INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI®

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

University of Alberta

Computer-Based Physics and Students' Physics Conceptual Growth

by

Guoqiang Zhou ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment
of the requirements for the degree of Doctor of Philosophy

Department of Secondary Education

Edmonton, Alberta
Spring 2002

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

National Library of Canada
Acquisitions and Bibliographic Services
395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale du Canada
Acquisitions et services bibliographiques
395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

Our file Notre référence

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-68647-7

Canada

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

University of Alberta

Library Release Form

Name of Author: Guoqiang Zhou

Title of Thesis: **Computer-Based Physics and Students' Physics Conceptual Growth**

Degree: Doctor of Philosophy

Year This Degree Granted: 2002

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly, or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as hereinbefore provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

Guoqiang Zhou
....
10815 - 83 Avenue
Edmonton, AB, Canada
T6E 2E6

Jan. 29. 2002.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

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 **Computer Based Physics and Students' Physics Conceptual Growth** submitted by Guoqiang Zhou in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Norma Nocente

Dr. Norma Maria Nocente, Supervisor

Dr. Wytze Brouwer, Co-Supervisor

P. Wright

Dr. Peter W. Wright

George H. Buck

Dr. George H. Buck

Frank Jenkins

Dr. Frank Jenkins

Dr. Arthur Stinner, External Examiner

Date: Jan. 17, 2002

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Abstract

This study was designed to explore the process of students' conceptual change and investigate the effectiveness of computer simulations in fostering students' conceptual change. Since the 1980s students' preconceptions have been an interesting topic in science education, and many scholars have been trying to formulate effective approaches to address students' preconceptions. In Chapter 2 and Chapter 3, I examine the two dimensions of constructivism, radical and social, reflected on the most popular model of conceptual change, Posner's model, and propose an argument format of science instruction that includes six steps. According to this approach, teaching should start from where students are. Students are given enough opportunities to express their ideas and defend and examine their positions through argument with others. Instead of forcing students to buy scientific concepts, the instructor moves to the position of persuading students to appreciate science.

In Chapters 4, 5, 6, and 7, I investigate the effectiveness of computer-based simulations in addressing students' preconceptions through qualitative and quantitative methods. This investigation lasted four terms, with 10 classes and a total of approximately 800 students involved. Interactive computer simulations, as demonstration and phenomena that require students to explain or make a prediction, were proved to be a helpful device in fostering conceptual change. Students' attitudes toward physics were somewhat independent of the use of simulations, although most of the students studied showed a preference for the use of simulations in physics classes.

My theoretical study on teaching for conceptual change suggests that the events that are applied to foster conceptual change, including simulations, would be better used in the construction or invention stage of a new concept rather than in the application stage. My findings from the evaluation of the use of computer applets supported this prediction. I discovered that computer-based simulations worked more effectively when

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

they were used in the exploratory stage of a new concept. Technology was not functional by itself for teaching and learning. Only when it was designed and used properly could technology help in education.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

A DEDICATION

To my lovely wife, Dr. Zhijin Judy Xu, and daughter, Rona Yang Zhou, for their support and understanding when I spent most of my time on this thesis.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Acknowledgements

Sincere appreciation must be extended to many people who have helped this study become a reality. My foremost gratefulness is to my supervisors Dr. Norma Nocente and Dr. Wytze Brouwer. They understood my potentialities and limitations with respect to this study. It was they who encouraged me to begin my work, facilitated my studies, and offered advice, assistance and honest criticism throughout. Special thanks to Dr. Brouwer for helping my wife and me settle down in Canada. His friendship will never be forgotten. Special thanks to Dr. Nocente for carefully reading my thesis.

I am also grateful to Dr. Peter Wright, a member of my supervisory committee, for reading my thesis and providing critical and practical suggestions. I should also thank Dr. George Buck and Frank Jenkins for serving as committee members and Dr. Arthur Stinner for serving as the external examiner from the University of Manitoba.

My thanks are also due to Dr. Brian Martin, Dr. David Austen, Terry Singleton, and other people who work in the MAP group. They provided me with a very pleasant and supportive environment to work in. Without their help, this study would have been much more difficult. My heartfelt thanks are also to the instructors who were involved in this study. Their cooperation was necessary for me to collect research data.

I own thanks to the IONCMASTE group. Many ideas in this thesis were triggered, amplified, examined, and modified in the lunch hour discussion that regularly happened with this group. In this group, Dr. Oliver Lantz was worth being specially mentioned here. He was the first reader of my first paper published in Canada and gave me valuable suggestions.

I would like to extend my thanks to Dr. Terry Carson and the Department of Secondary Education for providing me the opportunity to study here and also for providing me financial support.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Finally, but certainly not least, I save this section to acknowledge my wife, Dr. Zhijin Xu, and my daughter, Rona Yang Zhou, whose joyful and caring accompaniment through my study period has been very inspiring for the successful completion of this endeavor. I am also fortunate to have an encouraging father and mother in law. They helped us look after our daughter who was born during this study. Without their support, I would have had to postpone this success for at least one year.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table of Contents

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Page

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Page

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

List of Tables

Page

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

List of Figures

Page

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

CHAPTER 1

INTRODUCTION

1.1 Background of This Study

This study emerges from two main topics in the research on, and the practice of, science education. One is that science educators are paying more and more attention to conceptual understanding; and the other is that more and more educators are showing interest in integrating computers into instruction. As the thesis title implies, in this study I have investigated the interaction of these two topics.

1.1.1 Meaningful Conceptual Learning: Critical for Learning Science

Understanding is a common word in our language. When we say that we understand something, we mean that we know when it happens or exists, why it occurs in a certain way, and in which direction it probably will develop. Thus, understanding means much more than knowing the facts and imitating the operation. As far as science education is concerned, understanding includes conceptual understanding, mathematical understanding, and operational understanding, among which conceptual understanding is critical. We agree that conceptual learning is extremely important in learning science (e.g., Brouwer, 1995a), but what is conceptual learning?

According to Tennyson (1996), *concepts* are defined as classes of objects, symbols, and events that are grouped together in some fashion by shared characteristics. There are three kinds of concepts: object concepts, symbolic concepts, and event concepts. Object concepts exist in time and space and can easily be represented by drawings, photographs, models, or the object itself, such as tables and chairs. Symbolic concepts consist of particular kinds of words, numbers, marks, and numerous other items that represent or describe objects, events, or their relationships, either real or imagined.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Event concepts describe the interaction of objects, either living or inorganic, at a particular time. Referring to this definition or description of concepts, people may easily think that learning concepts is to learn certain words or phrases including to which objects or events they refer, which attributes these objects have in common, and whether one object belongs to the concept class or not. However, things are not so simple. We all know that concepts find their meanings within a theoretical context. The concept of kinetic energy is better introduced when we teach the relationship of work and energy, the work-energy theorem. The concepts of momentum and impulse are defined in the context of establishing the relationship between impulse and momentum, the impulse-momentum theorem. Without the theoretical context, we could not explain to students why we define the kinetic energy as the half product of mass and squared velocity and the momentum as the product of mass and velocity. Therefore, conceptual learning in this thesis means much more than memorizing the definitions of concepts. By meaningful conceptual learning, I mean that students build the learned concepts into their cognitive structure or schema and set up a consistent conceptual network. This conceptual framework is required by students to develop the higher order level abilities that enable them to use and apply their understanding in a meaningful way. In this sense, conceptual understanding is close to qualitative understanding. When we say we conceptually understand something, we mean that we know what is going on, that we have ideas about why it goes in a certain way, and that we know its history, current state, and can even make predictions as to its future situation. Therefore, conceptual understanding stands above the sum of various knowledge facts and reflects our high-level knowing at a holistic view.

The importance of conceptual learning becomes very clear when we examine a body of knowledge of one domain. Concepts form the basic elements of knowledge. The concepts and their connections encompass the dominating part of the body of knowledge.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

For instance, force, mass, motion, and their relationships are at the central position of mechanics.

The history of science demonstrates the importance of conceptual learning too. Historically, defining new concepts is an important part of scientific work. In many cases, as long as a new concept was defined clearly, a considerable amount of associated knowledge was constructed in return. For instance, physicists spent a great deal of time in the 17th century studying the collision between two pendulums without useful results because they preferred the definition of momentum as the production of mass and speed. Once they accepted the definition of momentum as the production of mass and velocity, the understanding of collision was constructed.

The importance of conceptual learning can also be illustrated by the close relationship between conceptualization and problem solving. Most educators agree that students' difficulties in problem solving quite often come from an incorrect understanding of the associated concepts. Research on problem solving suggests students should be able to describe a situation conceptually and to present the problem qualitatively before attempting a solution (e.g., Driver & Warrington 1985). Beyer (1988) analyzed problem solving in terms of a hierarchical sequence of procedure:
(a) recognizing a problem, (b) representing the problem, (c) devising a solution plan,
(d) executing the plan, and (e) evaluating the solution. Conceptual understanding is critical for steps (a), (b), and (e). In a comparative study of problem-solving approaches of experts and students, Larkin and Reif (1979) found that experts solve problems based on a strong understanding of concepts and a well-organized knowledge structure; in contrast, students' problem solving is dominated by superficial mathematical manipulations. Therefore, one critical step for students to become sophisticated at problem solving is to build up a deep understanding of physical concepts.

The study of psychology, such as Piaget's (1954) theory, also suggests the importance of concept in learning. According to Piaget, children cannot perform a high-

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

level cognitive operation until they form the relevant concept. For example, children of 18 months or younger cannot find a coin that is put under a coverlet although they see the process. That is because children have not formed the concept of object. The same amount of water is poured into two containers; children insist that the narrow glass has more water than the wide one does prior to achieving the concept of the conservation of volume at the age of 7-8.

Clearly, if teachers want students to learn science successfully, they had better work hard at concept learning. Unfortunately, traditional classroom teaching is not effective in terms of conceptual learning. Studies have documented that students can memorize the facts they learned from class, but they are often not able to use those facts to build arguments, to make predictions, to explain observed phenomena, to solve real-world problems, and to read and think critically (e.g., Carey, 1986; Champagne, Gunstone, & Klopfer, 1982). As a result of these studies, many educators support a change from an emphasis on facts and results to a new emphasis on teaching for meaningful conceptual understanding (e.g., Anderson & Smith 1987; Hiebert, 1986; Minstrell, 1982; Romberg & Carpenter, 1986). Since we have realized the importance of conceptual learning and the problem of our instruction in terms of conceptual learning, the remaining questions are, How do students construct conceptual understanding? and How can instructors effectively promote conceptual learning?

1.1.2 Computer Integration Into Instruction: Facilitate Learning

In the history of media, not long after a new kind of medium was invented, scholars attempted to investigate its applications in education. Paper, chalk, blackboards, projectors, radios, TV, and so on -- each had an impact on education as a new manner of communicating messages. Likewise, since the appearance of computers in the late 1970s, educators and administrators have been engaged in multiple ways of integrating computing technology into diverse aspects of education. It is obvious that computer

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

application in educational administration is effective, but the effectiveness of integrating computers into classroom instruction is still a topic under discussion. Can computer application help students' conceptual learning? Can computers bring better academic performance or positive attitudes? We do not yet have final answers for these kinds of questions.

After reviewing the last three decades of intensive studies on the integration of computers into classroom instruction, we notice that three groups of topics emerged: (a) learning *about* computers, (b) learning *from* computers, and (c) learning *with* computers (Jonassen, 1996). Convinced by the fact that computers have become a part of our society and life, some educators encourage schools to teach students the basic knowledge and skills about the computer. A general definition of computer literacy was developed by Hunter (1983), which is somewhat dated but still holds truth today: "the skills and knowledge needed by all citizens to survive and thrive in a society that is dependent on technology for handling information and solving complex problems" (p. 9).

Schwartz gave a more detailed description of computer literacy:

> Computer literacy takes shape as a group of behavioral skills that permits individuals to utilize computers within the parameters of societal expectations. I suggest that any computer literacy program should teach students the functions, applications, and implications of computer usage. Computer literacy training should, at minimum, promote the following outcomes: 1. Promote a basic understanding of how a computer works; 2. Provide basic skills for interacting with a computer to access stored information; 3. Familiarize students with various applications of available software programs; 4. Provide basic skills for using computers to run available software; and 5. Develop awareness of the computer impact on society (quoted from Logan (1995), p. 257).

For a time, many North American schools spent a fortune to set up computer classrooms or labs. The number of computers that a school possessed became an important criterion for being considered as a good school. Unfortunately, the cost was often met by decreasing music, art, or sports courses. This brought up a debate on the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

comparative educational functions of computer literacy and music or art courses (Oppenheimer, 1997).

The situation has changed a great deal with the development of the computer since it was invented. Today, students can access and learn to use a computer at home and in entertainment places. Software has become more and more user friendly, and children can use it without instruction on how the computer works. Because of these changes, computer literacy is no longer an important issue in today's schools. On the other hand, people realize that learning about computers should be situated in the act of using the computer to do something that is useful, meaningful, and intellectually engaging. Computer literacy for surviving in society can be fairly well developed when people study or work with computers. As we do not need a course about TV, we probably do not need a specially designed computer course for the sake of computer literacy. The family, the community, and the society can help carry out literacy education.

Most of the literature on computers in education focuses on learning *from* the computer, the most important among the three categories, which has a vast amount of literature. Based on the underlying belief that the computer is a new tool of communication, many computer-assisted learning programs are developed to help the traditional teaching and learning, and many studies are designed to test the effectiveness of these kinds of computer applications. Taylor (1980) presented the classic description of the role of the computer in education. He suggested that the computer could act as tutor, tool, and tutee. In the tool mode, students use computers in order to achieve some information processing or communication task. Examples include word processing, spreadsheets, database management, graphics, Internet accessing, email, and so on. In the tutee model, the user is teaching the computer or instructing it on what to do. Programming is an example of this mode.

The energy of scholars is, however, spent mostly in the tutor model, which typically represents the emphasis of learning from computer. In the tutor mode the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

computer is used as an automatic teacher, instructing the user by delivering information, requesting responses, and matching the student's response to what might be considered the correct answer. Computer Assisted Instruction (CAI) is representative of this group, which includes three formats of drill and practice, tutorial, and simulation. Drill and practice programs are designed to train students for specific skills. Normally, the program presents problems for learners to solve. Learners enter their answers and receive feedback about the accuracy of their answers. The right answer often comes up with a happy picture and a happy voice to reward learners. The wrong answer is followed by the request to rewrite. Unfortunately, most of the drill and practice programs are based on the reinforcement notion of behaviorists. The tutorial format allows information to be delivered by the computer instead of by the teacher. Compared with face-to-face instruction, computer tutorials possess some merit. Through computer tutorials, individual learners can decide the pace of learning and access different learning materials for their own needs. Some CAI programs include diagnosis at the beginning of a new topic. If students show readiness to proceed with this new material, they are supplied with the new material. If students are not ready, CAI provides remedial suggestions or instruction. After they finish the remedial instruction, students are diagnosed again. All these features allow the possibility of special instruction for individuals. However, computer programs can never exhaust the possible responses of students in the diagnosis phase. Many aspects of face-to-face teaching, such as body language and close teacher-student interaction, have a significant impact on the results of learning and teaching. Even worse, the majority of current CAIs do not reflect the research results of cognitive science. CAI becomes the electronic version of a textbook and reflects the instructionists' notions about teaching and learning. Salomon, Perkins, and Globerson (1991) critically commented on this point, suggesting that "no important impact can be expected when the same old activity is carried out with a technology that makes it a bit faster or easier; the activity itself has to change" (p. 8). Simulations represent a promising direction for the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

use of computers in instruction. They can supply learners with experiences difficult to obtain in traditional situations, and good simulations can facilitate thinking. Simulations developed within the perspective of instructionism fulfil the first function; namely, visualizing the not-easy-to-access phenomena. However, they can put students in a passive position as information receivers and may fail to enhance thinking. A representative example is a simulation of the explosion of an atomic bomb. The simulation demonstrates the process of exploration, but it cannot ensure that students will learn from it. This movie-like simulation has a style similar to teaching-oriented lecture, which is centred on teaching instead of learning.

The relative effectiveness of learning from computers has been under debate for a long time (Clark, 1994; Kozma, 1994). Clark maintained that media would never influence learning. He interpreted his position metaphorically by stating that media do not influence learning any more than a truck that delivers the groceries influences our nutrition. In contrast, Kozma stated that various aspects of the learning process are influenced by the cognitively relevant characteristics of media. He further stated that successful learning via media is a function of the match between the capabilities of the media and the cognitive tasks in which the student is engaged. For instance, computer programs can enhance learning by supporting processing capabilities that learners do not perform on their own in a complex learning task.

Why has this promising technology not produced a satisfying result for each reviewer? The fundamental reason lies in the underlying assumption of the computer primarily as a new form of "media." The computer is used in the framework of instructionists' pedagogy. The teacher is the source of information, the technology is the vehicle of the transmission of message, and the learners are the receivers of message. Depicting this critical point for understanding the current computer use in education, Jonassen (1996) promoted a shift in the view of the role of computer in instruction: the computer is a partner of learners in learning; in other words, the learner learns *with* the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

computer. In this perspective of instructional technology, the computer is treated as a cognitive tool or a mind tool which helps people think and understand. Basically, this is a tool mode, but the tool is not used by the instructor to deliver preplanned curriculum content; rather, it is used by learners to actively construct knowledge. In such cognitive tools, information is not encoded in predefined educational communications that are used to transmit knowledge to students. Instead of specialists such as instructional designers using technology to constrain students' learning processes through prescribed communication and instruction, the technologies are taken away from the specialists and given to learners to use as media for presenting and expressing what they know. Learners themselves function as designers using technologies as tools for analyzing the world, accessing information, interpreting and organizing their personal knowledge, and communicating what they know to others.

1.2 Modular Approach to Physics

Based on understanding of the importance of conceptual learning and the function of computer integration into instruction, a group in which I have been involved for several years has been working on a project titled "Modular Approach to Physics" (MAP). We have produced a package of on-line materials including simulations, tutorials, and video labs. A set of highly interactive simulations has been developed for conceptual learning. The tutorials are not an electronic version of textbook contents; they are brief instructional contents along with simulations for special concepts. Tutorials and associated simulations are integrated and organized according to the conceptual learning process. Video labs consist of computer-based lab activities that replace some traditional labs. The physical process, such as the free fall of a ball, was taped and input into the computer. The software was designed in such a way that students could interact with the digital process and get data. By using a computing tool such as Excel, students plot and analyze the data.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

In an extensive sense, the MAP can be called a CAI program, but it is different from other CAIs in many important aspects. First, the underlying theory of our project is constructivism, instead of instructionism. We are not treating the computer as only a new tool to deliver information. Rather, we integrate the constructivists' instructional approach into the sequence of material presentation and emphasize the interaction between learners and the computer. Second, the purpose of our project is not to use the computer to take the place of instructor as many other CAIs try to do. Our materials are developed to facilitate the instruction. Our materials may not be "logically" organized in the conventional way and do not fully cover every content topic of the curriculum. That is because what we try to do is to utilize the special features of the computer to help instruction at appropriate points. What we have done is to focus on conceptual learning through computer simulations. The material is driven by concepts, rather than by topics. Third, we take the cognitive tool perspective of instructional technology. Simulations are designed to allow students to input their predictions, and students can try more than one prediction. Tutorials do not primarily present facts, but rather guide and promote students to think. In the video lab section, students choose computer software, such as word processing, Excel, calculator, database, and the Internet to initiate data processing and obtain information. While students work with the computer, they construct understanding. Fourth, the parts of materials are relatively independent. The teacher can use the materials in any session of the instructional procedure, such as in the introduction to the lecture, the middle of the lecture, the concluding part of the lecture, the assignment, or the lab work. Students can access them in class and after class for any purpose of learning. This is why we call the project "Modular Approach to Physics."

In summary, the MAP project takes advantage of computer simulations, applies the view of computers as a cognitive tool, and embraces the goal of assisting teaching and learning. We believe that the MAP project, together with face-to-face instruction, can provide the possibility of using all kinds of media, such as lecture, video, audio, graphics,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

text, and so on, in instruction and create a rich environment for learning during and after school.

1.3 Purpose of This Study

This study includes two parts: the theoretical enquiry of conceptual learning and the experimental investigation of the effectiveness of the MAP project. There are many theories or hypotheses associated with conceptual learning, such as classical theory, prototypical view, and constructivism. My study takes constructivism as a framework to explore the process of conceptual learning. There are a number of areas in the study of conceptual learning. Some scholars study the formation of concepts, some study the classification of concepts, and some study the relationship between conceptual understanding and problem solving. Constructivists maintain that students come to school with their own understanding of the world. My study focuses on the process of conceptual change from student preconceptions to scientific notions. A model for conceptual change is proposed, and associated instructional strategies are explored.

