of ice.

E.g., From experience people know the characteristics of the three states of matter of water.

6. Emp W_E (an experientially related empirical way of knowing) when required of a person calls on the person's past experience outside of the laboratory or calls on a scientist's past experiment.

E.g., Describe the behavior of water upon freezing in a large lake.

E.g., Describe the effect of adding water vapor to a gas mixture in an experiment similar to that done by Raoult or Dalton.

The Empirical (Experience)-Theoretical Category

7. Emp K_E—The K (empirical experience and theoretical knowledge) is knowledge given to a person that combines empirical knowledge gained from experience or experiment with knowledge gained theoretically. There should be a strong link between the empirical and the theoretical knowledge that is presented. The two parts to the sentence should not make sense if separated and classified separately.

E.g., The observation that small bugs can walk on water can be explained by creating the concept of intermolecular forces.

E.g., One way of explaining the boiling point of water relative to hydrogen sulfide was to invent the theory of hydrogen bonding.

8. K Emp W_E-K The W (knowledge of an empirical way of knowing and a theoretical way of knowing) is knowledge given to a person that assists in knowing how to obtain knowledge relating empirical and theoretical statements.

E.g., Experience with states of matter may be combined with the theory of conservation of atoms to write a balanced chemical equation for the electrolytic decomposition of water.

E.g., Research chemists are able to use sophisticated equipment to obtain the conductivity and pH of water, and then use a theory of equilibrium to explain this evidence.

9. Emp W_E—The W (a combination empirical and theoretical way of knowing) requires a person to predict and/or explain something from experience or experiment.

E.g., How would you start to explain the observation that snow flakes come in many, many shapes?

E.g., Knowing from experience the state of matter of water at SATP, use stereochemistry and intermolecular force theory to explain this observation.

The Empirical (Law) Category

10. Emp K_L (law or generalization based empirical knowledge) is knowledge given to the person concerning a law or generalization or is knowledge given to a person that has been predicted from a law or generalization (i.e., by an Emp W_L).

E.g., The product of the hydronium and the hydroxide ion molar concentrations in any water sample at SATP is a constant—K_W—equal to 1.01×10^{-14} mol^2/L^2.

E.g., From the law of equilibrium, the predicted hydronium ion concentration in the solution is 2.4 mmol/L.

11. K Emp W_L (knowledge of an empirical way of knowing from a law or generalization) is knowledge given to the person concerning how to use a law or generalization to predict an unknown variable.

E.g., The amount of heat gained by water in a calorimeter can be predicted by multiplying the volume times the volumetric heat capacity times the change in temperature.
E.g., The Le Chatelier Principle may be used to predict the shift in equilibrium when sodium hydroxide is added to water.

12. Emp W_L (an empirical way of knowing from laws or generalizations) requires a person to predict an unknown variable in a law from the data available.

E.g., Use solubility generalizations to predict whether the following ionic compounds have high or low solubility.
E.g., Use a conservation law to predict the volume of water that must be added to 10 mL of concentrated sulfuric acid in order to dilute the concentrated acid to 0.75 mol/L.

The Empirical (Law)/Theoretical Category

13. Emp K_L/The K (knowledge of an empirical law and a related theory) is knowledge given to a person which combines knowledge of a law and the theory that explains the law.

E.g., The increase in the average kinetic energy of the water molecules was predicted by the laws of thermodynamics to be 368 kJ.
E.g., The 42 MJ of heat predicted from heat laws for the phase change of water may be explained as an increase in chemical potential energy.

14. K Emp W_L/K The W (knowledge of an empirical way of knowing from laws and generalizations and knowledge of a theoretical way of knowing from theories) is knowledge given to people on how to predict (or in the case of a theory—explain) a physical phenomena.

E.g., The shift in equilibrium in the water solution may be predicted by using the Le Chatelier Principle and explained using collision and rate of reaction theories.
E.g., The states of matter in this reaction in a water environment may be predicted from solubility generalizations, while the solubility might be explained by molecular polarity or hydrogen bonding.

15. Emp W_L-The W (an empirical way of knowing from laws and generalizations combined with a theoretical way of knowing from theories) is a way of knowing required of a person that requires combines knowledge of the use of laws, generalizations and theories.

E.g., Predict (from Le Chatelier's Principle or the Equilibrium Law) and explain (from collision-rate theory) the shift in equilibrium when a strong base is added to a water sample.
E.g., Use the theory of conservation of atoms and solubility generalizations to write a balanced chemical equation including states of matter for the reaction of potassium metal with water.

The (Scientific) Process Category

16. Pro K_S (scientific process knowledge) is knowledge given to the person which has resulted from a scientific process way of knowing employed in a science-education laboratory. Generally the scientific process words or a science-education context must accompany the knowledge in order to classify the knowledge as process knowledge. This category does not include psychomotor skills as these are classified as technological skills.

E.g., The students observed that the water rose the highest in the smallest diameter capillary tube.

E.g., The student interpretation of the disappearance of the ice from the sidewalk was that the ice sublimed.

17. K Pro W_S (knowledge of a process way of knowing in a scientific context) includes knowledge of how to use a scientific process. This category would include definitions of process skills, because these definitions generally include instructions of how-to apply the particular skill. Knowledge of a technological skill is not included.

E.g., The experimental design of the experiment should state the manipulated, responding and controlled variables along with a summary of the procedure being used.

E.g., The evaluation at the conclusion of this laboratory exercise should include five elements—an answer to the stated problem; an evaluation of the prediction; an evaluation of the theory, law, generalization or experience (TLGE) used to make the predictionx;an evaluation of the experimental design; and an attempt, if necessary, to restrict, revise or replace the TLGE.

18. K Pro W - Pro W_S (knowledge of a process way of knowing combined with a process way of knowing) is a category created to classify those statements in science-education that give the "recipe" to the person that he or she then follows. The statement is given knowledge of how and/or when to do a laboratory procedure and also requires the person to complete the instruction in a process way.

E.g., Add 15.0 mL of water to the solid solute and stir the mixture until the solute is all dissolved.

E.g., Obtain about a mole (one heaping tablespoonful) of ice and add it to the styrofoam calorimeter containing 100 mL of water at about 30°C.

19. Pro W_S (a scientific process way of knowing) generally requires the person to state a problem, design an experiment, identify variables, predict, make a table of evidence, collect evidence, analyze evidence, and/or evaluate an experiment. Because the instructions (K Pro W_S) are missing after an initial request statement, the number of Pro W tallies has to be determined from experience with the laboratory activity. Guidelines have to be established previous to using this category as to the maximum tallies that will be accepted for independent work. The Pro W category is separated from the K Pro W - Pro W_S in order to get an estimate of the relative independence of the laboratory work being done.

E.g., What interpretation may be put on the above observations of aqueous solutions?

E.g., Design and perform a laboratory experiment to determine the molar heat of fusion of ice.

The Epistemology (in Science) Category

20. Epi K_S (epistemological knowledge in a scientific context) is knowledge given to people in relation to the limits and validity of specific knowledge. Epistemological knowledge (Epi K_S) is specific to a particular situation and results from an epistemological way of knowing (Epi W_S) and should be differentiated from general knowledge given about an epistemological way of knowing (K Epi W_S).

E.g., The VSEPR Theory is accepted by the scientific community because the theory is able to explain and predict the shape and/or polarity of molecules, such as the water molecule.

E.g., The scientists expressed uncertainty because of the lack of evidence and because of a skeptical scientific attitude.

21. K Epi W_S (knowledge of an epistemological way of knowing) is knowledge given to people concerning the use of an epistemological way of knowing (i.e., information concerning the limits and validity of knowledge, the nature or origin of knowledge, and/or the theory of knowledge).