As the second part of my study, I investigate the pedagogical function of MAP. There are many topics in the area of computer integration into instruction. Besides the theoretical and technical concerns for computer integration designs, many people are interested in the effectiveness of integrating computing technology for improving knowledge, problem-solving skills, critical-thinking abilities, learning efficiency, learning interest, and so on. Other people investigate the gender difference associated with the computer application in instruction. These persons talk about the gender difference in attitudes toward the use of computers and the different results computer-assisted learning might produce for males and females. The purpose of my experimental study lies in answering the following questions:

1. What preconceptions do students have in introductory mechanics?
2. How effective is MAP in enhancing conceptual change?

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

3. Under what conditions is MAP effective?

For a long time conceptual learning has been recognized as important and difficult, but cognitive study has not successfully told us the mechanism of concept acquisition (Perner, 1994). By integrating the theoretical study and the experimental study, I expected to gain insight into the progress of conceptual learning, especially the process of conceptual change from preconceptions to scientific ones. The investigation of student preconceptions and processes of conceptual change will contribute to our understanding about student conceptual learning and provide suggestions to reframe our science education approach and then to improve our science education achievement. Moreover, because my study involves computer application in instruction, it contributes to the discussion of the effectiveness of computer application in instruction and the proper format of computer integration into instruction.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

CHAPTER 2

CONSTRUCTIVISM

Physical concepts are free creations of the mind and are not, however it may seem, uniquely determined by the external world. (Albert Einstein)

A student who achieves certain knowledge through free investigation and spontaneous effort will later be able to retain it; he will have acquired a methodology that can serve him for the rest of life. (Piaget, *To Understand Is to Invent*)

Tell me and I will forget. Show me and I may remember. Involve me and I will understand. (Chinese proverb)

2.1 Different Views About Conceptual Learning

How do human beings learn concepts? How can instruction effectively help a person learn concepts? These questions take up much of cognitive scientists' and educational researchers' time. There are some theories or hypotheses about learning concepts such as classical view and prototypical view, but the findings have not been very enlightening so far. As Perner (1994) said, "One of the most serious problems of cognitive science in the late twentieth century is the inability to explain how concepts can be acquired" (p. 852).

In the classical view, concepts are described in terms of a set of necessary and sufficient defining attributes that clarify which instance belongs to a given conceptual category and which does not. For instance, we define the concept of *dog* as (a) an animal, (b) with four legs, (c) with hair. When we meet an animal, we match these attributes with this animal to decide whether it is a dog. A learner forms a concept either by subtracting the intrinsic attributes from some of its examples or by being told the attributes (Smith & Medin, 1981). Regarding the construction of a concept, there is a rule that a set of simple, basic expressions is combined into new and complex expressions. Analogous to

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

composition in the language domain, learning concepts is conceived of as the formation of mental sentences out of a given mental vocabulary (Foder, 1975).

In the prototype theory (Rosch, 1975), concepts are organized around a certain prototype or example. A prototype of a class is an image constructed from experiences with examples of the class, including the typical features of the class, but not all of the defining attributes, as in the classical theory. Newly encountered instances are identified by comparison with the prototype. Again in the instance of a dog, children start to learn this concept when they first see a dog and are told that it is called a dog. An image of a dog is retrieved from the real dog and stored in their minds. This image is the prototype of a dog. Later on, when children see a dog-like animal, they match this animal with the prototype to decide whether it is a dog.

The classical theory of concepts categorizes objects, symbols, or events by defining or intrinsic attributes. However, we have many concepts whose defining attributes are difficult to identify and exhaust. Even for the simple concept of a dog, we need a long list of attributes to identify it. Even so, we may still wonder when we meet a wolf for the first time whether it is a dog. On the other hand, we use some concepts that are not clarified well in any stage of human knowledge development, such as mass and time in physics. Regarding conceptual formation, the classical view cannot tell us from where come the basic concepts which are used to build complex concepts. It is more a theory about the ontological structure of the concept rather than a theory that can tell us much about the process of conceptual learning. The prototype view of concepts categorizes concepts by similarity, but in many cases similarity is not sufficient to be used to identify the classification. Except for specialists, people normally cannot tell whether a wolf is a dog or not, although they have a prototype of a dog. The prototype view can explain only how the low-level concepts are formed, but it has difficulty in expressing the formation of higher-level complex concepts. And more critical, when we talk about the fact that individuals have different ways of categorizing concepts with

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

diverse perspectives or experiences, these two views are problematic. Furthermore, for the abstract concepts of physics, such as mass, inertia, and force, which are much more complex than simple ones such as dog, chair, and table, the classical and prototype views offer no way to interpret the associated learning convincingly.

In the last three decades, constructivists have focused on conceptual learning. They are interested in how children construct concepts from their experiences. Although we have not learned enough about the mechanism of conceptual acquisition, we do have some information about the conditions of conceptual change: from intuitive concepts to scientific ones. In the rest of this chapter, I will review the origin and development of constructivism.

2.2 Constructivism

Constructivism has two branches, radical and social, both of which will be examined in this section. The radical constructivist approach to teaching and learning appeared in the 1970s. It was rooted in Piaget's theory of psychological development. Not only did radical constructivists inherit many ideas from Piaget, but their research methods also reflected many aspects of those Piaget used. Social constructivists draw heavily from Vygotsky's theory, which applies a sociocultural perspective to psychological development. Social constructivism became popular in North America in the late 1980s.

2.2.1 Piaget's Theory of Cognitive Development

In psychological and educational areas we have two different streams: maturationism and behaviorism (Kohlberg and Mayer, 1972). Maturationists hold that the course of psychological development is genetically predetermined by heredity. Environment is important only insofar as it affects development by providing the necessary nourishment for the naturally growing organism. Therefore, the function of education is assumed to be to unfold the intellectual potential. Thus, the child is seen as a

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

plant: All the features it can evolve are predetermined and contained within the seed. Sunshine, air and water supply the plant with an environment in which to grow, but they do not have major effects on its primary characteristics. In this botanical model of development, development is contributed to mainly inborn factors. In contrast, behaviorists take the other direction, assuming that the environment is more responsible for development. The child's mind is viewed as a black box or machine. Given certain inputs, it will generate certain outputs if suitable reinforcement is provided. These environmental factors, inputs, and reinforcements determine children's psychological development. In light of this engineering model of development, school is like a factory. It produces or molds the functional workers whom the society needs. The mechanical transmission of knowledge to students finds inspiration in this model.

Piaget, born in 1896 in Switzerland, successfully started his career in biological science and later moved to psychology. His early intensive work in biology had a great impact on his later perspective on psychological development. Different from the two streams of development, on the basis of his study of the adaptive process of mollusks, Piaget concluded that biological development is due not only to maturation/heredity, but also to variables in the environment. Mental development is primarily a process of adaptation to the environment as an extension of biological development.

After his long study of children's behaviors, Piaget put forward a theory of psychological development, according to which children from birth through adulthood undergo four major development stages: the sensorimotor stage (age 0 to 2 years), the preoperational stage (age 2 to 7 years), the concrete operational stage (age 7 to 11 years), and the formal operational stage (roughly age 11 or 12 onward). In the sensorimotor stage, infants' reflexive behaviors gradually develop into early intelligent behaviors. Through physical maturation and interaction with the surrounding world, sensorimotor behaviors evolve into means-end problem-solving behaviors. By age 2, children have the notion of representation and are becoming mentally able to represent objects and events.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

They come to recognize that objects do not disappear when they move out of sight. They can solve sensorimotor problems through representation.

In the preoperational stage, there is a rapid development of representational skills including spoken language, but the thought of children is typically prelogical and egocentric. They are unable to assume others' viewpoints and believe that whatever they think is correct. Conflicts between perception and reasoning are generally resolved in favor of perception. For example, when liquid is poured from a short, wide container into a tall, narrow container, children will frequently say that the tall container contains more liquid.

In the concrete operational stage, children develop the use of logical thought. Such concepts as conservation, inversion, reciprocity, and classification are formed and used in problem solving. However, concrete and visual props are still necessary for logical operations. Children can apply logic to concrete problems but not to hypothetical and abstract ones. They cannot reach conclusions by reasoning hypothetically. Although they can recognize that no liquid was lost in the above example, they cannot conclude that any form of container will not alter the amount of liquid when the liquid is transferred from one container to another.

From age 11 or 12 onward, with the development of formal operations, children's cognitive structures become qualitatively mature. Children can apply logical reasoning to all kinds of problems, including hypothetical and abstract ones. They can predict that a given amount of liquid poured into cylinders of varying diameters will be higher or lower in a ratio inversely proportional to the diameter of cylinders.

The four stages create a continuum of development. Each new advance involves an integration and extension of the knowledge and reasoning of the previous level into new knowledge. Cognitive structures are changed, but prior formulations are never destroyed or eliminated. Previous knowledge and reasoning remain and are improved. The development process from a lower level to an advanced level is not automatic, but

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

self-regulated. The new construction or reconstruction of knowledge does not start from the outside, but from inside. It proceeds through disequilibration, followed by the assimilation and accommodation of experiences. When children are confronted with a new stimulus, they always first try to assimilate this stimulus into their existing cognitive structures. If the assimilation succeeds, children's cognitive structures stay unchanged qualitatively, but grow in terms of more precise and wider examples. However, this does not always occur. When a new stimulus cannot be assimilated into a cognitive structure, a cognitive disequilibration will follow. Children have to modify their existing structures or create new schemas so that the stimulus fits into them. This process is called *accommodation*. Accommodations cause the qualitative change of cognitive structure.

In the process of intellectual development, four factors are important: maturation, active experience, social interaction, and equilibration. Piaget viewed each of these factors and their interactions as necessary conditions for cognitive development, but none alone is sufficient to ensure cognitive development. Maturation or heredity sets broad constraints for development at any point in time. Active experience is necessary for children to construct or reconstruct schemata, be they physical or mental. When children are acting on the environment, such as moving in space, manipulating objects, seeing, listening, and thinking and reasoning, they are taking in the raw ingredients to be assimilated and accommodated. Social interaction is important for children to step out of their egocentric kingdoms. Through the interchange of ideas with others, children gain knowledge from others and check their ideas. Therefore, interaction with others can be a great source for cognitive disequilibration. Equilibration is the coordination of the other three factors and represents the regulation of development. With a desire for equilibration in cognition, children go through assimilation and accommodation. Equilibration is the regulator that allows new experience to be successfully incorporated into cognitive structure.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

For Piaget, all knowledge, including physical knowledge, logical-mathematical knowledge, and social knowledge, is a construction resulting from children's actions. Physical knowledge refers to the knowledge of the physical properties of objects and events, such as size, shape, texture, strength, and weight. Fully accurate physical knowledge cannot be acquired directly from reading or listening to what people write or say, but only through actions on objects. Children discover physical knowledge about an object while they act on the object with their senses. Logical-mathematical knowledge such as number and volume is constructed from thinking about experiences with objects and events. Since logical-mathematical knowledge is not inherent in objects, as physical knowledge is, children actually invent logical-mathematical knowledge. Social knowledge is knowledge on which cultural or social groups come to agree by convention, including the knowledge of values, morals, and language. Social knowledge cannot be extracted from physical or mental actions on objects; it is constructed when children act on other persons. It is through communication with peers and adults that children encounter opportunities for the construction of social knowledge.

Although Piaget's stage-like theory leaves space for criticism concerning the accuracy of stage dividing lines, the developmental trends of children pointed out by Piaget are well accepted. The necessity for each child to construct his or her own conceptual meanings from experience has become the basis of many learning theories, as mentioned above. What is more, the process of children's development is a good metaphor for thinking about the cognitive procedure of adults when operating in domains in which they, too, are novices. Piaget's work laid the groundwork for the mainstream of learning study in the last century.

2.2.2 Kuhn's Philosophy of Science

Scientific knowledge is derived in some rigorous way from the facts acquired by observation and experiment; it is proven knowledge and, thus, objective; personal values

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

have no place in science. Such was the common sense view of science before the 1960s. The origin of this view of science can be traced back to the 17th century when great pioneering scientists, such as Galileo and Newton, successfully rebelled against Aristotle's science through their experimental works. Philosophers such as Bacon summed up the scientific attitude of the times when they insisted that if we want to understand nature, we must consult nature, not the writings of Aristotle. The scientific observers should faithfully record what they see, hear, and so on with an unprejudiced mind. It is from these objective records that scientists make induction that leads to universal knowledge. This was the perspective of inductivists' science in the 17th century. Since then, because of the spectacular achievements of experimental science, the view of inductivists about the function of experiments has been enhanced. Experimentation has been treated as the unique method of science. According to empiricism and its extreme form, positivism, theories are not only to be justified by the extent to which they can be verified by an appeal to facts acquired through observation, but they are also considered to have meaning only insofar as they can be so derived. Although there are many exceptional events, such as Robert Millikan's suppressing the experimental data that did not support his hypothesis and Einstein's creating relativity through the aesthetic analysis of classical electromagnetism, these events did not stop positivists or objectivists from talking about value-free knowledge. Because knowledge is supposed to exist independently of knowers, it is no wonder that rationalists claim that there is one timeless and universal criterion with reference to which the relative merits of rival theories are to be assessed.

The publication of Kuhn's *The Structure of Scientific Revolutions* (1970) caused controversy in the positivist tradition of scientific philosophy. Based on his study of the history of science, Kuhn came to realize that traditional accounts of science do not bear comparison with historical evidence. His theory about scientific development places emphasis on the revolutionary character of scientific progress. Another feature of Kuhn's

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

theory is the important role in scientific progress played by sociological and psychological factors. Kuhn's picture of the way that science progresses can be summarized by the following open-ended scheme:

Figure 2-1: Kuhn's theory of scientific revolution

The disorganized activity that precedes the formation of a science eventually becomes structured and directed when a single paradigm becomes adhered to by a scientific community. A paradigm is made up of central commitments including theoretical assumptions, laws, and application techniques that the scientific community adopts. The paradigm defines problems, indicates strategies for their solutions, and specifies criteria for what counts as solutions. Scientists within a paradigm practice what Kuhn called *normal science.* Normal scientists develop the richness and precision of the paradigm in their attempt to interpret and accommodate the results of experiments. Sometimes meaning may change, but the foundation of the existing theory remains unchanged. However, normal scientists will inevitably encounter some experimental results or phenomena that the theory cannot explain, which Kuhn called *anomalies.* When anomalies get out of hand, a *crisis* period starts. In the state of crisis, more anomalies may be found, and some scientists become unsatisfied with the theory. The crisis will deepen when an entirely new hypothesis makes its appearance. A new paradigm will emerge from a successful hypothesis and attract the allegiance of more and more scientists. Eventually, the problem-ridden paradigm is abandoned, and most scientists drift to the new paradigm. Kuhn called this discontinuous change *scientific revolution.* After the revolution, science enters into a period of new normal science.

The major difference between Kuhn and positivists lies in their views about scientists' selection between rival paradigms. Kuhn was dubious about the timeless

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

criterion that positivists apply in the case in which scientists abandon the old paradigm for the new one. There will be no purely logical argument that demonstrates the superiority of one paradigm over another and that thereby compels a rational scientist to make the change. One reason that Kuhn believed that there is no such compelling demonstration stems from the fact that rival paradigms will subscribe to different sets of standards, metaphysical principles, and so on. Judged by its own standards, paradigm A may be superior to paradigm B; whereas if the standards of paradigm B are used as premises, the judgment may be reversed. Supporters of rival paradigms will not accept each other's premises and so will not necessarily be convinced by each other's arguments. It is for this reason that Kuhn compared scientific revolutions to political revolutions.

A second reason that there is no logically compelling demonstration that dictates that a rational scientist should abandon one for the other is the fact that a variety of factors, both logical and nonlogical, are involved in a scientist's judgment of the merits of a scientific theory. Examples of such factors are accuracy of prediction, particularly of quantitative prediction; the balance between esoteric and everyday subject matter; the number of different problems solved; and simplicity, scope, and compatibility with other specialties. Criteria such as these constitute the values of the scientific community. The means by which community values are specified must, in the final analysis, be psychological or sociological. Whether or not one theory is better than another is to be judged relative to the standards of the appropriate community, and an individual scientist's decision will depend on the priority that he/she gives to the various values. These standards or values will vary with the cultural and historical setting of the community and will be different from person to person. Imagine the following two cases. In one case, scientist 1 has trouble interpreting his/her experimental data with paradigm A. Why not try paradigm B? (His/her action is motivated by curiosity.) Surprisingly, it works. As a result, he/she publishes a paper using paradigm B. However,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

a few months later, he/she publishes another paper to report the match of his/her other data with paradigm A. In the second case, scientist 2 appreciates paradigm A, but all of his/her colleagues work in a new paradigm. He/she has to transfer to paradigm B because he/she does not want to be treated as out-of-date. These two imaginary but very possible cases strongly support Kuhn's (1970) position about science. Science is not purely logical. Values, personalities, interests, aesthetic considerations, and so on play roles. "Scientific knowledge, like language, is intrinsically the common property of a group or else nothing at all. To understand it we shall need to know the special characteristics of the group that create and use it" (p. 210).

Kuhn's philosophy of science takes science out of the realm of the absolute truth. Scientific knowledge, instead, is considered in part a social construction of the scientific community. Scientific research is not as different a behavior as we thought before, but shares some common characteristics with human beings' other enterprises. This philosophy of science reforms our understanding of knowledge and knowledge acquisition and should consequently change our view of the learning process. Because knowledge is a kind of construction rather than the discovery of existing universal laws, gaining knowledge calls for more flexible and active processes, whereas the view that knowledge is the mirror of the material world may suggest rote learning. Kuhn's new philosophy of science became another factor that affected the psychological and educational theories in the last century.

2.2.3 Radical Constructivism

Radical constructivists' studies of learning have become popular since the 1970s in the perspectives of Piaget's psychological development theory and Kuhn's scientific philosophy. Radical constructivism has a different view of knowledge from the traditional view. In the traditional view, knowledge represents how the world works in a way that is thought to be pregiven and independent of knowers. Knowledge is discovered

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

and is considered true only if it "correctly" reflects the independent world. Echoing the ideas of Piaget and Kuhn, radical conctructivist views of knowledge:

> give up the requirement that knowledge represents an independent world, and admit instead that knowledge represents something that is far more important to us, namely what we can do in our experiential world, the successful ways of thinking with abstract concepts. (Von Glaserfeld, 1995, p.7)

Knowledge is not discovered, but invented. Both personal and public knowledge are constructed by human beings. Knowledge is inseparable from knowers, and therefore knowledge is no longer absolute truth, but problematic. The adaptive function of cognition, a central idea of Piaget's theory, is enhanced by radical constructivists when they state that the criterion of knowledge is its viability to our experienced world, a "reality," which is "made up of the network of things and relationships that we rely on in our living, and which, we believe, others rely on, too!" (p. 7).

According to Von Glaserfeld (1993), "Knowledge is always the result of a constructive activity, and therefore cannot be transmitted to a passive receiver" (p. 26). Radical constructivists think that effective learning is not a passive activity. Rather, learning is an active procedure during which students reconstruct knowledge by themselves. Social factors influence cognitive equilibrium and signal that there is construction to be done. This new interpretation of learning inevitably shapes the form of teaching. Because learning is a process of construction, the traditional authority of the teacher as a knowledge transmitter has no reason to exist any longer. Teaching should be student centred. The beginning, the middle, and the end of instruction are organized based on students' prior knowledge and understanding. Teachers become primarily facilitators, encouragers, and stimulators of students' exploration and invention. As Piaget (1973) wrote:

> It is obvious that the teacher as organizer remains indispensable in order to create the situations and construct the initial devices which present useful problems to the child. Secondly, he is needed to provide counter-examples that compel reflection and reconsideration of overhasty solutions. What is desired is that the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

> teacher cease being a lecturer satisfied with transmitting ready-made solutions; his role should be that of a mentor stimulating initiative and research (p. 16).

2.2.4 Vygotsky's Theory: Social Constructivism

As illustrated above, Piaget's theory describes a picture of the intellectual development of children-in-action. Children approach mental maturation through their actions on the physical world and other persons. Exploring through experience is fundamentally important for cognitive development. In contrast, Vygotsky (1978) and his students proposed a sociocultural perspective of mental development, which assigns to social factors a much more determining role in this process. According to Vygotsky, within the general process of development, two qualitatively different lines of development, differing in origin, can be distinguished: the elementary processes, which are of biological origin, on the one hand; and the higher psychological functions, of sociocultural origin, on the other. By elementary processes, Vygotsky meant those functions of animals or human beings that are innate and totally and directly determined by stimulation from the environment. Higher psychological functions are referred to as those mediated activities through the use of signs and tools. They are a unique feature of human beings. The origin and the development of higher psychological functions are the focus of Vygotsky's theory. Vygotsky criticized psychologists for their attempts to derive social behavior from individual behavior. They often investigate individual responses observed in the laboratory and then study them in the collective. Vygotsky thought that such psychologists deal with the second level of behavior development. The first problem is to show how the individual response emerges from the forms of collective life. Vygotsky maintained that all higher mental functions originate from social relationships:

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (interpsychological), and then inside the child (intrapsychological), This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals (Vygotsky, 1978, p. 57).