E.g., The criteria that should be used to judge a theory which is acceptable to the scientific community is the ability of the theory to explain existing effects (e.g., the polarity of the water molecule), and to predict future effects (e.g., the bond angle of the water molecule).

E.g., When a theory cannot predict accurately, it should either be restricted to predicting within a restricted situation, or revised such that it is able to predict more accurately, or replaced with a new theory that is able to predict accurately.

22. Epi W_S (an epistemological way of knowing in science) is required of people when they are questioned about the grounds for, the validity of, or the limitations of specified knowledge or ways of knowing.

E.g., State the restrictions and assumptions associated with the Bronsted-Lowry Theory of acids and bases as employed within this last section covered in the textbook.

E.g., Why did Arrhenius have such great difficulty in getting his Theory of Ionic Dissociation accepted by the scientific community?

A Classification of Technological Knowledge and Ways of Knowing Name

STSC—The Nature of Technology Emphasis

A nature of technology emphasis speaks to the nature of the technological enterprise and its knowledge (epistemology) as well as including technological skills and problem-solving processes, and technological products (devices) and engineering processes. Since the 1960's the technology category has been given less emphasis in science education. The current push for a technological component in science education seems to include a broader base than previous curricula. Technological problem solving skills and attitudes are starting to be recognized as important emphases (i.e., the systematic "trial-and-error" elimination of possible solutions to a problem and the attitudinal skill that people *can* understand, "fix", and control technology).

The Technology Category

1. Tec K (technological knowledge) is knowledge given to people concerning technological products, processes and skills. Tec K refers to man-made products and designed processes.

E.g., A water-wall may be used to store solar energy absorbed by the wall in a passive-solar home.

E.g., The hot-water process for extracting oil from tar-sands has proven to be the most acceptable process yet invented.

2. K Tec W (knowledge of a technological way of knowing) is knowledge given to people concerning technological skills, attitudes, problem-solving approach, engineering skills, and empirical rules for predicting solutions to problems.

E.g., Water may be electrolytically decomposed in a Hoffman apparatus by employing a catalytic-electrolyte such as sodium sulfate.

E.g., Water may be used to mine sodium sulfate (salt cake) from the bottom of lakes.

3. Tec W (a technological way of knowing) is required of a person and is evidenced by a need to suggest changes, for example, in a technological process that might make the process more efficient, more economical, and/or less polluting.

E.g., Suggest changes to the Hoffman apparatus that would be necessary to the industrial production of hydrogen fuel from water on a large scale.

E.g., Design an industrial process to extract sodium sulfate from the bottom of a lake.

The Empirical (Technology) Category

4. Emp K_T (empirical knowledge in a technological context) is knowledge given to a person concerning work done by a third person (e.g., a chemical engineer). The knowledge must not be from a chemistry education laboratory (Pro K_T) or an industrial situation (Tec K). This category would include technical data and measurements made with various technological devices.

E.g., The technician determined the pH of the rain water to be 5.68.

E.g., The chemical engineer adjusted the flow rate to 500 L/s to increase the efficiency of the process for removing bromine from sea water.

5. K Emp W_T (knowledge of an empirical way of knowing in a technological context) is knowledge given to person concerning the methods used by engineers and technicians in their work.

E.g., The technician reads the water flow-rate from the meter by making sure that the error due to parallax is kept to a minimum.

E.g., The chemical engineer tests the quality of the water leaving the plant by using conductivity and photometric measurements.

The Technological Process Category

6. Pro K_T (technological process knowledge in a science-education context) is knowledge given to a student as a result of a student Pro W_T in a laboratory. The same process knowledge created in a chemical technologist or engineer would be classified as Emp K_T.

E.g., The volume of water measured by the student using a pipet was 10.0 mL.

E.g., In a laboratory simulation, a student found that the best container for water in a passive-solar greenhouse was a polyethylene container painted flat-black.

7. K Pro W_T (knowledge of a process way of knowing in a technological context) is knowledge given to a student concerning a method of operating a piece of technology or of controlling a technological process.

E.g., When titrating in the school laboratory, you should rinse all equipment with water both before and after use.

E.g., When designing a low-energy, passive-solar home for your school project, a water wall should be located to the south-west or west in order to store solar heat during the part of the day when excess heat is entering the home.

8. Pro W_T

E.g., What accepted technique would you employ for using the solar photometer so that reflection off of water or snow does not get measured as part of the total solar radiation.

E.g., Describe the process you should employ in the school laboratory to prepare an aqueous primary standard solution from a solid solute.

Epistemology (in Technology) Category

9. Epi K_T (epistemological knowledge in a technology context) is specific (not general) knowledge given to people in relation to the limits and validity of technological knowledge. The specific knowledge should come from applying an Epi W_T to a specific situation. More-general epistemological knowledge usually fits into the knowledge of an epistemological way of knowing (K Epi W_T) category.

E.g., Upon analyzing Charles Hall's search for a nonaqueous solvent for alumina it is apparent that the search is an example of a systematic trial and error approach to technological problem solving.

E.g., The bottom-line test of a technological process for the electrolytic decomposition of water by photoelectricity that was used by the engineers was the cost efficiency of the process.

10. K Epi W_T (knowledge of an epistemological way of knowing in a technological context) is general knowledge given to people concerning how technological knowledge comes to be accepted within the engineering community, along with knowledge concerning the nature, the limits and the validity of technological knowledge.

E.g., When judging any new technique which is acceptable to the engineering community, the technology must be economic, it must work reliably, and it must be simpler than the competition.

E.g., The process by which a new technology is developed by engineers or technicians is usually very empirical and involves a systematic trial-and-error approach.

11. Epi W_T (an epistemological way of knowing in a technological context) is required of people who must answer questions concerning the nature, validity, or limitations of technological knowledge.

E.g., What are the attributes of a process for the electrochemical production of electricity from water that would make the process acceptable to the engineering community?

E.g., Describe the life cycle of a technological device from the time that it is invented to the time it is discarded or replaced by a competing device.

A Classification of Societal Knowledge and Ways of Knowing Name

STSC—The Nature of Society Emphasis

A nature of society emphasis in science curriculum materials is primarily identified as being issue oriented. The issue may be a public issue, such as nuclear energy, toxic rain, pesticides, energy crises, resource crises, drugs, and air and water pollution; or the issue may come from within the scientific community, such as scientific honesty and the recognition of para-psychology as a science; or the issue may be philosophical, such as raised by the critical theorists concerning the mechanistic and reductionist orientations claimed to exist within the scientific community.

The other main aspects of a science-in-society curriculum emphasis are less issue oriented and more historical or societal oriented. Within this classification scheme sociological, national and historical knowledge presented within science curriculum materials will be considered to be part of a science-in-society emphasis. Although the term "science-in-society" is being used at this point, it should be recognized that "science-and-technology-in-society" may be a more appropriate term for this emphasis. Many of the issues are more directly technology-in-society issues than they are science-in-society issues.

The Societal (Sociological) Category

1. Soc K (societal knowledge) is knowledge given to students concerning a particular society or culture. This knowledge should result from a Soc W and should appear as knowledge that would normally appear in a social studies text rather than a science textbook.

E.g., Western societies are reliant on high technology for food, shelter and recreation.
E.g., We, in our modern society, tend to look for technological fixes for our problems.

2. K Soc W (knowledge of a societal way of knowing) is knowledge given to students about how to use a societal way of knowing (Soc W). Knowledge of a way of knowing should be methodological knowledge that can be converted by students into a way of knowing.

E.g., A sociologist gathers evidence to answer a stated sociological problem by using one or more of three techniques—interviews, questionnaires or observation.
E.g., A sociologist may use the technique of "walking in someone elses shoes" or may "step back" from society in making more subjective or objective observations, respectively.