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

> All higher mental functions are internalized social relationships; . . . their composition, genetic structure, and means of action—in a word, their whole nature—is social. Even when we turn to mental processes, their nature remains quasi-social. In their own private sphere, human beings retain the functions of social interaction (Vygotsky, 1981, p. 164).

For Vygotsky (1978), the higher mental functions are "neither invented nor passed down by adults" (p. 46), but are constructed through internalization. Internalization is "the internal reconstruction of an external operation" (p. 56). Vygotsky gave a good example of internalization found in the development of pointing. Initially, this gesture is nothing more than a child's unsuccessful attempt to grasp a certain object placed beyond his reach. His hands, stretched toward that object, remain poised in the air. His fingers make grasping movements. When the mother comes to the child's aid and realizes his movement indicates something, the situation changes fundamentally. Pointing becomes a gesture for others. The child's unsuccessful attempt engenders a reaction not from the object he seeks but from another person, the mother. Consequently, the primary meaning of that unsuccessful grasping movement is established by others. Only later, when the child can link his unsuccessful grasping movement to the objective situation as a whole, does he begin to understand this movement as pointing. At this juncture, there occurs a change in that movement's function: From an object-oriented movement it becomes a movement aimed at another person, a means of establishing relations. As a result of this change, the movement itself is then physically simplified, and what results is a form of pointing that we may call a true gesture. Internalization is not equal to copying, but an active construction. In the words of Leont'ev (1981), a student of Vygotsky, "The process of internalization is not the transferral of an external activity to a pre-existing, internal plane of consciousness. It is the process in which this plane is formed" (p. 57). In the example of pointing, the meaning and function of pointing are created during the interaction of the child and the mother. It involves the mother's understanding of the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

child's grasping movement, the child's linking his movement with the mother's reaction, and, probably, many repetitions of this event.

The notion of internalization implies a different view of the relationship between learning and development compared with Piaget's theory. Piaget believed that the level of development places limits on what can be learned and the level of the possible comprehension of that learning; that is, development precedes learning, and instruction must lag behind mental growth. On the contrary, Vygotsky (1978) insisted that learning should precede development, and the learning of culturally modelled concepts leads to development. Vygotsky distinguished two levels of development: "the actual development level determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). He called the distance between these two levels the *zone of proximal development* (ZPD). Through this concept, Vygotsky criticized Piagetian account of learning and development:

> Learning which is oriented toward developmental levels that have already been reached is ineffective from the viewpoint of a child's overall development. It does not aim for a new stage of the developmental process but rather lags behind this process. Thus, the notion of a zone of proximal development enables us to propound a new formula, namely that *the only good learning is that which is in advance of development* (p. 89, emphasis added).

> We propose that an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers. Once these processes are internalized, they become part of the child's independent developmental achievement (p. 90).

The ZPD concept makes two main contributions to education. On the one hand, ZPD suggests that educational evaluation should occur on two levels (the actual and the potential), rather than on only one level (the actual). Information from both levels is instructive for curriculum action. Teaching should fall into the scope of ZPD. On the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

other hand, ZPD tells us that children can perform functions they cannot do on their own with the assistance of adults or more developed peers. This fact turns our attention to the educational function of cultural apprenticeship and imitation in learning.

As well, there is another sharp difference between Vygotsky and Piaget. Through his observation of children's behaviors, Piaget found that children had developed practical intelligence before they developed spoken language. Studies of deaf mutes showed that they developed logical thought in the same sequential steps as normal children, with a one- or two-year delay in some operations. Based on information of this kind, Piaget concluded that language acquisition reflects intellectual development but does not produce it. At best, Piaget believed that language can facilitate intellectual development, but it is not ultimately necessary for it (Piaget & Inhelder, 1969). On the contrary, Vygotsky (1962) insisted that language acquisition results in intellectual development. He thought that the semiotic mediation of activity, primarily through speech, transforms human beings and creates the possibility of human society. Although children's use of tools during their preverbal period is comparable to that of higher animals, such as apes, as soon as speech and the use of signs are incorporated into any action, the action becomes transformed and organized along entirely new lines. "The most significant moment in the course of intellectual development, which gives birth to the purely human forms of practical and abstract intelligence, occurs when speech and practical activity, two previously completely independent lines of development, converge" (Vygotsky, 1978, p. 24).

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 2-1

A Comparison of Piaget's and Vygotsky's Theories

	Piaget	Vygotsky
Origin of mental function	Individual active experience with the physical world or other persons	The society and culture children live in
Mechanism of construction	Invented by the child-in-action	Internalized by the person-in-society
Typical behavior of construction	Any physical and mental action	Cultural apprenticeship, activity with more cultured adults or peers
Function of interaction	Source of disequilibration and thus development, source for social knowledge	Source of models of what constructions should look like
Learning and development	Development precedes learning; development is the driving force for intellectual maturation	Learning leads to development; learning is the driving force of intellectual maturation
Language and thought	Language acquisition reflects intellectual development but does not produce it; language can facilitate intellectual development but is not necessary for it	Language acquisition results in qualitatively improved thinking and reasoning and thus intellectual development

2.3 Preconceptions and Associated Issues

Although we have two theoretical frameworks for the construction of knowledge, radical constructivism, and social constructivism, the majority of studies have heavily drawn their frameworks from radical constructivism. In this section, I will briefly summarize these studies.

Constructivists believe that students come to school with their own understanding of the world, which greatly influences their learning (Driver, Guesne, & Tiberghien,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

1985). In the literature, students' conceptions are called *preconceptions*, *misconceptions* or, more broadly, *alternative frameworks*. These three labels, however, have differences. Preconceptions refer to those concepts that students construct before they attend school. The label of misconceptions is called for when we examine students' unacceptable conceptions from the viewpoints of science. Students' alternative frameworks imply attention to students' theory (including concepts), which is different from scientific theory. I will frequently use the word *preconception* because my study will focus on those students' concepts that have a firm origin from everyday life. These kinds of concepts can last very long, until adulthood, in spite of students' experiencing formal school education. Another reason that I prefer the label preconception rather than misconception lies in the fact that I share the belief of Driver (1989) that student concepts work well for students themselves in most cases. In the cases where student concepts do not apply, they most often fail to note them or refuse to pay attention to them.

As soon as we realize the existence of student conceptions, many studies are designed to identify them in various areas of science. In classic physics, for example, the following preconceptions have been documented. Forces are needed to maintain the motion (Clement, 1982; McCloskey, 1983); a force can be given to an object in the name of "impetus" (Berg & Brouwer, 1991; Clement, 1982; McCloskey, 1983); a heavy body falls faster than a light one (Champagne & Klopfer, 1980); gravity is related to the Earth alone (Bar, Zinn, & Rubin, 1997); and heat is some kind of material (Erickson, 1979, 1980).

Osborne and Freyberg (1985) reported their findings about the nature of children's ideas in science:

- From a young age, and prior to any teaching and learning of formal science, children develop meanings for many words used in science teaching and views of the world which relate to ideas taught in science.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

- Children's ideas are usually strongly held, even if not well known to teachers, and are often significantly different from the views of scientists.
- Children's ideas are sensible and coherent views from the children's point of view, and they often remain uninfluenced or can be influenced in unanticipated ways by science teaching.

Besides the massive ontological study about students' preconceptions, some studies go further to design strategies to help students change their intuitive ideas (Hewson & Hewson, 1983; Mitchell & Baird, 1986). The critical point of these proposed strategies is the use of cognitive conflict, a concept used frequently and explicitly by Piaget in his works. Posner, Strike, Hewson, and Gertzog (1982) proposed a model for conceptual change that states that students must become dissatisfied with their ideas before any conceptual change can occur. Echoing this model, a popular approach, "Predict-Observation-Explanation" [POE] (White, 1988; White & Gunstone, 1992), was designed and applied by educators in many different scientific domains. In this approach the teacher presents the conditions of a demonstration and asks students to predict what will happen in the demonstration. Then the demonstration is performed in front of the class. When students are watching the demonstration, they are persuaded to compare their predictions with what they see. Finally, the demonstration is explained scientifically.

Concept mapping is another recommended strategy. As Novak (1977) stated, the meaning of a concept is strengthened and defined by the network of propositions the learner has connected to it. In the process of mapping concepts, the teacher and learners can find out and realize the misunderstanding of concepts. On the other hand, mapping the concepts can help students build a big picture of the discipline and feel the coherence in the discipline's structure. This is important because related knowledge is easily stored, quickly retrieved and successfully applied, and readily transferable to similar situations. The studies on the differences between experts and novices in the physical sciences have shown that experts are experts not just because they know more facts than novices, but

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

also because their knowledge exists in a well organized format. The construction of conceptual relation appears to enhance experts' performance (Larkin & Reif, 1979).

Because of the importance of the concrete experience, the learning cycle is recommended as a useful strategy (Karplus, 1977). The learning cycle consists of three major phases designed to lead students to create by students themselves the concept; namely, *exploration*, *invention*, and *application*. The phase of exploration consists of exploratory activities in which students perform experiments that lead to the concept to be constructed. Invention occurs when students use exploratory activities as a basis for generalizing the concept. In the phase of application, students place the concept in new, concrete settings to reinforce their understanding of the concept and to introduce new possibilities for its use. During each phase, the teacher facilitates the learning process by initiating discussions, asking leading questions, and generally guiding students through the three phases. Creating an open, relaxed, and activity-orientated environment is essential (Lawson, 1988; Schlenker & Perry, 1983; Whisnant, 1983).

Some scholars have tried to reform curriculum and textbook writing in light of constructivism. Wang and Andre (1991) and Chambers and Andre (1997) recommended conceptual-change text. Normally, conceptual-change text includes four sections. The first part presents problems and context. The second part lets students predict what will happen. The purpose of this part is to activate students' preconceptions. The third part deals with common misconceptions and shows evidence to disprove them. The last part is the traditional text section covering the scientific concepts or topics. Some educators suggest learning-cycle text. Compared with traditional text, this text is written with a bottom-up structure which presents lower-order concepts first, rather than with a top-down structure presenting the higher-order concept first (Musheno & Lawson, 1999). Studies have shown that students reading conceptual change or learning cycle text outperform those reading traditional text.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Other scholars have proposed a historical approach to science teaching (e.g. Brouwer, 2000; Stinner, 1994; Stinner and Williams, 1993). They suggest the use of science story, large context problem, or story-line approach in the teaching of science. Stinner and Williams (1993) assumed that "diverse connections that enrich conceptualization can effectively be established in a multidisciplinary context that attracts the student and is historically well placed" (p. 93). They maintained that "Science teachers will be more effective if they teach by way of science stories (large context problems) that are connected to the history of science and provide appropriate evidence for the formation of concepts" (p. 101). To promote the use of science story, these scholars have developed many stories almost ready to be used in science classroom (Brouwer, 2000; Stinner, 1997, 2000a & 2000b). Stinner and his colleagues also offered a special course to graduate student teachers with ability of writing science stories in their prospective school classes.

One of the unfortunate conclusions from the group of strategy studies is that student preconceptions are very hard to change. They may persist into adulthood despite the formal teaching. For example, McCloskey (1983) found that 93% of high school physics students, prior to taking a physics course, believed an impetus-like quality was acquired by an object when it was set in motion and that this "impetus" maintained the motion. Hardly surprising, he also found that 80% of students still had the belief after successful completion of the course.

A third topic with preconceptions is about teacher education. Compared with the above two topics, this topic is not well documented. Although some ideas about teacher education are hinted at, very few papers can be found with special interests in how to prepare teachers for the constructivist approach of instruction. The interest in this topic is increasing now (Adams & Tillotson, 1995; Richardson, 1997). Most recently, a group of researchers from the University of Wisconsin reported their findings, limitations, and recommendations of their teacher education program. The goal of their program is to

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

graduate teachers who hold conceptual-change conceptions of teaching science and are disposed to put them into practice (Hewson, Tabachnick, Zeichner, & Lemberger, 1999; Marion, Hewson, Tabachnick, & Blomker, 1999).

In the history of physics, there existed two views about the nature of light: particle and wave. The particle view suggests light is particles coming from a light source. The wave view suggests light is a wave. These two views existed and competed for several centuries till modern physics combined two into one theory, which states that light is a wave as well as particles. Similarly, there are two views of constructivism: radical and social. Based on Piaget's work, radical constructivists go further into a position addressing the importance of individual experience in knowing. Social constructivists stress the impact of culture and society on an individual's learning. In this chapter, I discussed the birth of constructivism and the commonalties of these two views as well as the tension exists between them. Based on these discussions, in the next chapter I will explore the teaching approaches that are functional for conceptual learning. My basic assumption will be that learning involves both individual activity and social construction, which is a combination of both radical and social constructivism. I will start with current models of conceptual change and eventually propose my own model, which I believe is more acceptable in the combined constructivist framework.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

CHAPTER 3

TEACHING FOR CONCEPTUAL CHANGE

> *The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.* (Ausubel)

Piaget's theory suggests to us the discourse of intellectual development, but leaves much to be studied about how to promote this developmental process. Ontological study on student preconceptions confirms that students come to school with intuitive understanding, which is much different from scientific understanding. Because science education has been structured around scientific concepts or scientific understandings, we would ask how the teacher could facilitate students to change or modify their intuitive conceptions to scientific ones in the school setting. This is a key concern of constructivists' approaches to teaching and learning.

In this chapter, I will investigate the foundation and disadvantages of Posner's model for conceptual change. Posner's model was proposed in 1982 and was widely accepted until the early 1990s. Theoretical examination and practical studies however have been demonstrating that this model missed some important dimensions of learning activities, such as interaction and affect. With the concerns of social constructivism, I will propose a new model of teaching for conceptual change.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

3.1 Discourse of Conceptual Change: Posner's Model

3.1.1 The Parallelism Between Psychological Development and the History of Science

Many studies on conceptual change follow Piaget's (1970) hypothesis regarding the parallelism between the history of science and individual psychological development. "The fundamental hypothesis of genetic epistemology is that there is a parallelism between the progress made in logical and rational organization of knowledge [history of science] and the corresponding formative psychological process [individual development]" (p. 13). Examining Piaget's psychological developmental theory (Figure 3-1) and Kuhn's scientific developmental theory (Figure 3-2), this parallelism hypothesis becomes clear.

The studies on students' preconceptions supply partial evidence for this hypothesis. The results tell us that many students' preconceptions are reminiscent of well-known concepts in the history of science. This relationship has been documented across the scientific spectrum. For example, "a heavier body falls faster than a lighter one," "force can be given to an object under the name of 'impetus,'" and "force is needed to maintain motion." These conceptions held by people and scientists in pre-Newtonian times are well documented in the studies on students' preconceptions (Berg & Brouwer, 1991; Clement, 1982; Driver & Easley, 1978; McCloskey, 1983). "Heat is a kind of material that can flow from one object to another" (e.g., Erickson, 1979, 1980). This preconception reminds us of scientists' caloric view of heat in the 19th century.

The parallelism between the history of science and the psychological process does not exist only on this content level. Scholars are trying to convince us that there is also parallelism concerning the general features of the process of knowledge acquisition in the history of science and by students. The difficulty of changing students' preconceptions immediately reminds us that the same thing occurred in the history of science. Gopink

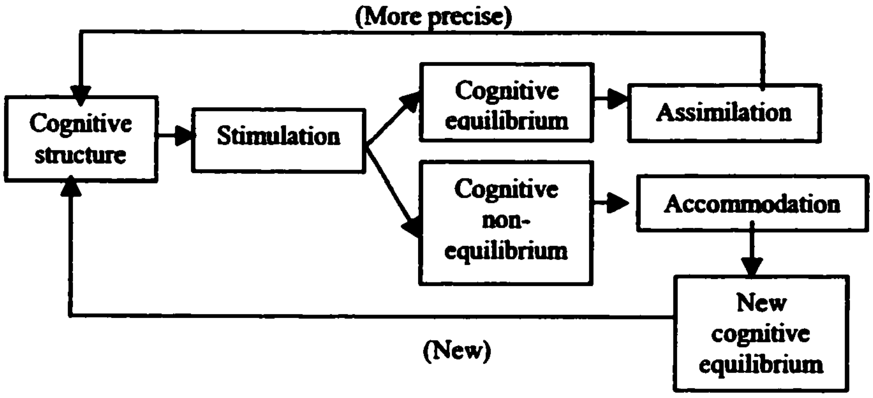


Figure 3-1: Piaget's psychological developmental theory.

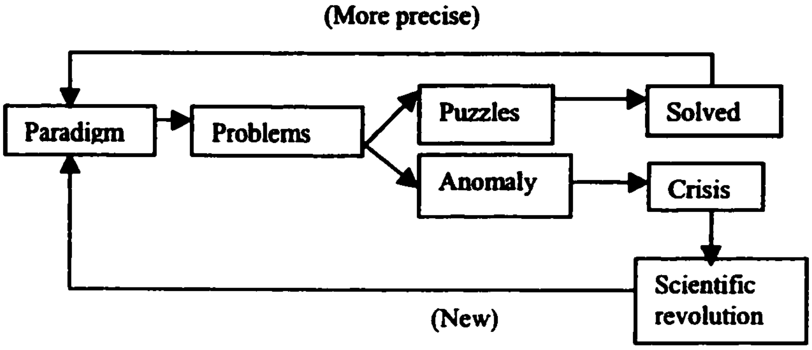


Figure 3-2: Kuhn's scientific developmental theory.

(1996) claimed that the fundamental cognitive processes are the same in students and mature scientists. Siegel (1995) further maintained that, like scientists, students need to assess their own ideas before any new view can be accepted.

This parallelism has two direct operating implications. First, knowing the conceptual obstacles in the historical development of science can help us predict students' preconceptions. Second, the history of science can, in some measure, throw light on the individual learning process and a suitable sequence of curriculum.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

3.1.2 Posner's Model

Posner et al. (1982) were inspired by Kuhn's theory of scientific revolution and suggested a model of conceptual change. They believed that "a major source of hypotheses concerning this issue [conceptual change] is contemporary philosophy of science" (p. 211). As illustrated in the previous chapter, in Kuhn's picture of science progress some necessary preconditions can be detected for scientific revolutions. They include the appearance of anomalies that eventually lead to scientists' dissatisfaction with the old paradigm; the appearance of a new paradigm that provides scientists with a choice; and the merits of the new paradigm such as solving more problems, more accurate predictions, closer match with subjective matter, and more compatibility with other specialties. Paralleling these conditions for scientific revolution, Posner et al. stated that there are several important conditions that must be fulfilled before conceptual changes are to occur:

1. There must be dissatisfaction with existing conceptions. Scientists and students are unlikely to make changes in their conceptions until they believe that their current conception will not work. It is reasonable to suppose that an individual must have collected a store of unsolved puzzles and lost faith in the capacity of his current conceptions to solve these problems.
2. A new conception must be intelligible. The individual must be able to grasp how experience can be structured by a new conception sufficiently to explore the possibilities inherent in it. To put this simply, an individual must be able to understand the new concept.
3. A new conception must appear initially plausible. Any new conception adopted must at least appear to have the capacity to solve the problems generated by its predecessors. Otherwise, it will not appear a plausible choice. Plausibility is also a result of consistency of the conception with other

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

knowledge. A new idea is less likely to be accepted if it is inconsistent with current agreed-upon knowledge.

4. A new conception should suggest the possibility of a fruitful research program. It should have the potential to be extended and open up new areas of inquiry.

In short, conditions of conceptual change can be described in terms of the dissatisfaction with the old conception and the intelligibility, plausibility, and fruitfulness of the new conception.

Posner's model attracted much attention from science education researchers, especially scholars in the camp of constructivism. Most strategies for conceptual change done in the 1970s and 1980s were based on, or related to, this model.