3. Soc W (a societal way of knowing) is a way of knowing required of students. This way of knowing should provide the student with Soc K.

E.g., Take 15 min from your day and observe and interpret the dependence of your family on science and technology.
E.g., Try to stand back from your society and interpret the effect of removing technology from your everyday life pattern.

The National Category

4. Nat K (national knowledge) is knowledge given to people that provides places and/or names regardless of where the places are on Earth. The knowledge given need not be intended for testing purposes to be classified as national knowledge. A sub-category of national knowledge is Canadian knowledge. To be classified a Nat K, K Nat W, or Nat W rather than Nat C or Nat P, an historical context involving the originator must be set for the statement. The originator or original community of engineers or scientists must be stated as <u>activists</u> for the statement to be classified as Nat K rather than Nat C.

E.g., Ron Gillespie of McMaster University in Hamilton co-developed the VSEPR theory of stereochemistry.

A Classification of Societal Knowledge and Ways of Knowing Name

E.g., The high-efficiency (95-98 % efficient) condensing gas furnace, now being marketted by an American firm, was originally developed by a Canadian in Manitoba.

5. K Nat W (knowledge of a national way of knowing) is knowledge given to a person concerning a national way of *doing* something that is technologically or scientifically oriented. This category is restricted to including a technological process or a scientific theory, law, generalization or experience that is mentioned as having been developed in a particular country or region. The statement must be stated historically, as the original engineer or scientist might have used the way of doing or knowing. If the context is not in the past (or original) tense, then a Nat C is recorded rather than K Nat W.

E.g., To predict the shape of molecules, Canadian Ron Gillespie used VSEPR Theory.
E.g., To make the gas furnace more efficient the Canadian solution was to improve the heat exchanger to the point that combustion water vapor condensed.

6. Nat W (a national way of knowing) requires people to use a nationally developed theory, law or generalization to predict an unknown effect or to use national experience (particularly engineering experience) to guide actions. The way of knowing is only national if an historical context is set by giving the name or place of the *originator* of this way of knowing. The way of doing or knowing may not be considered national now but was originally, before the rest of the engineering or scientific community accepted the approach.

E.g., Use the VSEPR Theory, co-developed by Canadian Ron Gillespie, to predict, as he originally would have, the shape of the water molecule.
E.g., Describe how the Canadian inventors of the high-efficiency (condensing), gas furnace were originally able to extract heat from the combustion water vapor.

The Historical Category

7. His K (historical knowledge) is knowledge given to people as a result of employing an historical way of knowing (His W). Historical knowledge can be differentiated from an historical context (His C) by whether or not the main intent of the sentence is to convey historical knowledge. Historical knowledge presented as a context may also be tested by teachers but is presented in the curriculum materials to set the context for a sentence used mainly to convey another kind of knowledge other than national.

E.g., H. Urey is credited with discovering heavy water at Columbia University in 1931.
E.g., The first heavy-water moderated and cooled nuclear reactor in the world was built in the early 1950's.

8. K His W (knowledge of an historical way of knowing) is knowledge given to a person that would train the person how to employ an historical way of knowing. (This category is unlikely to appear in science materials unless historical research methods are discribed.)

E.g., When Jacob Bronowski investigated the history of a scientific idea (i.e., in The Ascent of Man), he used an approach of relating the scientific and social presuppositions of the era to one another.
E.g., In the video series and book, Connections, James Burke presents an alternate view of historical analysis by relating technological advances to historical "progress".

9. His W (an historical way of knowing) is required of people who must answer questions concerning the interpretation of history.

E.g., Discuss how the water wheel may have influenced the development of the cottage industries in Britain during the industrial revolution.

E.g., Discuss how the concept of earth, air, fire and water as the elements of all things influenced the history of both science and society in the middle ages.

The Ecological Category

10. Eco K (ecological knowledge) is knowledge given to people concerning the environment, including human ecology. Laboratory safety, waste disposal, air and water pollution, and nuclear war are all examples of contexts for presenting ecological knowledge.

E.g., The eye may be damaged to a greater extent by basic solutions than by acidic solutions.

E.g., Lake water containing phosphates from detergents may becomed clogged with weeds and algae whose growth is promoted by the fertilizer effect of the phosphates.

11. K Eco W (knowledge of an ecological way of knowing) is knowledge given to a person about how to gain ecological knowledge first hand.

E.g., The effect of PCBs on humans must be extrapolated from experiments on small animals or by doing health studies on humans exposed to PCBs.

E.g., To treat an eye threatened by chemicals, flush the eye with water for at least 15 min.

12. Eco W (an ecological way of knowing) is required of people to answer ecological questions or solve ecological problems.

E.g., Determine the effect on various kinds of soil by their buffering of acid rain.

E.g., What environmental effects might be expected when a large hydroelectric dam is built.

The Reconstructional Category

13. Rec K (reconstructional knowledge) is knowledge given to a person as a result of someone else employing a reconstructional way of knowing. Reconstructional knowledge is knowledge of presuppositions and interests related to a social issue, and within science education this knowledge is particularly related to science-in-society issues.

E.g., Politicians in Ontario have been forced by electorate interest-groups to take a stance on the acid-rain issue.

E.g., The rapid use of energy resources by our "me generation" will likely gain us a very ignominious reputation in the history of Earth.

14. K Rec W (knowledge of a reconstructional way of knowing) is knowledge given to people concerning how to critically identify and analyze a social issue with the underlying assumption that a reconstruction of some aspect of society is required.

E.g., A reconstructional or critical approach to social issues requires one to identify the interests (e.g., political, economic and social) and presuppositions of the principal actors who are in positions of power or who want to be in positions of power.

E.g., Scientific and technological knowledge and attitudes are just a couple of the many forms of knowledge and attitudes necessary to becoming informed on a science-in-society issue.

15. Rec W (a reconstructional way of knowing) is required of people to critically analyze a situation presented to them. The critical analysis must attempt to get to the underlying foundations of a particular social, economic or social structure which exists in a particular situation. The question most often asked is, "In whose interest is this change being made (or not being made)?"

E.g., Write a critical appraisal of why, although the technology exists to divert water from Northern Alberta to Southern Alberta, the current provincial government is being very cautious in its proposals on this issue.

E.g., Why do you think tar sands plants are allowed to continue to allegedly spoil the fishing grounds of the native population on the Athabasca River in Northern Alberta?

The Epistemology (in a Societal Context) Category

16. Epi K_{SS} (epistemological knowledge in a science-in-society context) is knowledge given to people that resulted from an Epi W_{SS} being employed by someone else. This category is usually specific to a particular situation since it involves applying an Epi W_{SS} to a specific situation. [An epistemological category differs from the reconstructional category in their analytic and political orientations, respectively.]

E.g., The overt perspective taken on the acid rain issue by the President of the United States appears to be primarily scientific (i.e., more research needs to be done because scientists are uncertain as to the sources of the acid rain). The question remains as to whether the President understands that the nature of the scientific perspective on an issue requires the expression of uncertainty rather than dogmatic or absolute answers.

E.g., A fired environment official who has signed a pact of secrecy is put into an awkward position. For social, ethical and environmental reasons she might want to speak-up. However, the political party that fired her has a legal right to stop her from speaking in public about the controversy over which she was fired.

17. K Epi W_{SS} (knowledge of an epistemological way of knowing in a science-in-society context) is knowledge given concerning a way or ways of analyzing a science-in-society issue from the standpoint of how knowledge comes to be accepted by various segments of society.