3.2 Criticisms of Posner's Model

Empirical studies, which attempt to bridge the gap between a personally held concept and the scientific view, generally have revealed that preconceptions are hard to change. Preconceptions are apparently changed in school settings but may quickly reassert themselves in the broader context of daily life. Clement (1982) gave one example of the Aristotelian versus the Newtonian view of motion. In his study, 88% of pre-university physics students thought a coin experienced an upward force on the way up after it was thrown up. After the university mechanics course, there were still 75% of students who held this concept; namely "motion implies force." Redish and Steinberg (1999) described a case in which a student struggled with Newton's 3rd law. The student knew what Newton's 3rd law was but she changed her answer numerous times between the physics class model and her common sense for one particular test question that asked whether a truck or a car exerted a bigger force during a mutual collision between the two. The common-speech wording of the question led her to bring up her common sense: "Larger objects exert a larger force." In the study of Erickson (1979, 1980), students'

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

viewpoints on the nature of heat were found to drift between the idea of heat as a flowing substance and the idea of heat as molecular motion. The failure of practical efforts to change student preconceptions forces us to question Posner's model, on which practical work was built. Is something wrong with Posner's model?

3.2.1 Learning Has a Dimension of Social Construction

One of the main criticisms focuses on the lack of a social dimension of the learning. Posner's model provides a description of how individual students change their concepts about academic subject matter. When they become dissatisfied with their original beliefs, they will try to find an alternative one that is intelligible, plausible, and fruitful. This description focuses on personal cognition. It implies that all reasoning happens in the mind of the individual. However, there are a great number of theoretical and experimental studies suggesting that an individual learning in the classroom is not isolated, but rather is greatly influenced by interactions with others. As we discussed in the previous chapter, Piaget's theory treats social interaction as a requirement for children to construct social knowledge and as a resource of occasions for cognitive disequilibration that leads to the reconstruction of knowledge. In Vygotsky's (1981) account, social interaction becomes the origin of any higher mental function. "The human individual's activity is a system in the system of social relations. It does not exist without these relations" (Leont'ev, 1981, p. 47). In the process of learning and development, "children begin to use the same forms of behavior in relation to themselves that others initially used in relation to them" (Vygotsky, 1981, p. 157). On the other hand, many experimental studies done in the school setting have documented the merits of cooperative learning (e.g., Webb, 1982; Heller, Keith, and Anderson, 1992). For too long, people have assumed that the individual mind functions well independently for learning and have ignored the social dimension of knowing. When students fail a course, we say they did not work hard enough or that they were not smart enough.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Actually, learning is both an individual cognitive activity and a social construction. When Piaget and his followers insisted that children-in-action individually invent knowledge, they did not forget the function of social interaction in knowledge acquisition. Although Vygotsky and his students stated that knowledge is the internalization of a sociocultural relationship by people in society, they did not mean "transmission." Internalization is an active process. We have had some experimental studies to support this convention. In the study of O'Donnell and Dansereau (1993), college students listened to a pre-recorded lecture in one of four experimental conditions: (a) individual note-takers who reviewed their notes individually after the lecture, (b) dyads (two students) who took notes during the lecture with the expectation of cooperatively reviewing the material after the lecture, (c) dyads in which one partner listened to the lecture without taking notes and subsequently summarized the information to a partner who took notes during the lecture; and (d) dyads whose members took notes individually without expecting to review cooperatively, but who did in fact review cooperatively after the lecture. A free-recall test on lecture contents was administered to students. The study result showed that students who reviewed the lecture cooperatively outperformed, in a test situation, the students who reviewed the lecture individually. Among the three different ways of cooperative reviews, the unexpected cooperative condition (d) is most effective. Each individual contribution is therefore critical for group learning. In the study designed to investigate whether and how collaborative learning at the computer fosters conceptual changes, Tao and Gunstone (1999) found that the computer-supported collaborative learning provided students with experiences of co-construction of shared understanding and peer conflicts which lead to conceptual change. They also found that when co-construction of knowledge was accompanied by personal construction, conceptual change became stable over time. When students did not personally make sense of the new understanding, their change was short lived.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

3.2.2 Learning is Nonrational

The other main criticism of Posner's model focuses on the nonrational characteristics of learning. "Our central commitment in this study is that learning is a rational activity" (Posner et al., 1982, p. 212). This model implies that when students meet new experiences in the classroom which do not match their existing mental structure, they will feel dissatisfied and willingly accept new concepts to overcome this conflict; that is to say, academic understanding is the goal of student learning. However, the assumption that students approach their classroom learning with a rational goal of making sense of the information and coordinating it with their prior conceptions may not be accurate. There are both theoretical and empirical reasons to believe that learning is not rational. Piaget reminded us that affectivity plays an essential role in human beings' behavior. Affectivity, including interests, feelings, values, and so on, "constitutes the energetics of behavior patterns whose cognitive aspect refers to the structures alone. There is no behavior pattern, however intellectual, which does not involve affective patterns as motives" (Piaget & Inhelder, 1969, p. 158). Affectivity influences our selection of experiences. We pay attention to events we like or we are interested in but ignore others. There is no wonder that, in some cases, for the instructor cognitive conflict is clearly there, but students may not buy it. These kinds of events fail to occasion cognitive equilibration in students and thus will not result in cognitive development. Therefore, affectivity is a doorkeeper. It controls whether the mechanism of assimilation, accommodation, and equilibration happen or not during certain experiences.

Students come to class with different motivational levels, which can influence their cognitive engagement in academic task. Wentzel (1991) stated that students may have many social goals in the schooling context besides academic understanding, such as making friends, finding a boyfriend or girlfriend, impressing their peers, or pleasing the instructor. These goals may shorten the circuit of any in-depth intellectual engagement.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Students may passively face the conceptual discrepancy by just memorizing the scientific concepts without understanding them. We can roughly sort students' learning goals into two groups: mastery learning and performance learning. Students with the goal of mastery learning are more engaged in deeper cognitive processing and use more sophisticated cognitive strategies, whereas students with performance-orientated goals more often use surface processing and have less cognitive engagement (Dweck & Leggett, 1988; Nolen, 1988; Pintrich & De Groot, 1990). It is not difficult to understand that students may get good marks in traditional exams, but they still have difficulty in understanding the concepts. Traditional exams leave room for students to learn with performance-orientated goals. The conceptual change does not really happen to them.

3.3 Teaching for Conceptual Change: Post-Posner's Model

Generally speaking, Posner's model (preconceptions-dissatisfaction-conceptual change) correctly demonstrates the importance of cognitive conflict in the process of conceptual change. It supplies us with a model to study students' learning although this model has limits for classroom learning. In the following section of this chapter, I will analyse the findings about student learning difficulty and develop my own teaching model for conceptual change.

Diverse facts can cause difficulty for students in learning physics. The abstract feature of physics is one fundamental reason that many view physics as an unattractive course. Many surveys report students select physics as the most difficult subject to learn (Brouwer, Austen, & Martin, 1999). Besides this fact, we notice that the shortage of associated experience, the poor mathematical preparation, the low ability of formal logical operation, and the low level of motivation are experienced by students with learning difficulties. The studies of student learning difficulty observed that the existence of preconceptions, poor motivation, and inadequate learning strategies are three main reasons for low academic performance (Reif & Larkin, 1991; Salomon & Globerson,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

1987). I will attempt to integrate these findings into Posner's model to provide a rich model for students to develop more acceptable conceptions in physics. I call this new model the "Post-Posner model." In this new model the instructor deliberately motivates students to learn, promotes interaction in class and after class, and teaches meta-learning strategies or meta-knowledge instead of just creating discrepancies between students' understanding and scientific concepts.

3.3.1 The Learning Difficulty due to Preconceptions

As I stated above, students come to school with their own understanding about most of the basic topics of physics. These understandings are quite often different from scientific views. Changing these intuitive concepts is much more difficult than just building the new one. Daily life experiences quite strongly evidence the "truth" of preconceptions to students. This is the fundamental reason for the difficulty in changing preconceptions. Is heat a kind of substance or a kind of motion? There existed a long-lasting debate on this question among scientists in the 19th century. When you put your cool hand on a cup of hot coffee, you feel your hand "absorbing" heat from the cup. If you mix a half cup of hot coffee and a half cup of cool coffee, you will get a cup of coffee cooler than the hot coffee and warmer than the cool coffee. Caloric view of heat can explain these kinds of daily experiences and phenomena very well. Except those physicists with special efforts on understanding heat, most people have no occasion to change this view. Even in the scientific community, the caloric view did not disappear for a half century after the critical experiment of Benjamin Thompson, Count Rumford. It is no wonder that students refuse to change their preconceptions in the classroom within a limited time.

Constructivist approaches of instruction, such as POE, possess merits over traditional teaching because they recognize the existence of student preconceptions and try to change them. Unfortunately, these approaches, like their parent model (Posner's

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

model) of conceptual change, do not fully accept the significance of social communication in the process of knowing in the scientific community. Social communication has a fundamental role in scientific development. It supplies a forum for scientists to discuss, exchange information and ideas, and share beliefs on judging scientific findings. Similarly, in the classroom, interaction between teacher and student or student and student is important for learning. In class-wide discussion or group-scale activity, each student contributes ideas. His or her ideas occasion and are occasioned by others' ideas. Students can examine different possible views and probably make judgments. Realizing this point, I would like to change POE to PDODE (Predict-Discussion-Observation- Discussion-Evaluation). In this new format of POE, I embed discussion into the process of instruction and substitute "evaluation" for "explanation." I make the "E" change because I believe explaining phenomena or demonstrations is only one important part in the last stage of learner-centred inquiry activity. Besides the explanation, the teacher and students will compare student preconceptions with scientific notions, evaluate student ideas, and probably generalize the scientific thinking or reflect the inquiry process.

3.3.2 The Learning Difficulty due to Poor Motivation

In the summer of 1999 I conducted a survey on students' attitudes towards physics. In one question I asked students to mark the reason/reasons they were registered in physics class among four choices:

1. Physics is a compulsory course for my program.
2. Physics is useful for my future job.
3. My parents and friends recommended physics.
4. Physics helps me understand how the world works.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

All student responses included the first item or were just the first item. No students chose item 4. That is to say, most students come to physics class with external motivation instead of internal motivation. This is not a good sign for physics teaching.

Both experiences and studies tell us that externally motivated students very possibly employ superficial cognitive strategies. Their focus is on passing the exam or getting good marks. They spend a great deal of time on traditional problem solving and memorizing special skills for types of textbook questions. As far as understanding is concerned, they seldom try hard to make sense of what they learned, especially when scientific notions are in contrast with life experience. What they possibly do is to memorize knowledge. At best, students may relate what they learn to other topics within the subject for a better application in problem solving. But quite often they memorize knowledge pieces separately.

Students come to physics with generally unfavorable motivations. Can we expect them to change their concepts in this situation? How can we promote students to learn physics meaningfully? The fundamental way, as Brouwer (1995b) suggested, is to listen to students and respect their ideas. To be respected is the common need and hope for human beings. Scholars have been discussing student-centred instruction for a long time, but this will not be the case as long as the teacher focuses on scientific explanation and textbook-style problem solving. Constructivists' approaches to science teaching throw light on student understanding. At any stage of teaching, instructors should remember to ask what students think, let them express their ideas, and encourage them to reflect. A class well engaged by the instructor and the students is the best setting for learning for the learner and the teacher.

Educators are trying many ways to make learning interesting, such as using hands-on experiments, organizing outside exploring activities, employing narrative approaches, building the nature of science and the social issues of science and technology into curriculum, developing computer-based simulations and games, and so on. The

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

constructivist approach to science education welcomes all these strategies under the same norm. The norm is that students construct their understanding through the engagement in investigation and reflection. In all these strategies, student preknowing is important both because it is the basis of teaching new knowledge and because it is essential for motivating students to learn meaningfully.

Scholars have recognized the importance of preknowledge of students for a long time, especially after Ausubel et al. (1968) announced their finding: "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (p. 13). Mastery learning and its associated instructional approaches, such as diagnostic tests and computer-based self-paced learning, reflect this recognition. However, people have not realized, or at least have not paid enough attention to, the importance of student preunderstanding in terms of motivation. The instruction mediated with the consideration of what students already know is better than that planned solely based on the knowledge structure of the subject, but this so-called better instruction can still not ensure that students actively learn. Constructivism calls for a new format of teaching: the argument format. In this approach to teaching, the classroom is a forum for the teacher and students to examine and judge all possible ideas.

3.3.3 The Learning Difficulty due to Poor Metacognition

The strategies that students use in learning are associated with their understanding of learning. Understanding of learning is called *metacognition* or *metaknowledge* in the literature. Because learning strategy plays an important role in learning achievement, metacognition attracts attention from researchers because of its close relationship with learning strategies. Kuhn, Amsel, and O'Loughlin (1988) reported a series of investigations into the development of students' scientific thinking skills. White and Gunstone (1989) described a project to enhance effective learning which attempts to promote metalearning in a secondary school.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Metacognition is not a well-defined concept. It consists of many aspects and covers a wide range of topics. It is impossible to give it an inclusive operational definition because, as Paris and Winograd (1990) said, "Any cognition that one might have relevant to knowledge and thinking might be classified as metacognition" (p. 19). We generally understand metacognition as cognition of cognition. According to Paris and Winograd, for learning in a classroom setting metacognition has two essential features—self-appraisal and self-management. Self-appraisal includes personal reflections about one's knowledge states and abilities. Metacognitions of this sort are associated with answering such questions as what I have known and need to know; how I learn; when, where, why, and how to apply knowledge of strategies; and whether I can do a task. In contrast, self-metacognition refers to how metacognition helps to orchestrate cognitive aspects of learning. It is reflected in the ways that learners plan and perform learning tasks, it controls their learning behaviors, and it evaluates their learning processes and achievements.

The virtues of metacognition have been well documented. As Paris and Winograd concluded after reviewing many studies, students can enhance their academic learning and cognitive development "by becoming aware of their own thinking as they read, write, and solve problems in school" (p. 15). They also claimed that "a teacher can promote this awareness directly by informing students about effective problem-solving strategies and discussing cognitive and motivational characteristics of thinking" (p. 15).

This statement raises another question: Can metacognitive skills be taught? The answer to this question is yes. Because metacognition involves attitude, perspective, and habit, which are beyond knowledge and skills, metacognition cannot be taught in the traditional ways in which we teach knowledge such as 1+1=2. Students' attitudes and habits can, however, be greatly influenced by what and how students are taught in the classroom. "Since reflective things and metacognitive strategies do not automatically develop in learners, learning activities need to be structured so that they teach and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

support the use of metacognitive skills" (von Wright, 1992, p. 60). Teaching should be designed with an explicit purpose of metacognition acquisition. For the students, metacognition is obtained in an implicit way. Little by little, student attitude and perspective are developed through the metacognition-associated contents and activities. For example, more and more textbook writers and physics instructors agree that we should teach the topic of the atomic model in a story-line format, rather than by simply telling students what the commonly accepted model is. The teaching sequence starts with the finding of electrons, through Thomson's model, the Nagaoka's model, Rutherford's model, Bohr's model, to the Quantum model. The benefits lie in the facilitation of students in understanding the nature, development, methodology, and criteria of science, which will all influence student perspectives on knowing. From the perspective of social construction of knowledge, Driver (1989) went further to the position that metacognition must be taught:

> Learning science . . . is seen to involve more than the individual making sense of his or her personal experiences but also being initiated into the 'ways of seeing' which have been established and found to be fruitful by the scientific community. Such 'ways of seeing' cannot be 'discovered' by the learner—and if a learner happens upon the consensual viewpoint of the scientific community, he or she would be unaware of the status of the idea (p. 482).

Here I would like to mention the special role that the history of science plays in metacognition teaching. Although I have not found enough experimental data to support my argument, common sense tells me that the history of science can be functional in improving metacognition. My basic assumption here is that *knowing the history of science can help the learner understand his own learning process*. We all agree that topics such as criteria of confirmation, conditions for adequate explanation, the function and role of the experiment in scientific development, and the like are important for science learning in terms of promoting students to be open-minded to evidence. To teach these topics, as Ruse (1989) suggested, "rather than simply going straight at students with

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

such worthy (but boring) standard topics, . . . one does better to plunge into actual areas of science, from which the pertinent philosophical message can be extracted" (quoted from Stinner and Williams (1993), p.94). Today's scholars have accepted the importance of cooperation and communication. The historical episodes about scientists' collaboration, such as the fruitful regular meeting of Bohr, Heisenberg and Pauli which brought the birth of quantum mechanics, might help to develop students' awareness of cooperation and changing their learning behaviors from isolated to cooperative. It is hard to exhaust the list of functions that history may have for teaching and learning. The following are some more examples. The story about R. Kronig's loss of credit for finding electron spin because his supervisor did not encourage him to publish his ideas (Uhlenbeck, 1976) may affect students' attitudes toward the relationship between the teacher and students and cause students to become more active and critical learners. Einstein's difficulty in accepting quantum mechanics may make students feel more comfortable when they have trouble understanding the subject. The stories of Marie Curie may remind students of the importance of persistence in scientific knowing and encourage female students to pursue self-development in science. The attitudes of scientists towards failure can positively affect students' behavior when they fail.

3.4 More Criticisms of Posner's Model and the Argument Format of Science Teaching

3.4.1 Spiral Discourse of Understanding: A Personal Story

Scientific concept formation or scientific knowing has a time dimension. We cannot expect student preconceptions to be changed in a short time, for example, in one class, as Posner's model implies. There might be a middle state from preconceptions to scientific ones, in which two understandings simultaneously exist and compete with each other. Thinking about the middle state of the nuclear reaction will be helpful to understanding this co-existing state. But the middle state of learning may last a long time.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Therefore, curriculum agenda and instructional sequence should provide opportunity to rethink the concepts learned previously. "What is new evolves from what is old, and what is old is modified (re-structured) by what is new" (Davis, Sumara, and Kieren 1996, p.157). More experience and new learning may change a learner's attitude toward the old subject. Davis et al. described one case study of a class. The teacher chose to read the novel *The Chrysalids* (Wyndham, 1958) with her Grade 10 English students for her "anti-hatred" unit. She believed that by reading the book, her students would develop a deeper understanding of the issues of racism in their own world. But she was wrong. Students' responses were very different. For those students who had experienced racism in their lives, the reading became a powerful commentary on their experience. They changed their view of the world and formed an outlook about racism because of this reading. But for those students who suggested that racism did not exist in their lives, school, or community, the book was said to be dull. They had no emotional response to the reading. Although their written assignments suggested that they had an academic understanding of the issues concerned in the book, they did not see what was outside their structural possibility; that is, this reading did not change their structures. After this reading, the teacher set about to weave a richer web of experiences around the event of reading. She showed students films and invited guest speakers. Many of the students who thought the book was dull rethought the issues of the book, reread the relationship of the book and their experience, changed their view about the world, and showed sympathy for the victims of racism.

For the subject of the relationship of force and motion, the scientific conception is that the force is the cause of motion change; namely, acceleration. Students' alternative conceptions often include the idea that force is the cause of motion or velocity: no force, no motion. After studying Newton's 2nd law of motion, students can solve fairly complex numerical problems, but some of them still think that the object that is thrown up experiences no force at the highest point of motion. This mistake is caused by thinking

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

that at the highest point the object has no velocity and so experiences no force. So when instructors teach 2nd law, they should not only lead students to set up the equation F=ma, but also push students to rethink, within this new curriculum event, the relationship of force and motion, which the instructors had taught in the previous lesson on Newton's 1st law of motion. In the following, I would like to cite my own learning experience as the second example for this idea.

> *When I studied inertia in middle school, the teacher reminded us of daily life phenomena such as the passenger falling forward with the car's sudden stopping and showed a demonstration, as the textbook suggested. The demonstration was a common one. One weight was on the edge of a table. There was a strip of paper between the weight and the surface of the table. The teacher drew the strip suddenly, and the weight almost stayed still at its original position. I was born in a rural area and had no experience of taking the bus. Even though I observed the demonstration, what happened later proved that the demonstration did not make sense to me in the classroom. Several days after the class, one acrobat came to play in my village. One of his shows was about inertia. The acrobat put one stick upright on his lower jaw. At the top end of the stick was a glass cup full of water. A piece of glass covered the cup with an egg on it. The acrobat suddenly hit the piece of glass with another stick. The piece of glass flew, but the egg fell into the cup. This experiment reminded me of the teacher's demonstration. "That is because of inertia," I showed off to other watchers at the side. Even then, I did not really understand the demonstration. The show stimulated me to simply remember what I saw in class. I rushed back home after the show and repeated the teacher's demonstration. I used a match box as the weight first and failed several times. Then I changed to a book. It worked. But if I drew the strip slowly, the book still moved. I was puzzled with these experimental results. After I studied the theorem of momentum-impulse, I knew the effect of force was determined by the force as well as by the duration of the force. That teacher's demonstration and my own experiments came to make sense to me then.*

These examples have convinced me that learning is not a linear procedure. It needs rethinking and retrospection. We cannot hope that students will master difficult scientific conceptions in one lesson. Curriculum and instruction should function in a spiral format.