E.g., The restricted perspectives taken on an issue by an individual or group can be analyzed from written or oral communication by classifying each sentence into perspectives (e.g., aesthetic, ecological, economic, emotional, ethical, legal, militaristic, mystical, political, scientific, social, and technological).

E.g., There are positive and negative statements that can be classified on any science-in-society issue from any of twelve or more perspectives on an issue.

18. Epi W_{SS} (an epistemological way of knowing in a science-in-society context) is required of a person when analyzing the restrictions, presuppositions, values, and perspectives employed by segments of society when selecting sides on an issue.

E.g., Analyze the perspectives taken on the nuclear war issue in the article by the nuclear disarmament group and compare this to your analysis of the previous article by the pro-nuclear group.

E.g., Further classify the issue perspective statements that you have found by indicating whether or not the statements are positive or negative statements relative to the resolution on the issue being debated.

A Classification of Communicational Knowledge and Ways of KnowingName

STSC—The Nature of Communication Emphasis

The nature of scientific and technological communication is usually neglected as an overt issue in science education textbooks. Someone somewhere makes a decision as to how something should be communicated within the scientific community. Seldom is the process by which scientific communication gets legitimized discussed. Some obvious examples of communication systems employed in science are Arabic number symbols, SI metric units and symbols, IUPAC symbols and nomenclature, international quantity symbols in physics formulas, significant digit rules, and methods of expressing evidence and uncertainty in scientific talk.

The Communication Category

1. Com K (communicational knowledge) is knowledge given to people as a result of a Com W. Rules of communication would be classified as K Com W, whereas knowledge resulting from using these rules would qualify as Com K.

E.g., The chemical formula for sodium sulfate decahydrate is internationally communicated as $Na_2SO_4 \cdot 10H_2O_{(s)}$.

E.g., The predicted molar heat of fusion of water from this experimental design should be communicated with three significant digits.

2. K Com W (knowledge of a communicational way of knowing) is knowledge given to people concerning rules (usually arbitrary, but sometimes empirically or theoretically established) for communicating in science and/or science education.

E.g., Instead of calling $H_2O_{(l)}$, hydrogen oxide, the scientific community prefers to call this substance "water".

E.g., SI Metric Rules suggest that the mass of water should be communicated as 12.7 g, using all symbols, rather than a combination of symbols and abbreviations or words such as in 12.7 gm. or 12.7 grams.

3. Com W (a communicational way of knowing) is required of a person in science whenever an accepted set of communication rules (e.g., SI metric or IUPAC nomenclature) are employed in any type of communication.

E.g., Read out loud the following chemical equation for the decomposition of water—do not read the symbols literally, translate the international symbols into English words.

E.g., Predict the mass of water reacted and communicate your problem solving technique by communicating the formula with international quantity symbols, substituting with accepted significant digits and unit symbols, and communicating the prediction with accepted certainty and units.

The Epistemology (of Communication) Category

4. Epi K_C (epistemological knowledge in a communication context) is knowledge given to a person as a result of the use of an Epi W_C in a specific situation. The epistemological knowledge should relate to the way in which a system of communication gets accepted within the scientific community.

E.g., The IUPAC rule for communicating the name of a chemical hydrate has not received wide acceptance by the international community of chemists.

E.g., The rule for communicating significant digits that requires scientific notation is not as acceptable now that the simpler method of using SI prefixes is available.

5. K Epi W_C (knowledge of an epistemological way of knowing about communication) is knowledge given to a person concerning the limits and validity of communication systems used within the scientific community.

E.g., When analyzing a system of communication acceptable to the scientific community, the communication system should be simple and precise and should express the uncertainty or tentativeness of science.

E.g., When analyzing the language used in scientific communication, the language should reflect the nature of science by appealing to the evidence that supports or conflicts with a prediction made by a theory, law or generalization.

6. Epi W_C (an epistemological way of knowing) is required of people when they are asked to question the reason why a communication system might be accepted by the scientific community.

E.g., Comment on the necessity for using a system of significant digits when communicating values in the scientific community.

E.g., Why is the SI system of units and symbols superior or inferior to the English system of measurement?

A Classification of Pedagogical Knowledge and Ways of KnowingName

STSC—The Nature of Pedagogy Emphasis

Within science curriculum materials, and more covertly within science papers or lectures, pedagogy plays a very important role. In order for any scientific knowledge or way of knowing to be accepted within the scientific community, the members of the community must be educated or convinced of the validity of new scientific knowledge.

Some of the knowledge and ways of knowing presented within school situations, must of necessity be presented without supporting evidence or supporting theories. Usually this approach is covert, but if people are to become students of science they need to become conscious of how they know something at any particular point in their education. People need to become partners in their education, just as scientists need to know to what extent something is known in their particular field of expertise. People can accept and understand better the programmed science education they are getting, if they are let in on the purpose of a particular approach. People are also more likely to understand the nature of the scientific enterprise if they are let in on the parallels between the nature of science and the nature of pedagogy. Some examples are presented below but a common example that is heard in most science or science-education expositions is, "It is convenient to represent [this] as . . . ."

The Pedagogical Purpose Category

1. Ped K_p (knowledge of pedagogical purpose) is knowledge given to people to assist them in knowing what they are to do within a particular science-education exercise assigned to them.

E.g., The purpose of this laboratory work is to gain a better appreciation of the importance of water as a "universal" solvent.

E.g., The purpose of the test will be to test chemisty content as well as STSC types of questions.

2. K Ped W_p (knowledge of a pedagogical way of knowing in a pedagogical purpose context) is knowledge given to people concerning how to determine, or question, the purpose of a particular learning experience. K Ped W_p may also include how to provide clear instructions. This category, at present, is more applicable to teachers rather than other persons and is more likely to appear in teachers' guides than in curriculum materials.

E.g., When approaching a unit of subject matter the number of curriculum emphases is usually restricted to one or two.

E.g., When reading a laboratory assignment be sure to differenciate between the purpose of a laboratory exercise and the problem to be answered by the experiment.

3. Ped W_p (a pedagogical way of knowing related to pedagogical purpose) requires people to determine the purpose of, or the instructions required in order to complete, a teaching/learning assignment.

E.g., What was the purpose of going into the laboratory to determine the molar heat of water?

E.g., What kinds of questions should be expected on the test for this unit?

The Pedagogical Reference Category

4. Ped K_R (knowledge in a referenced (or given or memorized) context) is knowledge given to people as with the understanding that the given knowledge will always be given; or is referenced knowledge which the person will have to reference in the future; or is given or referenced knowledge which must become memorized knowledge for the future.

E.g., From memory, the equilibrium constant for water at SATP is 1.01×10^{-14} mol^2/L^2.
E.g., From referencing the periodic table, the boiling point of oxygen is -183°C.

5. K Ped W_R (knowledge of a pedagogically referenced way of knowing) is knowledge concerning how or when a referenced, given or memorized way of knowing can be employed. People are often given instructions as to how to use a table of values that may be provided for reference.

E.g., When a specific heat capacity other than for water is required in a quantitative prediction, the heat capacity will be given in the problem or must be referenced from a table of heat capacities provided.
E.g., To develop an understanding of the concept of phase and temperature changes requires a combination of ways of knowing including the time honored memorized, referenced, and given ways of knowing.

6. Ped W_R (a pedagogically referenced, or given or memorized, way of knowing) is required of persons to answer a question.

E.g., Use the CRC Handbook of Chemistry and Physics to reference the [ionization constant for water at 50°C in order to perform the following prediction.]
E.g., From memory, what is the H-O-H bond angle in water?