The phenomenon of rethinking reminds me to re-evaluate the importance of verifying experiments, which are designed to verify the theory learned in lecture lessons. In China, most researchers on experimental teaching have agreed that the curriculum

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

should include more inquiry experiments and reduce the number of verifying experiments. For them, except for improving experimental skills, verifying experiments has little use. I suspect this intention now. Being engaged in verifying experiments as new experiences (different from the experience in the lecture) and discussing these experiments can provide students with the possibility of rethinking the scientific conceptions learned in the lecture in relation to their experience, make them understand more about scientific concepts, and challenge their own alternative conceptions.

3.4.2 Cultural Issue in Science Education: A Personal Story

Student preconceptions come from student experiences including cultural views and the language with which they are born and raised; physical phenomena they see, hear, and read; media to which they are exposed; and prior education. This is a common and fundamental belief of constructivists. Among the factors relevant to the formation of student preconceptions in science, culture is a strong one. For example, some students from Nepal believe that the shaking of a pig's shoulder causes an earthquake (Bajracharya & Brouwer, 1997). Some Chinese students think that the lunar eclipse happens because the dog in the heavens bites the moon. In the following I cite my experience to illustrate the deep effect of Chinese culture on my concept of ghosts:

> *My childhood was full of ghost stories. I heard ghost stories from my parents, neighbors, relatives, classmates, etc. I also learned ghost stories from books, radios, TV, and movies. I still roughly remember one story my mother told me. One evening, a farmer (who was in the same village as my mom when she was a young girl) returned home late. While he walked along the side of a graveyard, he suddenly got lost. Many ghosts appeared around him. They teased him by blinding his eyes with hands, putting soil in his mouth, pulling his clothes, etc. He tried to escape, but the roads he could see and run along always led to the tops of graves. He became so scared that he had to shout for help. People in the village came out beating drums and striking gongs. He was finally rescued.*
>
> *The Chinese have a very famous book titled* Liao Zhai Zhi Yi. *This is a classical work of ghost stories. The author collected ghost stories from folks and edited them. Many movies and books are adapted from this book. Most Chinese children watch these movies and read these books. I did that too.*

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

> *The Chinese experience ghosts through festivals, especially the spring festival. Parents place food in front of photos of dead seniors and kneel down at these photos. They murmur something like "Bless all the family please!" On January 1 of the lunar new year (spring festival), all family members go to the graves of dead relatives and do the same thing. All Chinese families put red antithetical couplets on the door during the spring festival. Their content varies widely from good luck to praise of policy. Why red? One reason is that red symbolizes happiness and prosperity in our culture. Another reason is that people believe ghosts are afraid of the color red. Chinese people light firecrackers in the spring festival. One reason for this tradition is to frighten ghosts away.*
>
> *In this kind of living and cultural environment, ghosts were rooted in my mind. I would turn back from time to time to check whether something was following me while I was walking alone in the evening. It seems as though these things happened just yesterday. I still remember my silly actions in a spring festival. I lit firecrackers at every corner of the yard and two rooms where no people lived (we believe ghosts like dark and remote areas).*
>
> *In school my biology teachers told me that ghosts do not exist, and that after people die, everything is over. In my Chinese language class, one paper was about ghosts. The author tried to convince the readers of the nonexistence of ghosts. I began to talk in this way, as I was an atheist. Especially since I moved to the city after I graduated from junior high school, I have mostly stayed away from ghosts. I seldom hear and think about ghosts. The concept of ghost becomes more blurred day after day.*
>
> *After about 20 years of school education with majors in science and science education, however, what is my real feeling about ghosts? Several years ago (1996), I visited my parents in the countryside. One of my grandmas had died that winter. In the evening when I arrived at my village, I wanted to visit my grandma's family to show my grief for their loss. My mom and brother advised me to visit them in the daytime of the following day. Their reason was the new death of grandma, and they believed that ghosts were more active at night. What did I do? I waited till the next day to carry out my plan. After I came to Canada I lived in a house with a Canadian gentleman to save money on rent. I felt happy to live there until one day the gentleman told me about his son who used to live on the 3rd floor of this house and had died about five years earlier. At night when I heard the wooden house creaking, the ghost of the son flew through my mind.*

So what are the goals of science education? What can be the goals? In China, with the science determinism of Marxism, we always list "breaking down the superstition" as one objective of science curriculum. People talk about conceptual change in literature and seminars. But it turns out to be very difficult to change student preconceptions that come from cultural heritage. Do we insist on changing these concepts, or do we change our views about science education? In a new perspective, we think of teaching as

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

supplying students with an alternative way to explain a phenomenon. We leave it up to students to decide which one they will select, a cultural view or a scientific view. Recognizing the cultural issues in science education, we probably need to set up a more flexible goal for science education compared with traditional goals. Changing student concepts may be too ambitious and arbitrary in some cases.

3.4.3 Argument Format of Science Education

In the history of science a new framework takes the place of its previous one through scientific argument (Kuhn, 1993; Thagard, 1992). The dialogues between the caloric and the kinetic views of heat, the particle and the weave views of light, and the debate between Bohr and Einstein on quantum mechanics are typical examples in which both discussion and explanation play major roles.

The central position of argument in science development has caused science education scholars to show interest in the function of argumentation in the classroom. Driver, Newton, and Osborne (2000), based on their understanding of the history and philosophy of science, most recently considered the importance of the contribution of discursive practice to the construction of scientific knowledge. Osborne (2000), in addition, from rhetorical perspectives, provides new insight into the aims and purpose of science teaching and recommends the use of argument in science teaching. He stated that:

> a rhetorical characterization of the practice of science itself shows that argument is a central feature of the practice of science and that if developing epistemic goals and understandings about science within science education is important, the consideration of argument and reasoning should be a core feature of the practice of science education (p. 1).

Duschl, Ellenbogen, and Erduran (1999) reported a project that promotes argumentation in the middle school science classroom.

The argument format of science education possesses the features requested by the Post-Posner model I described above, namely, discussion, motivation, and metacognition.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Learning is a self-regulated activity and a process of social construction. Like scientists, students need to expose their ideas to evidence and common regulations for judgment and be convinced before accepting any new idea. As the word ***argument*** itself implies, the argument approach puts the teacher and the student at the same power level. The aim of this new science teaching approach is to persuade rather than force students to accept scientific views. This agrees with the goal of constructivists; namely, the reconstruction of knowledge by students. As the result of argument, students may prefer scientific views to their own concepts, or at least step closer to scientific views. On one side of the argument, the teacher must know students' ideas and listen to students. One result of this process is that students feel that they are respected and that any ideas they propose are significant for the class community. Students can be greatly motivated through this process. During the argument, the common criteria for evaluating hypotheses are discussed and reinforced. These kinds of meta-knowledge are necessary for students to understand science itself and issues about science and benefit their own learning activity, which can contribute a great deal to metacognition development.

The tenet of argument brings a useful insight to science education. The argument format of science teaching recognizes the possibility of students refusing the scientific view and the coexistence of the scientific view and the personal view. This coexistence reflects our concern about the influence of cultural background on science education. Argument needs time to achieve a result. Likewise, curriculum agenda should be organized in a sequence in which explanatory coherence of science is provided. Scientific concepts should be introduced in a spiral format, as the student learning process suggests. Experiments are portrayed as a tool to provide evidence in the course of argument instead of scientific method.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

3.5 Teaching for Conceptual Change: A Modified Approach

As Osborne (2000) claimed, an argument starts with a gap. In the classroom the teacher and students very likely have different ideas, and there are disagreements among students too. These differences provide an opportunity for arguments to occur. I assume a fruitful argument needs a premise that the two sides know each other well. We need preparation stages before an argument really happens. These stages allow the teacher to learn students' ideas. Recalling the modified POE approach we proposed in section 3.3.1, namely, PDODE approach, these stages can be the stages of "P" and the first "D." When do students learn the teacher's idea? It is at the end of this approach, at stage E. Therefore, real two-way argument is unlikely to happen in the PDODE approach. The PDODE approach portrays a linear process of teaching; namely, eliciting preconceptions, providing cognitive discrepancy, supplying scientific explanation, and comparing and evaluating scientific knowing and personal knowing. Learning is not a linear activity. Argument is a cursive process. People use diverse strategies to try to falsify an opponent's idea, such as falsifying the deductions of an opponent's hypothesis or disproving the evidence from which an opponent drew his ideas. The norms of argument provide some useful suggestions to improve the PDODE approach again. By linking the PDODE approach and the argument format of science education together, I propose the following instructional process (Figure 3-3).

I had a very hard time trying to draw this figure. One reason is that constructivists' instruction involves a number of components, and it is hard to include every one in this chart. Another reason is that when I try to think of special topics of physics, I find that constructivists' approaches for them can not be identical. It is hard to generalize or reduce all of this diversity into one chart. The third reason is the cursive aspect of argument. It is hard to reflect this aspect in the flow chart. Regardless, I need this chart to illustrate my complex thinking.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

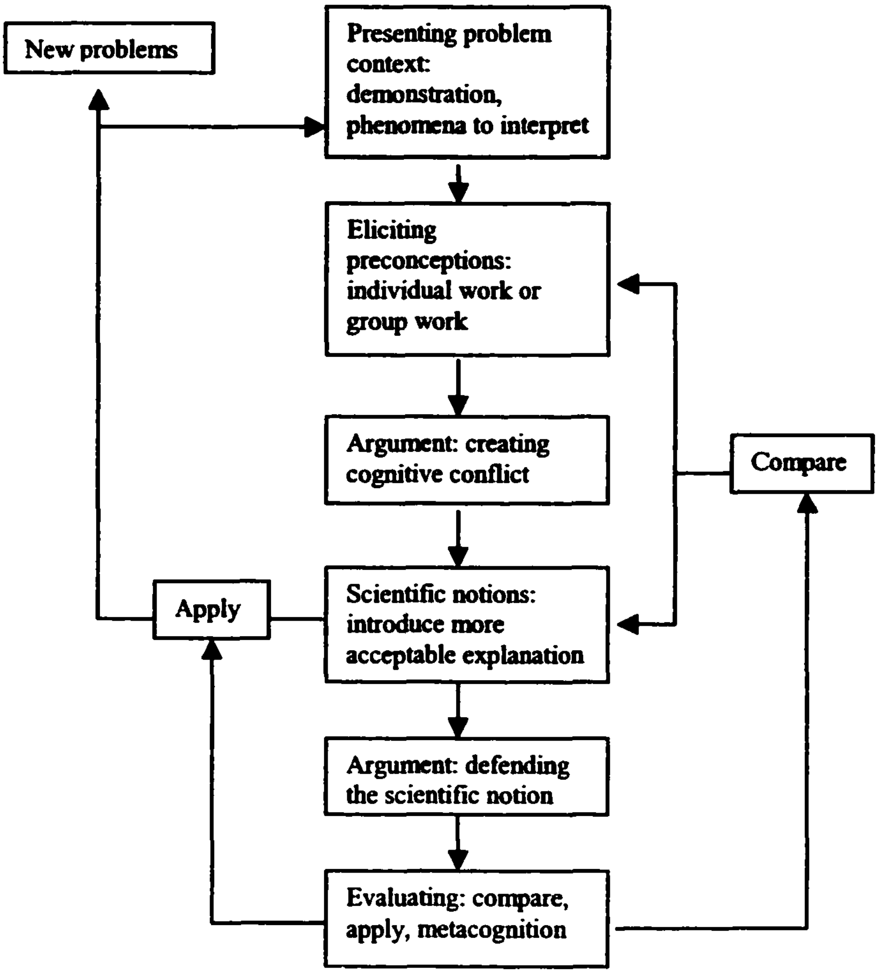


Figure 3-3: A new approach to science teaching.

Presenting problem context: My instruction model starts with problems. I assume that the problem-oriented instruction design is functional in terms of attracting students' attention, promoting thinking, and motivating participation. The formats of questioning can be diverse. The teacher can ask students to interpret phenomena or to watch a demonstration.

Eliciting student ideas: Students are asked to predict the result of experiments or interpret the phenomena. Students can work individually first, then are encouraged to share their thinking with partners. I expect that this discussion can help the students clearly recognize their preconceptions and the preconceptions that their partners have.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Through joining the discussion of student groups and listening to reports on the results of group discussion, the teacher gets to know students' preconceptions.

Argument—creating cognitive conflict: After the previous step, students become clear about their ideas and begin to wonder about the different ideas that their classmates have. Experiments are performed in this step, the results of which are quite often different from students' predictions. Here, if the instructor is anxious to offer students scientific concepts, hoping to use these scientific concepts to take the place of students' concepts, the instructor will fail to convince students. They may think that something might be wrong with the demonstrations, or they do not believe that their concept is wrong. The instructor should be responsive to students' wondering, design new experiments, and demonstrate them. In the case of interpreting phenomena, students' interpretations often have inconsistencies. Pointing out these inconsistencies is a way to create students' dissatisfaction with their own interpretations. Sometimes students' ideas work well for one phenomenon, but not for others. Showing students that their ideas lead to obvious wrong deductions is a common way to deal with students' unscientific opinions.

Scientific notion: In this step, evidence which leads to scientific notions is supplied and scientific explanations are introduced. Quite often the events used to create cognitive conflicts can provide evidence for introducing scientific concepts.

Argument—defending the scientific notion: In the case in which students challenge scientific notions, the instructor needs further evidence to convince them.

Evaluating: This step is a further effort to encourage students to accept scientific ideas by comparing scientific notions with students' ideas and applying scientific notions to new problems. Clear identification can help students to discover where they were wrong and to remember scientific ideas. More applications can demonstrate the validity of science. Besides these, evaluating the ways of personal knowing and scientific knowing may help students in terms of metacognitions. Generalizing the scientific method reflected in a special case is recommended for constructivist instruction.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

As you may realize, in this approach the teacher is doing two kinds of things. One is to break down students' less acceptable ideas. The other is to introduce scientific notions to students. At first sight, the breaking down appears to happen in the third step, argument— creating cognitive conflict. In fact, the breaking down continues through the whole process. This is a dynamic and dialectical process in terms of the breaking down of students' less acceptable ideas and the establishment of acceptable scientific ideas. Just as breaking down an old theory and building up a new theory often happened at the same time in the history of science, we could not say that one happened absolutely ahead of the other. Breaking down students' concepts helps in setting up the new visions. The validity and fruitfulness of new ideas helps students get rid of unacceptable ideas. This dynamic process is designed and organized by the teacher at the macro pedagogical level, but it is driven by the argument between the teacher and the students.

3.6 An Example of the New Approach

In the following I would like to give one example to further illustrate my thinking about instruction. The topic is Newton's 3rd law in a simple magnetic phenomenon: a magnet attracting a small nail.

When I wrote physics textbooks for Chinese students before I came to Canada, I started the text with a demonstration. I put one bar magnet and one metal bar, respectively, on two floating blocks in water. Then the text gave the scientific conclusion inferred from this demonstration, followed by an application of the law to more situations. This kind of scientific explanation-centred curriculum sequence places students in a passive position. In contrast to this traditional way, the new instructional approach will start from where students are.

Quite commonly, students have difficulty understanding the 3rd law in a nonequilibrium situation (Zhou, Martin, Brouwer, & Austen, 2000). They think a large

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

truck exerts a bigger force on a small car in a collision and the magnet exerts force on the clip, but not vice versa. Therefore, we start the instruction with a demonstration.

Demonstration: placing a metal nail near the S or N pole of the magnet. The nail moves onto the magnet.

The teacher can do this demonstration on the overhead projector so that all the class can see it, or students can do it on their own. In the latter case, students can feel the force when they hold the nail close to the magnet. Following the demonstration, the teacher asks students questions in the following order:

Questions: *1. Does the nail exert any force on the magnet?*

2. How does this force compare with the force the magnet exerts on the nail?

Students can respond to these questions based on their watching the demonstration or construct their ideas by performing the hands-on experiments in a group. For the first questions, students' responses can be grouped into three categories: "no," "yes," and "do not know." For the second question, a high percentage of students will very likely respond "smaller," and the rest will reply "equal" or "do not know."

The next two hands-on experiments will serve the functions of creating cognitive conflict and introducing scientific concepts.

Experiment 1: Hang one metal block and one button magnet with a similar mass from a level stick. Move one of them close to the other. The metal block and the button magnet attract and move toward each other,

Experiment 2: Hook up two spring force scales. One person holds one spring scale and another person the other one. One person pulls or both pull at the same time. We find out that the readings of both scales change simultaneously and always keep the same magnitude.

Based on the first experiment, students construct the scientific concept that when an object experiences a force, it also exerts a force on the object acting upon it. Through

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the second experiment, students get evidence for the conclusion that the action force is always equal to the reaction force. Once again, these two experiments can be demonstrated by the instructor or done by students themselves.

Students may argue that they did not see the magnet move towards the nail, but rather only the nail moved toward the magnet; therefore action and reaction cannot coexist and have the same magnitude. The teacher can remind students that the nail and the magnet experience different frictional forces on the table. Here, he/she employs the explanatory success/consistence in the classroom, which plays a fundamental role in the replacement of old theories in the history of science.

Then the teacher can move to the last step, "evaluating." He/she can explicitly discuss with students the notion that the explanatory consistency is an important requirement in judging ideas or theories. The teacher can remind students that real-life phenomena are normally complicated and involve many variables. Solely visible and touchable variables, on which students quite often construct ideas, are not enough to scientifically understand the phenomena. Very often people are fooled by what they see and what they feel in daily life, for example, "The sun rises in the east and sets in the west." The way to correct these mistakes is to use scientific reflection and scientific experiments.

Regarding the cultural issue mentioned above, the instructional approach illustrated here is a model for general topics, but not 100% effective for special topics that involve cultural difference, such as the existence of ghosts, the creation of life, and the cause of earthquakes. The preconceptions associated with these topics are hard to falsify. Here, I would like to cite another story to illustrate the difficulty:

> *One summer, farmers in my hometown had had no rain for a long time, and young crops were going to die. People were hoping for rain. One day, a group of senior ladies swept a pool in my village as a kind of prayer for rain. My young sister responded to this activity by saying, "Let's see if we will get rain." I left to go back to work, and I do not know if they later had rain. My concern here is, rather, the difficulty of answering the questions behind my sister's questions,*

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

> *"Does the activity of the ladies cause rain?" and "Does somebody control the weather?" If the farmers received rain later, some people may see positive answers to these questions. Others who hold opposite views may argue that it was time to rain, and even if the ladies had not swept the pool, they would still have had rain. If the farmers did not have rain, people who hold the cultural view may say that this is because those ladies swept only one pool, not all the pools in the village. People who oppose the cultural view may have evidence to support their view. It can be hard to judge in these kinds of debates.*

Although I say that preconceptions from culture are hard to change, this does not mean that I intend to exclude cultural views from the classroom. In fact, discussion of these views helps students learn scientific views (Jegede & Okebukola, 1991). What am I suggesting here? My approach can still apply in this more difficult case, but the goal of the argument process should not be to break down students' ideas, but rather to demonstrate the validity and success of scientific ones. Science should be portrayed as a fruitful alternative perspective for these topics. Whether and when students adopt scientific views is up to the students themselves. It is hoped that, with more science-related experiences, students can move closer to adopting scientific views while still acknowledging the existence of cultural views, just as in my mind the concept of ghosts has eventually diminished, although not completely disappeared.

Posner's model for conceptual change, popular for a decade, has been receiving criticism because it misses some dimensions of learning, such as the functions of interaction and affectivity for learning. To remedy its disadvantages, the Post-Posner model features an interactive and motivating learning environment, teacher's attention to metacognition skills and cultural issues, and an argument format of communication between the teacher and students. The POE approach, derived from Posner's model, should be expanded to PDODE through considering the social dimension of learning. However, a more suitable approach that reflects the Post-Posner model should include six steps: presenting problem context, eliciting students' ideas, arguing—creating cognitive conflict, introducing scientific notion, arguing—defending the scientific notion, and

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

evaluating. In the next chapter, I move my focus from theoretical analysis to classroom-based study and evaluate the effectiveness of the MAP project in addressing students' preconceptions. The results will provide direct and indirect evidence for my discussion in this chapter.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

CHAPTER 4

THE EFFECTIVENESS OF COMPUTER INTEGRATION AND THE HYPOTHESES OF THE EVALUATION STUDY

4.1 The Effectiveness of Computer Simulation

According to Merrill, Hammons, Vineent, Reynolds, Christensen, and Tolman (1996), a simulation is a representation or model of a real or imagined specific object, system, or phenomenon. Most phenomena can be represented by simulation, from galaxies to atoms. The professional flight trainer is a common example of a high-fidelity simulation. Through the use of hydraulic arms that move the trainer around, functional "surround cockpits" with mock-up controls and instrument panels, and video-graphic pictures of the terrain, pilots feel that they are really flying in an airplane or space shuttle. In reality, the simulator remains on the ground the whole time. The flight trainer is so effective that pilots are not required to spend as much time in a real cockpit to be certified.