The Epistemology (in Pedagogy) Category

7. Epi K_P (epistemological knowledge in pedagogy) is knowledge given to people (e.g., teachers reading a teachers' guide) that results from an Epi W_P way of knowing. Epi K_P is usually quite situational and specific because it results from applying a Epi W_P to a specific situation. The knowledge should speak to the limitations, validity and assumptions associated with pedagogical knowledge.

E.g., Classroom experience with the teaching/learning of phase change phenomena indicates that people have trouble integrating the phase change (temperature versus time) curve of water with the potential energy versus time graph of water. This empirical knowledge from the classroom is supported by formal educational research, but still needs some theoretical structure to explain why this is so. Perhaps the reason lies in the variety of different kinds of knowledge and different ways of knowing which are almost randomly thrown at people trying to make sense of the topic.
E.g., For pedagogic convenience it is appropriate to invent the hydronium ion to represent a hydrated proton.

8. K Epi W_P (knowledge of an epistemological way of knowing in a pedagogical context) is knowledge given to people concerning 1. the way in which science-education knowledge is validated and accepted within the science-education community, 2. the limits of and assumptions associated with this kind of knowledge, and 3. the nature of pedagogy itself.

E.g., When analyzing pedagogic ways of knowing look for given, referenced and memorized ways of knowing.
E.g., The way to test any theories or generalizations of teaching and learning is to gather evidence in the classroom situation.

9. Epi Wp (an epistemological way of knowing in a pedagogical context) requires people to employ their knowledge of an Epi Wp.

E.g., What ways of knowing the chemical formula and state of matter at room temperature of water were used by you in your last chemistry education course?

E.g., How do generalizations and theories of learning get to be accepted by the science-education community?

APPENDIX D

Science in a Technological Context

A. The Meaning of Technology

Technology is commonly associated with the artifacts ("[illegible]ade" things) of human societies, but it is really much more than that. Technology also includes the methods developed by mankind to deal with situations and problems, including the so-called "scientific method". The history of development of human societies is inseparable from the history of technological development.

1. materials technology ("hard" technology)
   a. materials generally available to the public
   b. specialist materials that affect the general public
2. methods technology ("soft" technology)
   a. techniques and systems used by the general public
   b. techniques and systems used by specialists

B. The Nature of Technology and Science

Technology	Science
1. Technology is developed to satisfy human needs to do something new, or make it work better.	1. Science is developed to satisfy human needs to know and understand something more completely.
2. Technology is usually local in development and often local in application - related to given times, societies and cultures.	2. Science is more international in scope, pertaining to nature and humanity as a whole.
3. Technology is more empirical in nature, often created by trial and error.	3. Science is more theoretical in nature, often created by mental process alone.
4. Technology is valued by how well it works.	4. Science is valued by how well it explains.
5. Technology emphasizes methods and materials, knowledge and applications of activities.	5. Science emphasizes thought systems and processes, analysis and synthesis of idea structures.
6. Technology leads to discovery of scientific LAWS.	6. Science leads to creation of scientific THEORIES.
7. Technology often allows testing of theories, leading to the advancement of science.	7. Science often creates a need to test theories, leading to development of advanced technology.

TECHNOLOGY

Technology–Science Interdependence

All too often, discussions of technology assume that technology is the application of principles discovered by scientific activity. This is often the case, but just as frequently, technology "leads" science, and develops long before research provides understanding of the theory behind a process or device. Perhaps more importantly, the development of technology often provides the scientific problems that leads to advancement in science.

As an example of science advancing technology, consider the incandescent light bulb. Edison acted as a pure technologist to develop an effective bulb, using electrical theory that was already well established.

A good example of technology advancing science is the research into chemical medicines based on folk-lore knowledge, that extracts crushed from certain plants affect human body chemistry.

The change in human society that has occurred in the last few centuries reflects an amazing accumulation of knowledge – both empirical and theoretical. The reason for this abrupt increase probably has to do with the interdependence of science and technology. Applied separately, neither science nor technology seems to be very productive. When applied together, a cyclical process develops with science advancing technology, advancing science, advancing — which has proven very effective for gaining knowledge.

Exercise:

Classify each of the following questions as to whether it is basically a scientific or a technological question. Then, in each case try to write another question about the same situation from the second viewpoint.

Example:
What can a nail be coated with to stop corrosion? This is a technological question. A scientific question might be: What are the chemical reactions going on during corrosion of iron?

1. How much silver nitrate can be made from 1 kg of silver?

2. Does taste depend on the shape of molecules in food?

3. Why is the sky blue?

4. What fertilizer will make wheat grow best?

5. What can thorium be used for?

OVERVIEW

ComW

1. An expression for the magnitude of physical quantities has two parts, a __________ and a __________.

ComW–EpiWs

2. The use of significant digits for the number part of a measurement conveys __________ in the measurement.

3. Give a statement to express the application of significant digits to exact numbers, - that is, how many significant digits an exact value is considered to have.

PsdKR PsdKR KComW

4. Explain the following statement. Include the words precise and precision in your explanation. "The way a measurement is recorded conveys not only the magnitude of a physical quantity but also the limitation of the measuring instrument."

ComW/EpiWs

PsdKR

5. Explain the differences in meaning of:

ComW/EpiWs

   a) A package of drink mix labelled 10 g

   b) A sample of $CCl_{4(l)}$ measured to be 10 g

   c) A sample of $KI_{(s)}$ measured to be 10.0 g

   d) a sample of $H_2O_{(l)}$ measured to be 10.00 g

EcoK EcoK EcoK

6. Humans consume food which provides energy for life processes when the food is metabolized in the body. The metabolism of the food can be represented in a greatly oversimplified manner as the oxidation of glucose. It is estimated that on an average day, an individual consumes the equivalent of 500 g of glucose, $C_6H_{12}O_{6(s)}$, and intakes about 3000 g of oxygen. Convert these mass quantities of glucose and oxygen to amounts in moles.

(EmpW – HeW) x 2

EpiKT/EmpKT

7. Although, gasoline is a mixture of hydrocarbons, assume that octane, $C_8H_{18(l)}$, is representative of its average composition. On that premise, the complete combustion of exactly one mole of gasoline would require exactly 12.5 moles of oxygen. Predict the relative amounts of gasoline and oxygen that would react in mass units.

(EmpWT – HeW) x 2

Read the ensuing article then answer the questions which follow.

Chlorofluorocarbons and Ozone – A Technological Dilemma

Various scientific research institutes are being challenged by the proposition that reactions in the upper atmosphere involving certain chlorofluorocarbons (spray-can propellants and refrigerants) are depleting the earth's ozone shield. Ostensibly, the depletion of the ozone would allow more of the sun's ultraviolet radiation to reach the earth; increased exposure to the UV harms most forms of life and also might affect climate.

The chlorofluorocarbon-ozone question poses a classical dilemma to modern science and technology: the economic stakes are high; the supporting data and calculations are inconclusive; crucial links in the chain of evidence will require several years of research; if the basic hypothesis is correct, ozone depletion would occur even if chlorofluorocarbon production stopped today – nitrogen oxides join chlorofluorocarbons as suspected hazards to the ozone layer.

The chlorofluorocarbons, discovered in 1930, are derived from methane, CH_4, or ethane, C_2H_6, and contain fluorine as well as chlorine and bromine. As a class, the compounds are almost chemically inert and display an unusual blend of other properties that has led to a variety of industrial uses for them. Of the more than ten commercial chlorofluorocarbons, the most important are Freon 11 (trichlorofluoromethane, $CFCl_3$), and Freon 12 (dichlorodifluoromethane, CF_2Cl_2). These two are used widely as spray-can and aerosol propellants and in household, commercial and industrial refrigeration and air conditioning. Cumulative world production of the two Freons has reached an estimated six million tonnes by 1974, according to E.I. duPont de Nemours, Wilmington, Delware, the largest of six major producers in the U.S.; and worldwide production rates of both Freons has been rising about 10% annually for the decade preceding 1974. Sales of the two chlorofluorocarbons is well into the hundreds of millions of dollars.

There is a consensus in the scientific community that relatively small amounts of free atomic chlorine, Cl, could affect the ozone layer. Early in the 1970's, it was found that both Freon 11 and Freon 12 drift slowly to the upper atmosphere, where ultraviolet radiation from the sun initiates their dissociation into free atoms. The chlorine atoms produced by this reaction can bring about the conversion of ozone, O_3 to oxygen, O_2:

$$Cl + O_3 \longrightarrow ClO + O_2$$

$$ClO + O_3 \longrightarrow Cl + 2O_2$$

A single chlorine atom could theoretically cause the destruction of tens of thousands of O_3 molecules. The extent to which the ozone layer may be destroyed may depend on the rate at which the chlorofluorocarbons reach the upper atmosphere, the region of the ozone layer. Scientists have detected Freon 11 and Freon 12 in very small concentrations throughout the troposhere, which extends from the earth to the region of the ozone layer. Research data has indicated that the concentrations are rising and that the total amounts of these compounds in the troposphere corresponds roughly to the amounts estimated to have been produced to date. Such a prediction is reasonable because the Freons being extremely stable and only slightly soluble in water, would be expected to persist and accumulate in the stratosphere. Other research has shown the chlorofluorocarbons can participate in more than enough different reactions in the atmosphere. Presently, conclusions about the affect of chlorofluorocarbon emissions on the ozone layer are at variance. Some reports have concluded that the continued release of Freons at the present rate would lead to an eventual ozone depletion of 16.5%. Other reports have played down these conclusions because "the reactions in the model calculations contain errors whose magnitude has not been established".

The international controversy about the Chlorofluorocarbon-Ozone Theory continues. Such controversy stem, in large part, from the limited knowledge of atmospheric physics and chemistry and by the difficulty of making reliable measurements. Regardless of the prevailing controversy about this theory, the ozone layer will continue to get close scrutiny by scientists. Such attention is further enhanced by reseach showing that nitrogen oxides from fertilizers and exhausts of supersonic aircraft also can cause ozone depletion.

Select examples from this article to illustrate:

8. acceptable science writing - qualifying uncertain or unproven statements.

9. how technological skills and problem solving are interdependent with scientific knowledge.

10. how technology may change society in ways both expected and unexpected.

11. common applications of technology.

12. the importance of measurements repeated often over long time periods.

13. the validity of theories based on unproven assumptions, or lacking experimental evidence.

14. What laboratory procedures are used to ensure that a precipitate is completely separated from other substances before its mass is measured?

15. What technological skill makes determining a mass with a lab balance proceed more quickly?

16. Predict what mass of oxygen must react with 24 g of carbon if burning the carbon sample produced 88 g of carbon dioxide.

17. What law is illustrated in Question 16?

18. A 1 kg box of cat food is labelled as containing (not less than) 90 parts per million of zinc. Predict how much zinc is in the cat food, in mass units and amount in moles.

19. Explain whether the amounts you predicted in Question 18 could be more or less than the values you reported, and whether precision is important.

20. Natural gas for home heating is almost pure methane. Predict the mass of carbon dioxide that is added to the atmosphere by an average home burning 700 kL (about 5.01 kg) of natural gas in a month in winter.

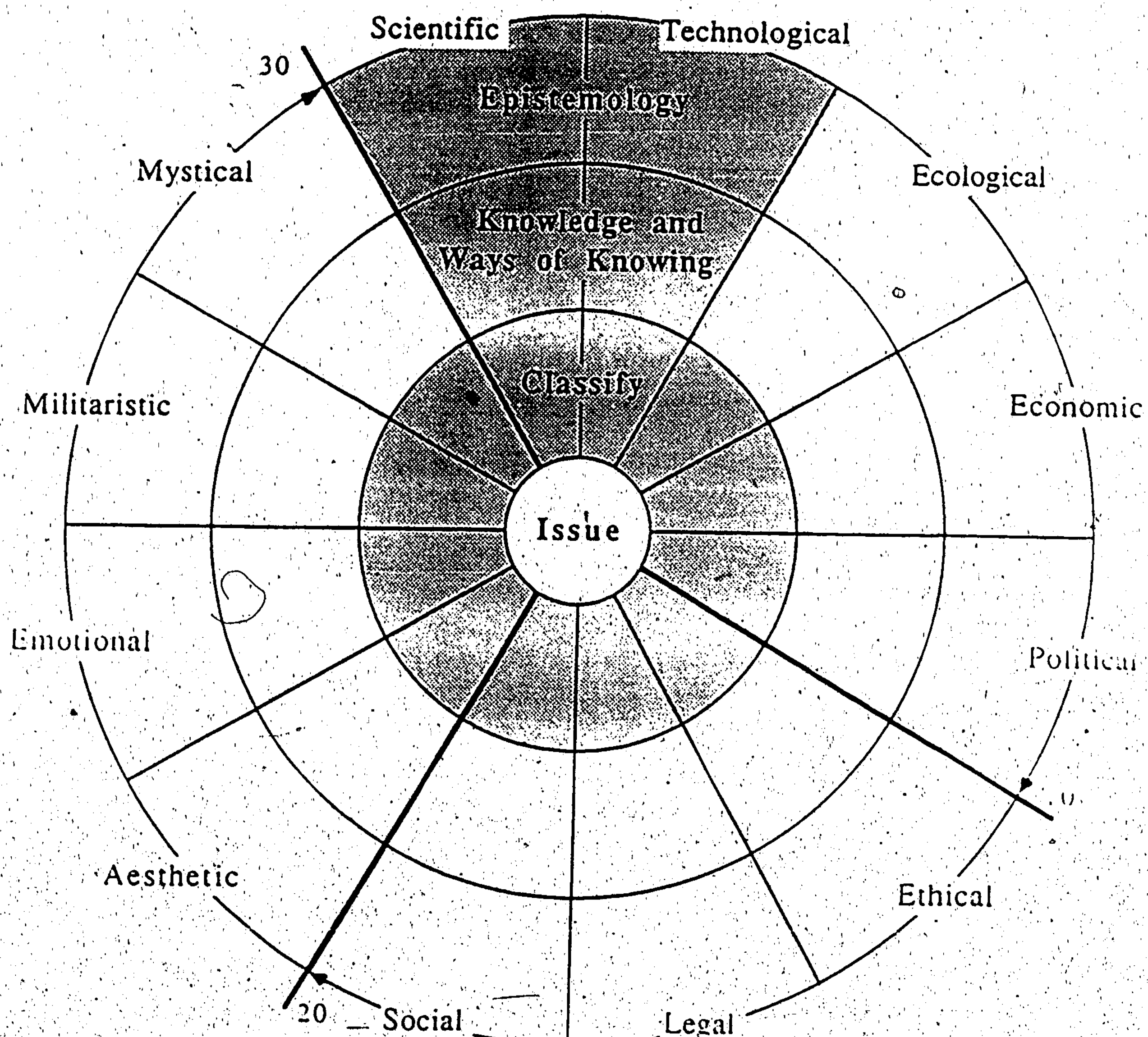
21. The reaction of baking powder may be represented:

$$CaHPO_{4(aq)} + NaHCO_{3(aq)} \rightarrow CaNaPO_{4(aq)} + H_2O_{(l)} + CO_{2(g)}$$

Predict the mass of $NaHCO_3$ that must be contained in baking soda for each 1.00 g of $CaHPO_4$? Why don't the ingredients react in the can?