Although current computer simulations seldom have such a high level of fidelity, they are helpful for instruction. For example, if we want students to have experience on the growing of plants or the fission of nuclei, the traditional lab cannot be of much help. Computer simulations afford an alternative way. In a context of learning to fly a plane, Merrill et al. (1996) listed six major reasons for simulations to be a valuable educational application:

1. Simulation involves less risk than reality. If learners crash their planes during a computer simulation, they can simply press a button and try again. The potentially fatal mistakes cause no harm.
2. Training costs are reduced. In a real crash situation, an airplane may cost millions of dollars to replace or repair, to say nothing of lives lost. We cannot

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

afford to have the expensive equipment destroyed or used for the training of unskilled learners.

3. Simulations are frequently more convenient than real-life situations. The simulation can be used at any time regardless of weather conditions, daylight, and other constraints.
4. Simulations minimize the negative effects of time. Some phenomena take place in reality over great periods of time. Through simulations, time can be compressed so that the learners can experience the critical elements of the phenomenon several times within a short period.
5. The ability to focus on specific aspects of a phenomenon is frequently increased. Through the use of color graphics, sound effects, animation, and textual descriptions, useful aspects of the situation can be enhanced and extraneous aspects can be minimized, thus making it easier for students to learn the critical information.
6. The experiences in a simulation are repeatable. Students can review an experience over and over again until their responses become natural and automatic.

As you can see, these six points are all on practical issues. I am more concerned about the effectiveness of computer use in a pedagogical sense. Does the computer simulation improve the learning achievement? Overall, studies have shown the effectiveness of simulation programs although the advantages are not so exciting.

Atkinson and Burton (1991) designed a study to test the effectiveness of the use of a simulation in a course. The objective of the course is to teach students to use DOS commands. The program provides a simulation environment supplementing information presented in the class. The program simulates a computer with files on a hard disk and a floppy disk drive. Students could use DOS commands safely to erase files, remove directories, and rename files on these two simulated disks—all of which could cause

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

problems if actually executed on a real computer. The study found that students reporting a higher level of program use performed better on related course assignments and quizzes than did students with a lower level of usage, although the difference was not significant.

Another investigation done by Shlechter and Bessemer (1992) examined the effectiveness of a computer-based training system (SIMNET) combined with appropriate role-playing activities for training students to master conditional knowledge. SIMNET is a simulated battlefield environment consisting of combat vehicle simulators with simulated combat support. Also, the simulation is conducted under constraints similar to those affecting actual battlefield conditions. The real-field performances of experimental students who receive SIMNET training and those who receive the training before the SIMNET was finished were compared. Data analysis demonstrated the effectiveness of SIMNET for training military students to apply their newly acquired knowledge to real-life problems and situations. Besides, the researchers stated that the positive transfer of SIMNET program training was seemingly attributable to the students' role-playing activities during this training. That is why they reached the conclusion that using interactive computer-based simulation systems that provide students with opportunity for role-playing activities could train them to acquire the conditional knowledge necessary for successful performance in a dynamic vocational environment.

Reiner (1998) mainly used class-observation techniques to study the effectiveness of a simulation-based computer micro-world on learning. In this study, thought experiment is involved in the learning task. Physicists often use thought experiments to construct new insights about the world. Inevitably, it is necessary for instructors to let students perform thought experiments when they learn physics. On the other hand, collaborative learning is highly valued for active and meaningful learning. How can teachers facilitate collaborative learning, which involves thought experiments? In Reiner's study, the learning task is on optics. Students need to form a hypothesis and prediction, and test through thought experiments because light rays are invisible. Based

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

on the basic reflection and refraction laws of light, a CAI program used in the class can visualize the hypothesis and test result, which makes it easier to communicate ideas and mental reasoning among the group. Reiner carefully observed the behaviors of student groups. Through analysing their talking and performances, he found that with the aid of the CAI program, even though group members had diverse individual ideas, they were able to compromise with no problem. Reiner therefore concluded that thought experiments, when conducted in the context of a computer-based micro-world, are powerful tools for collaborative learning.

The studies examined above focused on the function of computer programs in knowledge acquisition or problem solving. The MAP project concentrates on the use of simulation in a constructivist environment to enhance conceptual change. Not many studies on this topic are available in the literature. The limited number of studies results in an unclear picture. Tao and Gunstone (1999) investigated whether and how collaborative learning at the computer fosters conceptual changes. In this study a suite of computer-simulation programs developed to confront students' alternative conceptions were integrated into physics instruction in a Grade 10 science class in high school. Pre-test, post-test, and delayed post-test were administered to the class to determine students' conceptual change, and their interactions were recorded. The analysis of quantitative and qualitative data showed that the computer-supported collaborative learning provided students with experiences of co-construction of shared understanding and peer conflicts that led to conceptual change. Zietsman and Hewson (1986) used computer simulation to diagnose and remedy alternative conceptions about velocity. Their results indicated that computer simulation could be a credible representation of reality, and that remedy produced significant conceptual change in students holding alternative conceptions. Carlsen and Andre (1992), however, in a study on electrical circuits, found that using text designed to produce conceptual change resulted in better performance on tests, but that

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

using a computer simulation in addition to the text produced no greater change than the text alone did.

4.2 The Model of Simulation Design for Enhancing Conceptual Change

4.2.1 Models of Simulation Design

Computer simulation has a history. Its development features three stages: movie-like simulations, quasi-interactive simulations, and interactive simulations. In movie-like simulations, the computer simulates the physical process at a macro or a micro level. The function of simulations focuses on visualization. Through computer simulations students can see what they cannot see in life and in traditional labs. At this stage simulations are not interactive, although they may be vividly animated and beautifully colored. Students have no way to jump into the process. At stage two, the quasi-interactive stage, computer simulations become seemingly interactive. Using a few buttons, students can ask the computer to show the visualized process for a chosen situation among a couple of choices, but nothing more. The possibility of interaction is very limited, and the interaction does not make the second stage much different from the first stage. At these two earlier stages, computer simulations are fundamentally information oriented. With the development of computer language and, more importantly, the new insight of cognitive science, computer simulations for education are moving into stage three, the interactive stage. At this stage computer simulations are highly interactive. Students are allowed to act on screen. They can make predictions and test their predictions with the computer simulation. In the following, I will illustrate features of these three stages through the simulation of the phenomenon of Young's double-slit interference of light.

In the computer simulation of Young's double-slit interference of light, two slits behave as coherent sources of light waves that produce an interference pattern on the viewing screen. Curved lines are used to represent the invisible crests of light waves. The simulation is animated so that it seems that from the two slits curved lines continuously

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

radiate. These lines travel through the space between the second barrier and the screen to reach the screen and create an interference pattern. This simulation is somewhat effective because it helps visualize the fundamental mechanism of light inference. At the second stage, two buttons are added to the bottom of the screen. These buttons work as switches. Click one of the two buttons, and we get an interference pattern representing the case with a bigger distance between the two slits. Click this button for a second time, and we get another pattern associated with a small distance. The other button, representing the distance between the second barrier and the screen, works in a similar way. Except for supplying more information, the simulation has no advantage in terms of educational functions compared with its previous version. At the third stage, the position of the screen and the two slits can be continuously changed. The simulation cannot only show students what the interference pattern looks like at different situations, but it can also provide students with the opportunity to test their predictions. If I want to reduce the distance between bright fringes, how should I change the distance between S1 and S2 and the distance between the second barrier and the screen? If I change either of these two distances or their combination, how will the pattern change? For these kinds of exploratory questions, students can construct and test their answers through moving the position of the screen or the two slits.

4.2.2 The Model of Simulation Design for MAP

After examining the rich resources of CAI programs that include a component of simulation of physical phenomena, I have noted that many CAI programs use the technology only as an alternative way of presenting information (at stage one or two), but show very little advantage in the fundamental educational principle compared with conventional text-based materials. Simulations are primarily used to present not-easy-to-get experiences. Their designs, however, fail to successfully reflect the theoretical insights in cognitive science. In concurrence with the comment of Salomon et al. (see

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

page 7), I think this disadvantage of CAI programs may be one of the main factors that had zero or only a tiny positive influence on its effectiveness.

Simulations of MAP are at stage three. Their designs are theoretically based on constructivism. The design model is compatible with my model for conceptual change. These simulations are supposed to be embedded in the instructional process illustrated by Figure 3-3, functioning through eliciting student preconceptions, creating cognitive discrepancy, and/or providing evidence for introducing/confirming/applying scientific concepts. Following is one example of the simulations of MAP.

The computer simulates a ball rolling down an incline and then moving on a horizontal table (Figure 4-1). Students are prompted to draw arrows to indicate the velocity of the ball at three points along the path. Most students will draw the velocity arrows correctly (the lighter arrows in Figure 4-1). From the literature, however, we know that many students have trouble in the next step—drawing arrows to indicate the acceleration of the ball. Students believe that a high velocity necessarily implies a big acceleration, and they draw a longer arrow at point 2 than at point 1 (the darker arrows in Figure 4-1). The simulation is so carefully designed that students can see the difference between their predictions and the actual fact by clicking the "view results" button (in Figure 4-1, the darker ball represents students' prediction, and the ghost ball represents the reality). The simulation allows the student to make a number of different choices, but only the correct choices will duplicate the motion originally shown. This ability for students to 'see' the outcome of their predictions or choices will, it is hoped, ease the transition to the correct explanation. Traditional lab experiments cannot as easily give students this ability to see the results of their predictions. By making the outcome of student choices visible on the screen beside the actual situation posed, the simulation can be helpful in creating cognitive conflict and in facilitating conceptual change. When students try their predictions on the computer, they can work individually or in a group.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

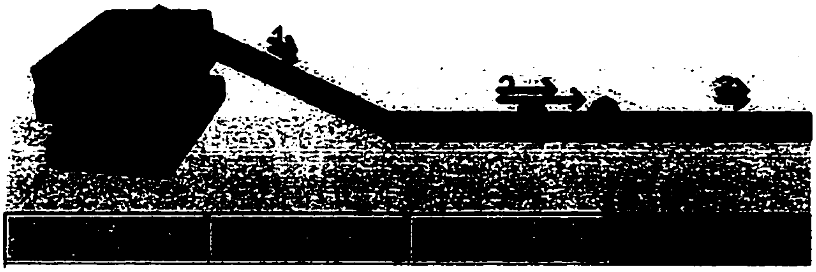


Figure 4-1. A ball rolls down an incline and then moves on a horizontal table. (The light arrows represent velocity. The darker arrows represent acceleration.)

4.3 Hypotheses for the Evaluation Study

My evaluation study will focus on the effectiveness of MAP in conceptual change. Because all of the simulations of MAP are designed to reflect constructivist teaching strategies, I assume that MAP helps students move from their alternative concepts to scientific ones when it is used in the constructivist teaching environment.

Attitude is important for learning, and the effectiveness of MAP in affecting student attitude was also investigated. Generally speaking, computer-supported programs should be more attractive than textbooks because they integrate text, graphics, animation, and pictures. I assume that MAP positively affects student attitude toward physics.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

CHAPTER 5

METHODOLOGY

> *Some get great value on method, while others pride themselves on desponding with method. To be without method is deplorable, but to depend on method entirely is worse. You must first learn to observe the rules faithfully; afterward, modify them according to your intelligence and capacity. The end of all methods is to seem to have no method.* (*The Tao of Painting,* by Lu Ch'ai, 1701; as cited in Janesick, 1998, p. 84)

5.1 Research Design and Associated Methods

The research design for my evaluation study was basically quantitative. However, I integrated into the research design some methods that are normally used in the qualitative research. My belief about the research method is that no single method is good enough for any fairly complex project in educational research, and the researcher should adopt whatever method is useful to the purpose of his/her study.

5.1.1 Descriptive Study

A descriptive study is the basis for both qualitative and quantitative research. It is designed to help to understand the status of the studied objects at one point in time (Gall, Borg, & Gall, 1996). In this research I conducted descriptive studies to investigate the preconceptions and attitudes that students brought to the class by giving them a pre-test. By giving students a post-test, I obtained data about their conceptual understanding and attitudes after the course. These descriptive studies are the basis for the comparative and correlation studies described below.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

5.1.2 Comparative Study

In the quantitative research domain, a comparative study is one of the most popular formats. It is designed to control one or more variables and allows researchers to investigate the difference between the results in the presence of these variables and those in their absence and to gain insight into the effect of these variables in the studied process (Gall et al., 1996). I employed this method to investigate the effectiveness of MAP in changing students' conceptions and attitudes. A test on conceptual understanding and a test about students' attitudes were administered to both the treatment classes and the control classes before and after the course. The performances of treatment and control classes were compared.

Because the instructors of the treatment classes were not same as those of the control classes, the difference in students' achievements may partially come from differences of instruction. For this reason I needed supplementary data from another kind of quantitative research design to answer my research question: whether MAP helps students to change their preconceptions. Within the treatment class I administered a survey to investigate how often students accessed the program after class. According to the results of the survey, I grouped students based on the efficiency of program accessing. Then I compared the performances of these subgroups in order to determine whether there was an achievement difference between students who often accessed the program and those who seldom did.

5.1.3 Correlation Study

A correlation study is another popular format of quantitative research. It is designed to find the relationship between variables and predict a future event or outcome from variables measured at an earlier point in time (Gall et al., 1996). In my study I used this kind of design to study the relationships of various preconceptions and the correlation between conceptual learning and problem solving.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

5.1.4 Sampling for Quantitative Research

Sampling is one key step for quantitative educational research. Samples, or those who participate in a study, must be selected in such a way that the researchers can generalize the conclusions from the sample to the population, which is the target that we try to understand. Researchers introduce the parameter of "population validity" as one of the criteria for judging experiments. It is the extent to which the result of an experiment can be generalized from the sample to a larger group (Gall et al., 1996). According to statistics, the bigger the sample size, the smaller the sample error; that is, a sample with a bigger size can better reflect the population than a smaller one can. It is generally agreed that for correlation research, the sample size should be no smaller than 20. The minimum numbers for comparative experimental study and survey research are 15 and 100, respectively (Sudman, 1976). Another theoretical criterion for sampling is the random selection of the sample from the target population. Compared with the size criterion, the randomness criterion is more difficult to achieve for practical educational research. A majority of reported studies in literature have biases in terms of sample selection because of the limited accessibility to target persons, institutes, and so on, for any researcher.

The sample for this study consisted of students registered in the introductory physics courses at a large university. There were several sections of these introductory physics courses. Sections whose instructors taught with MAP were selected as treatment groups, and other sections in which students did not access MAP materials were used as control groups.

5.1.5 Interview

Standardized achievement tests and questionnaires can supply researchers with relatively objective data and are easily administered to a larger number of participants with low cost and less time, but they cannot probe deeply into respondents' opinions and feelings. An alternative method used to obtain a deep understanding is the interview,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

which makes it possible for researchers to gain information that individuals probably would not reveal by any other data-collection method. This was supported not only by our experiences, but also by some reported studies (Gall et al., 1996). On the other hand, in science education literature many researchers report cases in which students get right answers in standardized tests by guessing or through the wrong understanding of the phenomena. Therefore, the right answer for one special question does not necessarily mean students understand the associated phenomena (Berg & Brouwer, 1991).

Individual interviews were conducted to remedy these shortcomings of quantitative measures. I invited five or six students from each class for interviews in order to obtain a deeper understanding of students' conceptual understanding. The interviews occurred during the progress of the class.

5.1.6 Group Interview

Group interviews have been used recently by more and more educational researchers. By definition, a group interview is a carefully planned discussion designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment (Krueger, 1988). The discussion is relaxed, comfortable, and enjoyable for participants as they share their ideas and perceptions. Group members influence each other by responding to ideas and comments. The interactions in the group stimulate participants to state feelings and beliefs that they may not express if interviewed individually. The interviewer is not in a role of directing discussion. He/she asks questions and then allows participants to state their views and draw out the views of others. According to Krueger, the group should include wide sampling of views, but not too large to block the opportunity for some individuals to speak. The ideal size is approximately 6 to 10. In this study, near the end of the course I sent a letter to some students inviting them to a physics discussion (Appendix A). The discussion allowed me to gain insight into students' attitudes toward MAP, the instruction, physics, and so on.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

5.1.7 Sampling for Qualitative Research

Unlike for quantitative research, the purpose of qualitative research is normally not to test hypotheses or theories, but to develop a deeper understanding of the studied phenomena. It is basically of the nature of interpretation. Sampling for a qualitative study is therefore much different from what it is in quantitative research. In contrast to the random selection in quantitative research, the process of sampling for qualitative research is called purposeful sampling (Patton, 1990). The sample is selected from those that typically represent the studied phenomenon. It can be more than 100, but it can be less than 10, even only 1.

In my study, individual interviewees were selected based on the conceptual pre-test and class observations. Those students with more conceptual problems became my interviewees. Group interviewees were selected according to an in-class survey and the class observations. Those students who represented subgroups with various attitudes toward the class components were selected for group interviews. The group interviews were balanced in gender and other associated features. For example, in one of the group interviews I did, there were four males and four females. Three of them had shown a positive attitude to the on-line materials, three of them had negative attitudes, and the rest had no preference. Among them, some students were active in class and some of them were relatively not active. Through this method of selecting the sample, I was able to get a wide range of opinions and avoid extreme one-sidedness. All of the interviews were taped or filmed with the permission of the interviewees.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

5.1.8 Class Observation

Achievement tests, questionnaires, and interviews are sometimes called self-report measures because they are primarily based on the participant's self-performance. These self-report measures have bias because they may not reflect the facts, especially when participants know what the desirable behaviors are and when they feel some imaginary negative effect of the research on them. Sechrest (1979) suggested the method of observation be conducted in natural real-life situations for studying social attitudes such as prejudice because self-reports of these attitudes are often biased by the set to give a socially desirable response. Currently, observations have become one popular method in social science studies. They can supply researchers with situated material.

In my study I did real-time class observations. I regularly sat in the class to observe the behavior of the teacher and students. I observed the teacher's class design, applet use, and interactions with students. I observed the students' engagement in the learning process and their attitude toward CAI programs. Some scholars reminded us of the bias of observation; namely, the effect of the observer on the observed. For example, students and teacher are likely to change their normal behavior pattern when an observer enters the classroom. Fortunately, this was not a problem for my observations because I sat in the classroom throughout the course. The long duration of my participation probably could reduce this negative effect to zero.

For each class I wrote down the outline of the class agenda and focused on the vignettes that were full of student and teacher interactions or that typically illustrated the instructor's organization of conceptual teaching. Margin marks were made when I had questions or quick reflections on the instruction. After class I met with the instructors to discuss some points of the class and with students who asked questions in the class to further explore their thinking. I reflected on the class and wrote journals at the end of my class observation notes.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

5.1.9 Physics Clinic

In the middle of the course, I asked the instructor to do me a favor by announcing the setup of my physics "clinic." I invited any students who had problems with the class to come to my office for consulting. Some came occasionally, but four students came regularly, once a week. Some of their questions were conceptual ones, but more were about problem solving. This clinic supplied me with good opportunities to interview students—with their permission, of course. The purpose of interviews was to identify students' conceptions and their attitude about physics instruction and MAP. I always reminded myself not to propagandize MAP applets when I interviewed students.

I applied one strategy in my clinic. As a doctor does in his medical clinic, I started my service with a diagnosis. Whatever question students asked, I always required them to try the question first and tell me their own understanding. Then I worked on the critical points where they failed. To make students feel comfortable with my strategy, when a new student came, I explained the process to him/her first and then encouraged him/her to vocalize his/her thinking. Most of the visits were taped with the permission of student visitors.

5.1.10 Review of Students' Assignments

In order to get a richer source for understanding student learning, I applied to mark student assignments and received permission. Students here were different from Chinese students I knew. Chinese students would not start to write on their assignment book until they had a quite comprehensive solution plan. They did prework on scrap paper. In contrast, many Canadian students took the assignment book as scrap paper. They wrote down whatever came to their minds and erased or crossed out lines when they changed their ideas. Although this made marking harder, it benefited my study. From what they wrote down, I could get a glimpse into the process of their thinking. I copied down the typical errors for later analysis.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

5.1.11 Student Writing

With the same aim as the assignment review, about the middle of the course I sent each student a letter inviting him/her to write to an email account I had set up (Appendix B). The comments could be on any component of the instruction, such as MAP design and use, instruction plan, and teaching approaches. The name of the instructor was deliberately omitted for the sake of confidentiality.