22. In 1807, Sir Humphrey Davy used the most powerful battery in existence at that time to decompose potash (potassium chloride), producing the first potassium metal on Earth. Predict the mass of potash decomposed to produce each gram of potassium.

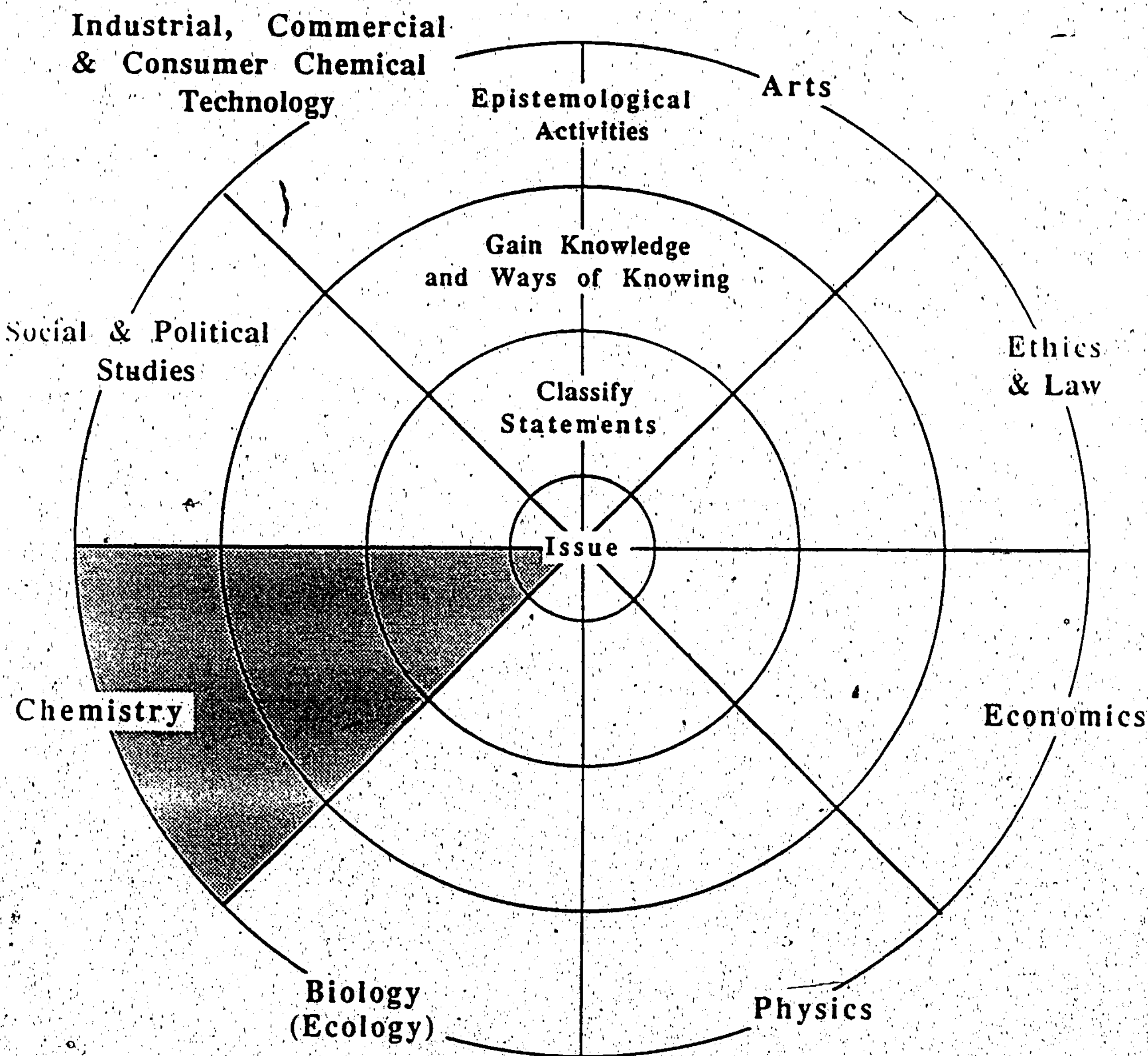
Appendix D2



Science and Technology In Society Issue Perspectives
STSC Chemistry 10, 20 and 30 Scope and Sequence