Table 5-1 lists my activities during three subsequent terms within a whole calendar year when I intensively carried on my evaluation study of MAP. I specify these three terms as Term-A, Term-B, and Term-C in the order of time.

Table 5-1

Activity Inventory

	Term-A	Term-B	Term-C
Pre and post conceptual tests	Yes	Yes	Yes
Pre and post attitude tests	Yes	Yes	Yes
In-class survey	Yes	Yes	Yes
Interview	Yes	Yes	No
Group interview	Yes	Yes	No
Physics clinic	Yes	Yes	No
Class observation	Yes	Yes	Yes
Review of assignments	No	Yes	No
Students' writing	Yes	Yes	No

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

5.2 Instruments

5.2.1 FCI Plus for the Conceptual Test

The instrument I used for conceptual achievement tests was a combination of the Force Concept Inventory (FCI), which has thirty questions, and three more questions from the literature, which I call FCI-Plus. The first version of FCI was published by Hestenes, Wells, and Swackhammer (1992), and a slightly modified version was published by Mazur (1997). FCI was designed to be a test of student understanding of Newtonian mechanics. One of its outstanding features is that the questions are designed to explore the understanding of basic concepts in a way that is understandable to the novice who has never taken a physics course, while at the same time being rigorous enough for the initiate. All of the questions are of a conceptual nature. The test was not produced to fully cover the domain of mechanics. The questions were created for the topics on which students most often have preconceptions. To answer them, simply recalling the definition of a concept is not enough, but students need to understand them and apply them to some situations. Therefore, these questions can solicit students' intuitive concepts and, in the meantime, test students' understanding of concepts. FCI has been widely and successfully used for testing the effectiveness of physics classes (Hake, 1998; Mazur, in press; Redish, Saul, & Steinberg, 1997; Redish & Steinberg, 1999). Most physicists agreed that the FCI is "one of the most reliable and useful physics tests currently available for introductory physics teachers" (Huffman & Heller, 1995, p. 138). From the results of the pilot trial I did in evaluating MAP, I know that students have preconceptions about the independence of components of motion and about gravity in space, which the FCI did not cover. I therefore added three questions into the FCI, one for motion independence and two for gravity. These three questions were taken from literature studying student preconceptions and are of a conceptual nature (Berg & Brouwer, 1991; Whitaker, 1983).

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Because all the questions in FCI-Plus were developed and widely used by university instructors and researchers, the validity of FCI-Plus in testing students' conceptual understanding was not a problem. For the reliability of FCI-Plus, I used the split-half method to estimate the reliability coefficient, which resulted in 0.90 for both classes in Term-C. I used another method—Kuder-Richardson 20—with a result of 0.89. The index of reliability, which is defined as the correlation between observed scores and true scores, is 0.95. These results confirm that FCI-Plus is a highly reliable test.

5.2.2 Instrument for Attitude Test and In-Class Survey

I compiled the attitude test questionnaire (Appendix C) and the in-class survey (Appendix D) with reference to the literature. The attitude test includes a set of Likert-scale questions. In each question students were asked to choose their response for a statement from the five choices *very true*, *true*, *uncertain*, *not true*, *not at all true*. The attitude test was focused on students' attitudes toward physics as human behavior and as a course. The in-class survey consisted of Likert-scale questions too. This survey was conducted in each treatment class to collect information about the frequency of students' accessing MAP after class, students' attitudes toward MAP, and students' motivations for learning.

5.3 Data Collection and Analysis

For the conceptual and attitude tests, data were collected from the returned student answer sheets. Individual interviews, group interviews, and class observations were recorded in notes and/or audio-/videotape for the follow-up analysis. SPSS computer software was used to analyse the data for the comparative and correlation studies. The connections between the study purpose and the data sources are illustrated in Table 5-2.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 5-2

The Connections Between Study Purposes and Data Sources

		Study purposes			
		Students' conceptions	Effect of MAP on conceptual change	Effect of MAP on attitude change	Conditions under which MAP is effective
Data sources	Conceptual tests	♠	♠		♠
	Attitude tests			♠	♠
	In-class survey		♠	♠	♠
	Individual interview	♠	♠	♠	♠
	Group interview			♠	♠
	Class observation	♠	♠	♠	♠
	Exam marks		♠		
	Physics clinic	♠		♠	♠
	Assignment review	♠	♠		
	Students' writing			♠	♠

Note: The symbol ♠ indicates that the column and the row variables of that cell are related. I obtained information from the row variable to understand the column variable.

5.4 Ethical Issues in This Study

In many cases educational research that involves human subjects has ethical issues. If they are dealt with improperly, it may harm or create inconvenience for the participants. Furthermore, they can hamper subsequent studies because the studied individuals or institutions become concerned about the possible or imaginary negative effect of the study on them. To respect the right, privacy, dignity, and sensitivities of the studied persons or institutions and to keep the research going smoothly, many countries have set up associated regulations. The samples for my study were university students. I

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

therefore took some measures to maintain the privacy and reduce the possible negative impact of ethical issues on my study:

1. Before the study I sent students an invitation letter and one consent form. In the invitation letter I told the students the purpose of the study and how they would be involved. I told them that all the data that I obtained from them would be used for research purposes only and not be revealed to other persons, that the test results would not affect their marks, and that they could withdraw from the study at any time if they wanted to do so. Finally, I told them that their participation was very important for the study and invited them to participate. Students were asked to sign the consent form if they agreed to take part in the study (Appendix E).
2. Before any test was administered or interview conducted, the instructor or I briefly told students the contents of item 1.
3. The questionnaires had a cover page. This page briefly included the content of item 1.

5.5 Limitations of This Study

The sample of my study included students registered in physics courses at a large university. This sample was not a random sample, but a somewhat convenient one. This feature of the sample causes uncertainty when I infer conclusions from my study for a population, such as physics students in Canada or in the world. In my study the instructors of the treatment and control classes were different. Students' achievements may result from many factors, including the teachers' teaching styles, MAP use, and their possible interaction. Conclusions drawn from class means may become meaningless for the research questions if they are not examined carefully.

One limitation of my study could have come from students' attitudes toward it. In my study I found the test reliability and the ethical issue to be conflicting sometimes.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Because I had told students that the test would not impact their course marks, some did not pay much attention to the test. When I interviewed one student after the pre-test, I asked him why he chose a certain answer, and he said he didn't know. "I just crossed one answer because I knew you wouldn't mark it." I appreciated his frankness, but what he did generated problems with the reliability of the test results. I could not find an effective way to deal with this matter except to tell students that their serious participation would be important for the research.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

CHAPTER 6

DATA ANALYSIS AND DISCUSSIONS: STUDENTS' PRECONCEPTIONS IN MECHANICS

As mentioned in Chapter 2, there are many studies on students' preconceptions of physics in literature. However, most are focused on one or two specific concepts. For example, Erickson (1979, 1980) examined students' conceptions of the nature of heat, Clement (1982) investigated students' conceptions of the relationship between motion and force, Berg and Brouwer (1991) studied students' conceptions of rotational motion, and Bar et al. (1997) focused their study on students' conceptions of gravity. These studies have produced knowledge about students' ideas on individual topics, but supplied little about the correlation among these conceptions.

According to Piaget's theory, intellectual development occurs when cognitive structure changes through the assimilation and accommodation of experiences. Students' thoughts have, to some extent, consistence at any stage of the procedure of their cognitive development. Vygotsky viewed mental functions as the result of internalization of social relationships. From this perspective, students' preconceptions are better described as representative of a widely accepted knowledge system—everyday common knowledge—than as individual inventions. It does not matter whether we take students' preconceptions as either individually constructed or socially constructed. I am fairly confident that students' preconceptions are not isolated from each other. In this chapter I will report my findings on students' preconceptions in mechanics and the features of these preconceptions.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

6.1 Sample

Results reported in this chapter are mainly drawn from the Term-A and Term-C tests. In the Term-A test, the control and treatment groups were comprised of 361 and 191 students respectively who were registered in an introductory algebra-based physics course. In the Term-C test, the control group and the treatment group were comprised of 89 and 71 students respectively who were registered in a calculus-based first-year physics course. Both courses covered the same topics: kinematics, dynamics, and heat, but the calculus-based course was more challenging than the algebra-based one. They were designed for different students. The algebra-based course was generally set up for first- or second- year university students from different science-related departments, while the calculus-based course was limited to physics and chemistry students. Therefore, students registered in the calculus-based course had a better background in mathematics and science than those enrolled in the algebra-based course. The pre-test was administered in the first week of classes and the post-test in the last week.

6.2 Students' Preconceptions in Mechanics

The instrument I used, Force Concept Inventory (FCI)-Plus, is a long test, covering many topics, such as motion and force, action and reaction forces, velocity and acceleration, and gravity; and therefore it can address a range of students' preconceptions. Most preconceptions are probed by more than one question. Students' preconceptions as discovered by the pre-test are summarized in the following tables (Table 6-1 and Table 6-2). The post-test data were also included in the tables for the purpose of comparison. Each table includes three columns: selected students' responses to the situations designed to test students' conceptual understanding, the percentage of students who chose these responses in the pre-test and post-test, and the possible preconceptions involved.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 6-1

Students' Preconceptions in Mechanics (Term-A)

Note: Data in bold and italic are for the treatment group (N=191) and the data in plain text for the control group (N=361).

The designed situations and the selected students' responses	Percentage of students who chose these responses (%)		Preconceptions reflected by these responses
	Pre-test	Post-test	
When two metal balls drop down from the same height, the heavier one takes considerably less time to reach the ground than the lighter one.	14 ***14***	15 ***13***	1. Heavier bodies fall faster than lighter ones.
When two metal balls roll off a horizontal table at the same speed, the heavier ball hits the floor considerably closer to the table than the lighter one.	35 ***40***	35 ***36***	
The dropped stone will speed up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the Earth.	11 ***11***	15 ***9***	2. Gravity gets stronger when objects move closer to the Earth.
A thrown-up ball experiences a steadily increasing downward force of gravity on its way down to earth.	11 ***13***	12 ***8***	
When an astronaut standing on a flat lunar surface gently lets go of a wrench, the wrench will float in space with no force or go far from the Moon's surface because of the gravity of the Earth.	43 ***48***	42 ***40***	3. There is no gravity on the Moon.
When a large truck collides head-on with a small compact car, the truck exerts a greater amount of force on the car than the car exerts on the truck.	67 ***62***	52 ***52***	4. Greater mass exerts greater force.
When a big male student suddenly pushes a small female student, he exerts a larger force on her than she does on him.	47 ***31***	32 ***28***	

(table continues)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The designed situations and the selected students' responses	Percentage of students who chose these responses (%)		Preconceptions reflected by these responses
	Pre-test	Post-test	
A large truck breaks down on the road and receives a push back into town by a small compact car. The force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.	65	63	5. Most active agent produces the largest force.
	59	*52*	
When a big male student suddenly pushes a small female student, he exerts a larger force on her than she does on him.	47	32	6. Only active agents exert force; obstacles exert no force.
	31	*28*	
A puck moves on a frictionless surface. Students fail to notice the force exerted by the surface.	29	18	
	38	*25*	
An office chair is at rest on the floor. Students fail to notice the upward force exerted by the floor.	10	4	
	12	*4*	
A boy who is swinging freely experiences a force in the direction of his motion.	76	64	7. Motion implies force. As soon as the force stops, the motion stops.
	74	*54*	
A woman is pushing a large box across a horizontal floor at a constant speed. If she suddenly stops pushing, the box immediately comes to stop.	20	21	
	23	*17*	
An elevator is lifted up at a constant speed by a steel cable. The upward force exerted by the cable is greater than the downward force.	73	64	8. Largest force determines the motion.
	76	*71*	
A woman is pushing a box across a horizontal floor at a constant speed. The constant horizontal force applied by the woman is greater than the total force that resists the motion of the box.	67	56	
	62	*54*	

(table continues)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The designed situations and the selected students' responses	Percentage of students who chose these responses (%)		Preconceptions reflected by these responses
	Pre-test	Post-test	
A woman is pushing a box at a constant speed on the floor. If she doubles the force she applies to the box, the box will move with a constant doubled speed or with a constant speed that is greater but not necessarily twice as great.	61 ***60***	54 ***51***	9. Velocity is somewhat proportional to applied force.
When a ball is shot out at high speed into a frictionless curved channel that is anchored to a table top, the ball experiences a force in the direction of motion.	77 ***74***	66 ***59***	10. Students view the impetus of an object as a force.
A tennis player serves a ball to his opponent's court. The tennis ball experiences a force even after it has left contact with the racquet.	65 ***71***	59 ***55***	
A boy throws a steel ball straight up. The ball experiences a steadily decreasing upward force.	77 ***73***	59 ***53***	11. Impetus dissipates while an object moves against resistance.
A ball is attached to a string and is swung in a circular path in a horizontal plane. When the string suddenly breaks, the ball will fly away non-tangentially.	18 ***13***	14 ***6***	12. There exists a centrifugal force.
A boy who is swinging experiences a force outward on the radius.	32 ***30***	18 ***12***	
The positions of two moving blocks at successive equal time intervals were given to students on a graph (one moves with a uniform velocity and the other accelerates). Students were asked to answer if the blocks ever have the same speed. Many students thought two blocks had the same speed at the points when they were at the side-by-side position.	27 ***31***	37 ***37***	13. Objects have the same velocity at the moments that they move side by side.

(table continues)

The designed situations and the selected students' responses	Percentage of students who chose these responses (%)		Preconceptions reflected by these responses
	Pre-test	Post-test	
The positions of two moving blocks at successive equal time intervals were given to students on a graph (both of them moving with a constant speed but with different initial positions and initial speeds). Students were asked to compare the accelerations of the blocks. Some students thought the object further ahead always had a greater acceleration than the object behind. Some students thought the faster block necessarily had the bigger acceleration.	43 *46*	42 *41*	14. Students confuse acceleration with position or with velocity.
When two metal balls roll off a horizontal table at the same speed, the heavier ball hits the floor considerably closer to or further from the table than the lighter one.	46 *52*	46 *43*	15. Students did not realize that the component of motion are independent of each other.
In a uniformly moving train, an object falling from the ceiling will hit the floor behind the point, which is vertically below the point of the ceiling where the object was hanged to.	36 *40*	23 *27*	
A ball horizontally fired by a cannon will go straight for a while first and then fall toward the ground in a curve.	20 *22*	14 *16*	16. Students did not realize that the components of motion act simultaneously.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 6-2

Students' Preconceptions in Mechanics (Term-C)

Note: Data in bold and italic are for the treatment group (N=71) and the data in plain text for the control group (N=89).

The designed situations and the selected students' responses	Percentage of students who chose these responses (%)		Preconceptions reflected by these responses
	Pre-test	Post-test	
When two metal balls drop down from the same height, the heavier one takes considerably less time to reach the ground than the lighter one.	11	9	1. Heavier bodies fall faster than lighter ones.
	12	***9***	
When two metal balls roll off a horizontal table at the same speed, the heavier ball hits the floor considerably closer to the table than the lighter one.	44	34	
	33	***36***	
The dropped stone will speed up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the Earth.	6	7	2. Gravity gets stronger when objects move closer to the Earth.
	6	***5***	
A thrown-up ball experiences a steadily increasing downward force of gravity on its way down to earth.	6	4	
	14	***2***	
When an astronaut standing on a flat lunar surface gently lets go of a wrench, the wrench will float in space with no force or go far from the Moon's surface because of the gravity of the Earth.	28	35	3. There is no gravity on the Moon.
	35	***33***	
When a large truck collides head-on with a small compact car, the truck exerts a greater amount of force on the car than the car exerts on the truck.	73	68	4. Greater mass exerts greater force.
	71	***41***	
When a big male student suddenly pushes a small female student, he exerts a larger force on her than she does on him.	36	42	
	37	***19***	

(table continues)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The designed situations and the selected students' responses	Percentage of students who chose these responses (%)		Preconceptions reflected by these responses
	Pre-test	Post-test	
A large truck breaks down on the road and receives a push back into town by a small compact car. The force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.	70 *69*	75 *59*	5. Most active agent produces the largest force.
When a big male student suddenly pushes a small female student, he exerts a larger force on her than she does on him.	36 *37*	42 *19*	6. Only active agents exert force; obstacles exert no force.
A puck moves on a frictionless surface. Students fail to notice the force exerted by the surface.	38 *30*	24 *29*	
An office chair is at rest on the floor. Students fail to notice the upward force exerted by the floor.	13 *11*	2 *0*	
A boy who is swinging experiences a force in the direction of his motion.	62 *69*	59 *35*	7. Motion implies force. As soon as the force stops, the motion stops.
A woman is pushing a large box across a horizontal floor at a constant speed. If she suddenly stops pushing, the box immediately comes to stop.	7 *16*	14 *12*	
An elevator is lifted up at a constant speed by a steel cable. The upward force exerted by the cable is greater than the downward force.	74 *70*	62 *35*	8. Largest force determines the motion.
A woman is pushing a box across a horizontal floor at a constant speed. The constant horizontal force applied by the woman is greater than the total force that resists the motion of the box.	63 *55*	57 *32*	

(table continues)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The designed situations and the selected students' responses	Percentage of students who chose these responses (%)		Preconceptions reflected by these responses
	Pre-test	Post-test	
A woman is pushing a box at a constant speed on the floor. If she doubles the force she applies to the box, the box will move with a constant doubled speed or with a constant speed that is greater but not necessarily twice as great.	49 ***53***	40 ***32***	9. Velocity is somewhat proportional to applied force.
When a ball is shot out at high speed into a frictionless curved channel that is anchored to a table top, the ball experiences a force in the direction of motion.	74 ***73***	62 ***47***	10. Students view the impetus of an object as a force.
A tennis player serves a ball to his opponent's court. The tennis ball experiences a force even after it has left contact with the racquet.	56 ***52***	46 ***37***	
A boy throws a steel ball straight up. The ball experiences a steadily decreasing upward force.	49 ***52***	42 ***20***	11. Impetus dissipates while an object moves against resistance.
A ball is attached to a string and is swung in a circular path in a horizontal plane. When the string suddenly breaks, the ball will fly away.	18 ***18***	10 ***6***	12. There exists a centrifugal force.
A boy who is swinging experiences a force outward on the radius.	24 ***33***	16 ***5***	
The positions of two moving blocks at successive equal time intervals were given to students on a graph (one moves with a uniform velocity and the other accelerates). Students were asked to answer if the blocks ever have the same speed. Many students thought two blocks had the same speed at the points when they were at the side-by-side position.	28 ***22***	31 ***22***	13. Objects have the same velocity at the moment that they move side by side.

(table continues)

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The designed situations and the selected students' responses	Percentage of students who chose these responses (%)		Preconceptions reflected by these responses
	Pre-test	Post-test	
The positions of two moving blocks at successive equal time intervals were given to students on a graph (both of them moving with a constant speed but with different initial positions and initial speeds). Students were asked to compare the accelerations of the blocks. Some students thought the object further ahead always had a greater acceleration than the object behind. Some students thought the faster block necessarily had the bigger acceleration.	36	39	14. Students confuse acceleration with position or with velocity.
	37	*24*	
When two metal balls roll off a horizontal table at the same speed, the heavier ball hits the floor considerably closer to or further from the table than the lighter one.	62	46	15. Students did not realize that the components of motion are independent of each other.
	50	*49*	
In a uniformly moving train, an object falling from the ceiling will hit the floor behind the point, which is vertically below the point of the ceiling where the object was hanged to.	27	29	
	35	*27*	
A ball horizontally fired by a cannon will go straight for a while first and then fall toward the ground in a curve.	12	6	16. Students did not realize that the components of motion act simultaneously.
	21	*4*	

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

6.3 Features of Students' Preconceptions

Comparing my findings with the results in the literature, I noticed the following features concerning students' preconceptions:

1. Students' preconceptions are quite different from scientific concepts. This feature of preconceptions has been documented by many studies and confirmed by my study. For example, students' preconceptions #1, 2, 3 in the right column of Table 6-1 and Table 6-2 are quite different from the Newtonian view of gravity; preconceptions #4, 5, 6 are different from Newton's 3rd law; preconceptions #7, 8, 9 are different from Newton's 1st and 2nd laws.

2. Although culture does affect children's perspectives, students from different countries have similarity in their ideas on force and motion. Clement (1982) reported that college students in the USA thought a force ("impetus") could be given to an object and motion implied a force. Viennot (1979) found that high school and university students from France, Britain, and Belgium thought that force was proportional to velocity and that action forces equaled reaction forces only when bodies were at equilibrium. My study shows that Canadian university students share similar preconceptions with their peers from other countries, which are represented by preconceptions #4 to 7 and #9 to 11 described in Table 6-1 and 6-2.