Appendix D3

School Subjects

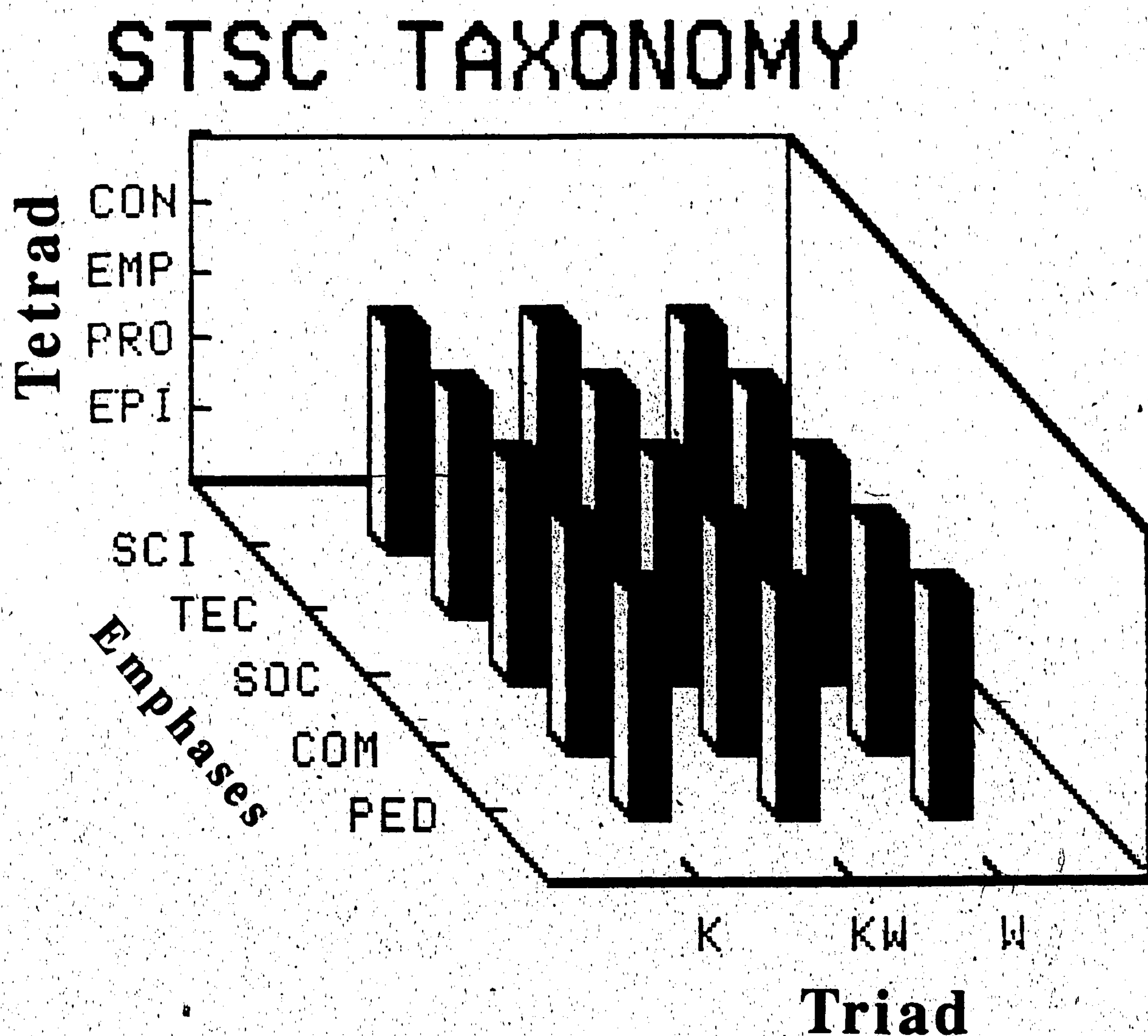


Appendix D4

The STSC Taxonomy of Curricular Discourse

Emphases and Knowledge Forms	Resultant Knowledge (K)	Procedural Knowledge (KW)	Action Required (W)
	The K-KW-W (Epistemological) Triad		
Science			
1. Theoretical	The K	K The W	The W
2. $Empirical_E$ (experiential)	Emp K_E	K Emp W_E	Emp W_E
3. $Empirical_E$—Theoretical	Emp K_E—The K	K Emp W_E—K The W	Emp W_E—The W
4. $Empirical_L$ (laws)	Emp K_L	K Emp W_L	Emp W_L
5. $Empirical_L$—Theoretical	Emp K_L—The K	K Emp W_E—K The W	Emp W_L—The W
6. Process	Pro K_S	K Pro W_S	Pro W_S
7. Epistemological	Epi K_S	K Epi W_S	Epi W_S
Technology			
8. Technological	Tec K	K Tec W	Tec W
9. Empirical	Emp K_T	K Emp W_T	Emp W_T
10. Process	Pro K_T	K Pro W_T	Pro W_T
11. Epistemological	Epi K_T	K Epi W_T	Epi W_T
Society			
12. Societal	Soc K	K Soc W	Soc W
13. National	Nat K	K Nat W	Nat W
14. Historical	His K	K His W	His W
15. Ecological	Eco K	K Eco W	Eco W
16. Reconstructional	Rec K	K Rec W	Rec W
17. Epistemological	Epi K_{SS}	K Epi W_{SS}	Epi W_{SS}
Communication			
18. Communication	Com K	K Com W	Com W
19. Epistemological	Epi K_C	K Epi W_C	Epi W_C
Pedagogy			
20. Pedagogical Purpose	Ped K_P	K Ped W_P	Ped W_P
21. Pedagogical Reference	Ped K_R	K Ped W_R	Ped W_R
22. Epistomological	Epi K_P	K Epi W_P	Epi W_P

Appendix D5


STSC TAXONOMY
Tetrad
CON
EMP
PRO
EPI
SCI
TEC
SOC
COM
PED
Emphases
K
KW
W
Triad

Curricoulum Vita Frank Jenkins

Personal:

Born Franklin Winston Jenkins 1944-03-23 at Edson. Alberta, Canada.

Married to Karen (1967), with two sons, Trevor, born 1973, and Keir, born 1976.

Currently residing at 3516-104 Street, Edmonton AB T6J 2J7.

Phone 1-403-434-9610 or at school 434-8451

Schooling:

Grades 1-3 at Sterco, Alberta (1950-52).

Grades 4-12 at Seba Beach, Alberta (1952-62).

Undergraduate Education:

B.Ed., University of Alberta, Edmonton AB (1962-66).

Graduate Education:

1971 - M.Ed. in Secondary Physical Science Education, University of Alberta, Edmonton AB.

198? - final stages of a Ph.D. in Secondary Education (curriculum studies). University of Alberta, Edmonton AB. The topic of the research is the epistemological analysis of STS curriculum materials.

Teaching Experience:

1966-67 - Seba Beach High School, Seba Beach AB.

1967-70 - Harry Ainlay Composite High School, Edmonton AB.

1971-79 - Queen Elizabeth Composite High School, Edmonton AB.

1979---- - summer sessional at University of Prince Edward Island, Charlottetown, PEI.

1979-80 - some secondary science curriculum and instruction teaching at the U of A as a graduate teaching assistant.

1980-?? - Harry Ainlay Composite High School, 4350 - 111 St., Edmonton AB T6J 1E8, Phone 403-434-8451.

Professional Activities:

- long time member of the ATA Edmonton Regional Chemistry and Physics Councils.
- founding president of the new Edmonton Regional Chemistry Council (1973).
- vice-president of the Edmonton Regional Physics Council (1972).
- Chemistry Director of the ATA (Alberta Teachers' Association) Science Council (1974-76).

- chemistry-education organizer and host with GETCA (Greater Edmonton Teachers' Convention Association) for several years
- member of Alberta (Department of) Education Chemistry Ad Hoc Committee (1975-77).
- member of many Alberta (Department of) Education exam committees (1971-76).
- member of many Edmonton Public School Board exam committees (1971-79).
- cooperating teacher and faculty consultant assisting student teachers and writing practicum materials.
- current president of the ATA Science Council Edmonton Regional Chemistry Council or organizer of the annual Chemistry Education Workshop at the University of Alberta

Inservice Activities:

- speaker at over one dozen teacher institutes and conventions in Alberta (1977-).
- speaker at international Conference for New Directions in Chemistry Education (Hamilton, 1978).
- summer sessional for chemistry teachers at U of PEI (Charlottetown, 1979).
- speaker at CHEM ED '79 (two different presentations) (Waterloo, 1979).
- speaker at Dalhousie University chemistry teachers' institute (Halifax, 1979).
- sessions at the New Brunswick Teachers' Association subject council days (Sackville, 1980).
- plenary speaker at the Sixth International Conference on Chemical Education (U of Maryland, 1981).

Administrative Experience:

1969-70 - students council advisor, Harry Ainlay C.H.S., Edmonton AB.

1972-76 - executive positions with ATA Science Council.

1973-?? - director of the ALCHEM (Chemistry Materials) Project.

1977-79 - science department head, Queen Elizabeth C.H.S., Edmonton, AB.

1983-?? - president of The Author Group (ALCHEM) Inc. - a team of teacher-authors who write science curriculum materials

Writings:

1969 - unpublished physics laboratory manual.

1973 - began work as an author-director of the ALCHEM project which has written and published 17 volumes (approximately 1500 pages). ALCHEM is a grass roots, local curriculum materials development project aimed at producing classroom oriented chemistry materials. The three main themes of the material were pedagogical chemistry, applied chemistry, and descriptive chemistry.

1980 - co-author of Solar Energy: Solar Education for the '80's, a high school physics elective.

1980 - presented a paper "The Potential of a Teacher Generated Frame of Reference as a Curriculum Research and Development Perspective" at the annual meeting of the Canadian Society for the Study of Education (Montreal).

1981 - presented a paper "Custom Tailoring the Chemistry Curriculum to the Culture: A Perspective from Canada" at the Sixth International Conference on Chemical Education (U of Maryland).

1984 - currently writing a new set of chemistry curriculum materials - STS Chemistry - Chemistry in Context - which emphasize *science, technology and society* as major curriculum emphases. The STS component is integrated into the standard chemistry education content.

Awards:

1962 - Alberta Hotel Association Scholarship

1977 - Domtar Award for Canadian high school chemistry teachers (1977)

1980 - Chemical Manufacturers Association (CMA), High School Regional Catalyst Award (1980) - the third in Canada

1983 - Canadian Teachers' Federation HILROY Fellowship

1983 - ATA Science Council Certificate of Achievement in Science Teaching

1983 - ATA Science Council "Distinguished Service Citation" for extended service to science education in Alberta

1984 - Government of Canada grant under the Public Awareness Program for Science and Technology for "seed" money to write "Science Curriculum Materials in a Science, Technology and Society Context"

Extracurricular Activities:

parenting, coaching hockey and fastball, community volunteer work, energy and resource conservation activities in school, home and community, design of low-energy, passive solar homes, computer programming of word-processing formats, gardening, skiing, and swimming.