3. Although college students are normally older than high school students, they have similar intuitive understandings about the world. Berg and Brouwer (1991) tested 315 Grade 9 students in Edmonton, Canada, and found that students thought force ("impetus") could be given to an object, that a force was required in the direction of motion, and that there was no gravity in space and on the moon. Champagne and Klopfer (1980) stated that seventh- or eighth-grade students in the USA thought that heavier bodies fell faster than lighter ones. Erickson and Agurirre (1984) reported that high

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

school students generally did not think of the components of motion as independent. My test showed that the university students shared similar understanding of these topics with school students as represented by preconceptions # 1, 3, 7, 10, and 15 in Table 6-1 and Table 6-2.

4. Students' conceptions are often reminiscent of conceptions that are well known from the history of science. There are parallels between students' conceptions and historical conceptions. As described in Table 6-1 and Table 6-2, many students, as did people of Aristotle's time, thought that heavier bodies fell faster than lighter ones (preconception #1), that a force was required to maintain a motion (preconception #7), and that a force or impetus could be given to an object (preconception #10). These findings are compatible with the study report of Bar and Zinn (1998), who observed that a parallel existed between student concepts and historical concepts concerning action at a distance.

5. Students' preconceptions come from their experiences. The interview recordings supplied me with a supplementary source to obtain insights into the students' understandings. During the interviews, when I asked students why they thought there was a force in the direction of the motion of a pendulum, they said, "[a force] keeps the ball moving this way [along the curve]." Two interviewed students did hands-on experiments to support their ideas. One student pushed the teacup on my table and said, "[I] push it and it moves. [I] stop pushing and it stops moving." The other student pushed a pencil on my table instead of a cup and said similar things (students were interviewed individually). In the pilot test, when I asked one student why she thought a metal block had a higher temperature than a wooden one after the blocks had been sitting in a room for a long time, she cited a real-life example to explain her answer. She said if we put metal and wooden objects in sunlight, the metal one would be much hotter than the wooden one.

6. Some preconceptions are relatively easy to change, but some are very difficult to change through traditional teaching. Many studies reported that preconceptions are

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

hard to change. Some preconceptions, apparently changed in the school setting, may even rapidly reassert themselves in the broader context of daily life (Clement, 1982; Erickson, 1979, 1980). In my study, however, I found that some preconceptions were relatively easy to change. An example is the preconception about the ability of inactive agents to exert forces. Minstrell (1982) asked middle school students to draw the forces that a pendulum experiences. About 50% of the students omitted the tension in the string. When Sjoberg and Lie (1981) asked high school students to draw the force(s) experienced by a book sitting on a table before they taught the concept of normal force, only 50% of the students drew the upward force exerted by the table. In my study only 10% of university students failed to notice the force that the floor exerts on the chair before they took the university physics course, and this number decreased to 4% after the course.

Many preconceptions, however, did not change much after a four-month university physics course. Preconception #7 was resistant to change. For example, at the beginning of the course in Term-A, about 76% of the students in the control group believed in the existence of a force exerted on the direction of a boy's movement on a swing. After the course, 64% of the students still held this Aristotelian conception. Preconception #4 is another hard one. Of the university students, 67% thought that a big truck exerted a larger force on a small car during a head-on collision in the pre-test. In the post-test; still 52% of the students thought the same thing. Preconception #10 was also found to be a resistant one to change. In the pre-test, 58% of the students thought that a tennis ball experiences a force produced by the server's hit. In the post-test, the number of students who thought the same thing was around 55%.

Because I assumed student preconceptions came from their experiences, I am inclined to hypothesize that the more familiar the phenomenon is to students, the more resistant the involved preconception is to change. Students experience events involving motion and force every day. They have more experiences and a relatively longer period

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

of time to form their own concepts in these areas before they meet them more formally in science classes and may therefore find these conceptions more resistant to change.

7. Students' conceptions appear to be situation dependent. Although after the course almost all the students knew that a satellite experienced a gravitational force in space (only one student did not know this in the pilot post-test.), many of them still did not realize that the moon also exerted a gravitational force on objects near its surface. The following situation was given to students in the pilot post-test. An astronaut standing on a flat lunar surface throws a ball horizontally. Choose diagram 1 to 5 below to best show the track of the ball (Figure 6-1). Paths 1, 2, and 5 were chosen by 27.5% of the students. Figure 6-2 shows some typical student explanations for their choices. The upper explanation says, "Because there is no force of gravity (or any other forces), the ball will continue undisturbed along its path of motion." The lower explanation says, "The moon has no gravitational attraction to the ball so it will not fall toward the surface but outside gravity (such as Earth) may attract the ball away from the surface." In the control group of the Term-A test, about 50% of the students thought there was no gravity on the moon in the post-test.

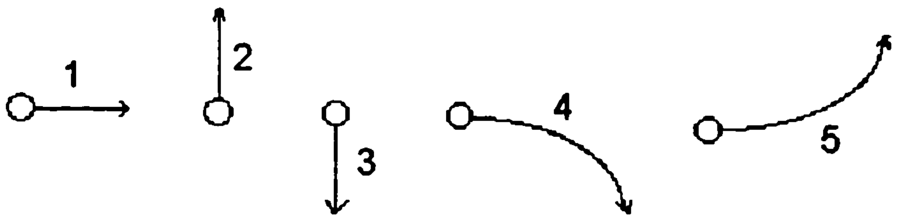
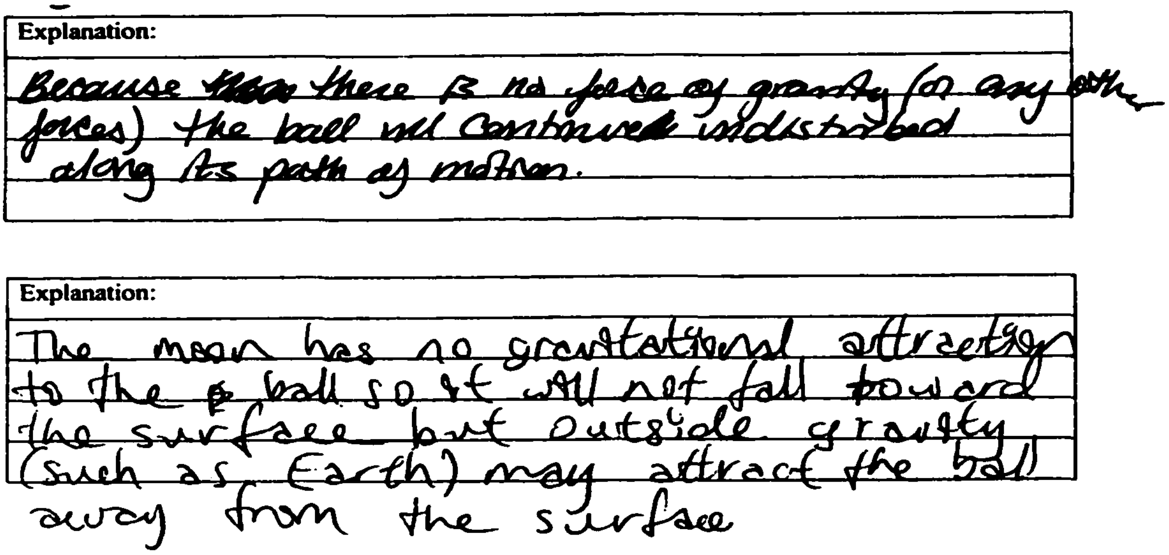


Figure 6-1. Path of a ball thrown horizontally on the moon.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.



Explanation:

Because ~~there~~ there is no force of gravity (or any other forces) the ball will continue undisturbed along its path of motion.

Explanation:

The moon has no gravitational attraction to the ~~p~~ ball so it will not fall toward the surface but outside gravity (such as Earth) may attract the ball away from the surface

Figure 6-2. Students' conceptions of the moon's gravity.

Another example is about students' understanding of the ability of obstacles to exert force. For the control group of the Term-A test, whereas about 10% and 4% students failed to notice the force that the floor applies on the chair in the pre-test and post-test respectively, 28% and 18% students failed to see the force that the surface exerts on the puck in the pre-test and post-test.

Von Glasersfeld (1995) has made the point that, in almost all cases, children's conceptions make sense to children themselves. They have their own ways of construing events and phenomena that are coherent within their domain of experience. Osborne and Freyberg (1985) reported a similar finding. My findings do not agree totally with the idea of coherence but do conceptually support the report of Lijnse (1990), who found that some students held different conceptions of energy in different problem situations.

8. Careful instructional design is necessary to change preconceptions. As learners, students quite often fail to see the connections among the topics taught in the class. Students may learn by rote due to a lack of strategies and abilities to build a big picture of

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

physics, or an absence of the intention to make extra effort to extend their learning to new situations. It does not seem difficult to connect the gravity of the moon with the gravity of the Earth and the universal law of gravitational force, but many students could not complete this conceptual transfer in our paper-pencil tests. During interviews, when I reminded the students to think about the source of the gravitational force and of the universal gravitational force law, most students who had thought that there was no gravity on the moon changed their minds. The following illustrates a similar sequence about the concept of force and motion (R = Researcher, S = Students).

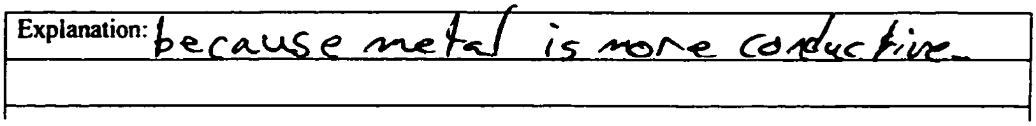
> *R:. Why do you think there is a force in the direction of motion [of the pendulum]?*
>
> *S: [A force] keeps it moving this way [along the curve].*
>
> *R: But when we take our foot off the accelerator, a car still goes on for a while, doesn't it? It doesn't stop right away.*

The student was silent for a while. Obviously, he was struggling with my challenge. It was not too long before the student said, "I see."

This finding indicates that students can transfer knowledge if they are directed properly and explicitly to extend their basic principles to new situations. Careful instructional design is necessary to overcome many preconceptions. Novak (1977) claimed that the meaning of a concept is defined and strengthened by the network of propositions the student has connected to it. The cases discussed above show the importance of building the "big picture" of physics and generalizing the application of the principles of physics to as many situations as possible. Teachers should not take for granted that students will transfer their understanding of physical laws and principles to new situations, although this transfer might appear to be straightforward in the view of the instructor. How to help students build an integrated and consistent knowledge structure is a topic instructors should seriously consider.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

9. Teaching does not always help students move in the right direction. In the pilot test, three questions, both in the pre- and post- conceptual tests, were designed to test students' understanding of heat, temperature, heat capacity, and thermal equilibrium. Students did not show any evidence of conceptual growth in these areas. In fact, the percentage of students who held alternate conceptions in the domain of heat increased after instruction. The course did not address the relevant topics directly but covered the concepts of thermal conductivity and emissivity of materials. The treatment of these topics appeared to strengthen the students' alternate conceptions. For example, students thought that a metal block had a higher temperature than a wooden block after they sat in a room for a long time because metal was a better thermal conductor than wood (Figure 6-3. The explanation says, "because metal is more conductive."). The class discussion of thermal conductivity may have helped push students who did not take this concept into account in the pre-test towards an unacceptable alternate conception. Teaching may not always help students move in the right direction. This is an interesting finding.



Explanation: because metal is more conductive

Figure 6-3. A student's response to the question of the equilibrium temperature.

10. Students may get the 'right' answer although they have unacceptable preconceptions. The last question of the FCI-Plus tests students in the following situation. An astronaut is making repairs on a spaceship in a polar orbit around the earth. While above the equator, the astronaut lets go of the spaceship. Students were asked to predict and then draw where the astronaut would be when the spaceship was above the North

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Pole. Some students chose the right answer, "stays with the spaceship," due to their belief that both the astronaut and the spaceship were moving freely in a circular orbit. Others chose the right answer because they believed, correctly, that both the astronaut and the spaceship were experiencing the same gravitational acceleration. In the pilot test the following situation was presented to students: Person A lifts a load by means of a pulley system (Figure 6-4), and person B lifts the weight by hand. Students were asked to compare the work done by the two individuals. Five students arrived at the right answer by wrong reasoning. Their typical explanation for their answer was, "They are doing the same amount of work because the force exerted by A and B are the same." (Figure 6-5). Champage and Klopfer (1980) and Gunstone and White (1981) reported the same finding when they tested students in other situations. Therefore, a particular correct student response does not guarantee that a student understands the physical situation.

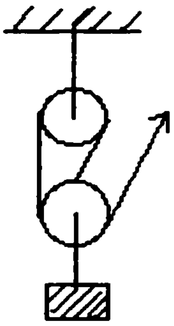
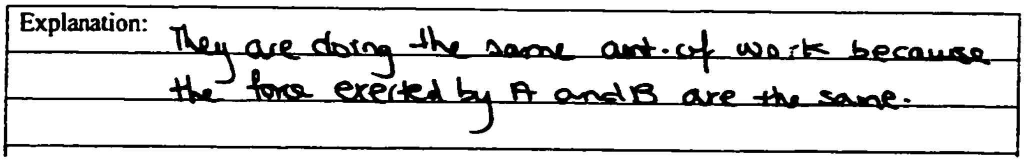


Figure 6-4. A pulley system.



Explanation: They are doing the same amt. of work because the force exerted by A and B are the same.

Figure 6-5. A student's misunderstanding of the concepts of work and force.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

6.4 Students' Everyday Cognition

Insights into students' cognition were provided by the conceptual test and in what they told me during interviews. The following four characteristics were detected about students' cognition:

1. Students think by way of analogies.

Analogies play a very important role in scientists' work. For example, in the early 20th century, based on the knowledge that in an atom there are positive and negative charges, scientists proposed several models about atomic structure through analogy. Thomson in 1903 proposed a plum-pudding model of atomic structure. In this model, the atom is described as a volume of positive charges with electrons embedded throughout the volume, much like raisins in thick pudding or seeds in watermelon. In 1901 Perrin compared an atom to the solar system. The element with positive charges is located at the centre of an atom in the same way that the sun is at the centre of the solar system, and electrons are seen as planets orbiting the sun. Nagaoka in 1903 proposed a Saturn-like model of the atom. According to this model, there is a core at the centre of an atom consisting of the positive charges and a Saturn ring-like band outside the core on which electrons are distributed. In my study I found that students think through analogies as scientists do. Students view an object as a container. It can store impetus or the force as a result of a "hit." Just as a car runs on gas, an object will move on impetus. An object will slow down while the impetus is dissipating. Impetus is thus seen as a kind of "go power." When I interviewed students for question 13, one of my interviewees made a gesture of throwing a ball up. I typically heard that the "intrinsic force" (caused by the act of throwing the ball up) was used up when the ball went up against gravity. The pushing action of people is seen as a metaphor or prototype for the force action. Because the floor or surface cannot push, some students failed to draw the normal force that the floor acts on the chair (question 19 of FCI-Plus test) or that the surface acts on the puck

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

(question 11). The social phenomenon that the stronger party plays the determining role is another metaphor students used to interpret dynamic process. They think that the strongest force determines the motion. For example, some students think that the upward force of the cable must be bigger than the downward force of gravity because the elevator is being pulled up (question 17). And for the same reasoning, a woman's applied force should be larger than the total resistance force because the box is pushed forward (question 25).

2. Students' thinking is vague with situation-dependent meanings.

The approaches of scientists and students using analogies are quite different. Based on their current knowledge about a subject, scientists use an analogy to further *investigate* the phenomenon. Students, however, use an analogy to *interpret* the phenomenon. Therefore, students' concepts are most often phenomenological in nature. For example, in the case of linear motion (question 13), students think that the force of "throw up" (impetus) has one dimension only, upward, but in the case of circular motion (questions 6 & 7), students see impetus as a kind of bendable matter which keeps the ball moving in a curve. It is clear that students have no fixed definition of impetus. It is just a tool they use to interpret a situation. Meanings can change with situations.

Students' concepts are often mixed up and poorly differentiated. Thus words such as *force*, *energy*, and *power* are often used interchangeably by students. In the case of question 13 (a boy throws a ball up in the air), a conversation between a student and the author went something like this:

R: What forces are acting on the ball when the ball goes up?

S: Gravity is always there. It is downward. And an applied force; it is upward.

R: Where does that force come from?

S: "The boy. He threw the ball up." (with a gesture of throwing a ball up)

R: You mean that force is still acting after the ball leaves the boy's hand?

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

> *S: "Hm. . . . Well, I mean the energy the boy put on the ball. It keeps the ball moving up.*

From a scientific view, students' concept of impetus is close to the scientific concept of momentum or energy. That is why I am wondering whether we can teach momentum or energy before force rather than the other way around. Exploring this possibility, however, is beyond the scope of this thesis.

Students often confuse sufficient conditions and necessary conditions. For students, that A causes B to occur means that B must need A. Such facts as people pushing a box across a floor become evidence for students to think that motion implies force. They did not see the difference between what makes the object move and what keeps it moving. Among the closely connected concepts of force, inertia, momentum, and energy, students do not know which they should start with in order to solve a problem.

3. Perception plays an important role in students' cognition.

Only a small number of the students who held preconception #4 in the pre-test changed their mind after instruction. The application of Newton's 3rd law in nonequilibrium interactions still proved to be illusive (question 4). The fact that one object damages the other appears to create a conceptual obstacle for them to believe that action force is, even in this kind of case, still equal to the reaction force. In such a complex case, students are often attentive to some visible variables and ignore others. In a complex situation such as a collision, there are other factors such as the mechanical energy involved, and the energy involved in the damage caused may complicate the situation and may make it difficult for students to focus on the nature of the forces involved in the collision.

Another example demonstrating the great influence of perceptions on students' cognition is the lack of discrimination between velocity and position. In the situation posed in question 19, over a quarter of the students thought that two blocks have the same speed at the moment they move side by side. For some students, being ahead in position

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

means having a bigger velocity, and a bigger distance means a bigger acceleration (question 20). The variables such as initial positions and time intervals are often ignored in students' intuitive thinking.

One interviewee told me an interesting story. In question 7 students were asked to predict which path a ball, which is swung in a circular path in a horizontal plane, will follow after the string suddenly breaks. The student got the right answer: The ball will go straight out along the tangential line of the circle. However, he came up with this choice not through the application of Newton's 1^{st} law; he instead thought of a track and field meet. An athlete throws a discus after he makes a few turns. If the discus did not go straight forward, it would hit the spectators sitting on the sidelines. This is why he concluded that the discus or the ball must go straight along the tangential line. The same interviewee told me another interesting story. The teacher was giving an example of problem solving after he taught the principles associated with the rotational motion of a rigid object. The question was to determine the minimum angle between a ladder and the ground in order to keep the ladder from slipping off when a person steps onto it. The student told me that when the teacher solved this problem, his mind momentarily went back to the time many years ago when his father adjusted the position of a ladder before he stepped onto it to fix the roof of their house. He was standing beside him when his father did this. The flash of recall made this student closer to the situation of the question and reportedly made the solution more meaningful and easier to understand.

Perception-dominated cognition was said by Piaget to be the feature of children's knowing. Children enter the formal reasoning stage at approximately 11 years of age and, as early as 16, intellectual development is essentially complete. My findings, however, tell us that the cognition of university students still relies on visible facts or concrete experiences. This finding is coherent with the claim of Schlenker and Perry (1983) that the majority of high school students and nearly half of college students are still not good at abstract reasoning. Their thinking still possesses some features of the concrete

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

operational stage. Perception still plays a very important role in university students' cognition.

4. Not all preconceptions are equally important.

After examining the preconceptions listed in Table 6-1 and Table 6-2, I found that the preconception "motion implies (net) force" is the central one among many preconceptions in mechanics (Figure 6-6). Other preconceptions in dynamics can be a direct deduction from this concept when applied in various situations. For example, in the case of a falling body, the following deduction can easily lead to the conclusion that heavier bodies fall faster than lighter ones:

1. A force is required by motion.
2. Heavier bodies experience a bigger force.
3. Therefore, heavier bodies fall faster.

Of course, not all the deductions of surrounding preconceptions from the *core preconception* are completely correct in logic, but remember that students' reasoning is not perfect in logic. For instance, they often mix up sufficient conditions and necessary conditions. Students build their own hierarchical conceptual structure based on their imperfect logic and vague concepts.

I quantitatively investigated the correlation among students' preconceptions. As Table 6-3 reports, the correlation coefficients among students' preconceptions in dynamics, namely preconception #7, 8, 9, 10, and 11 in the Table 6-1 and 6-2, are all significant at a significant level of 0.01. This indicates that students' preconceptions in dynamics are significantly related to each other. Having one of them very likely means having some others.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

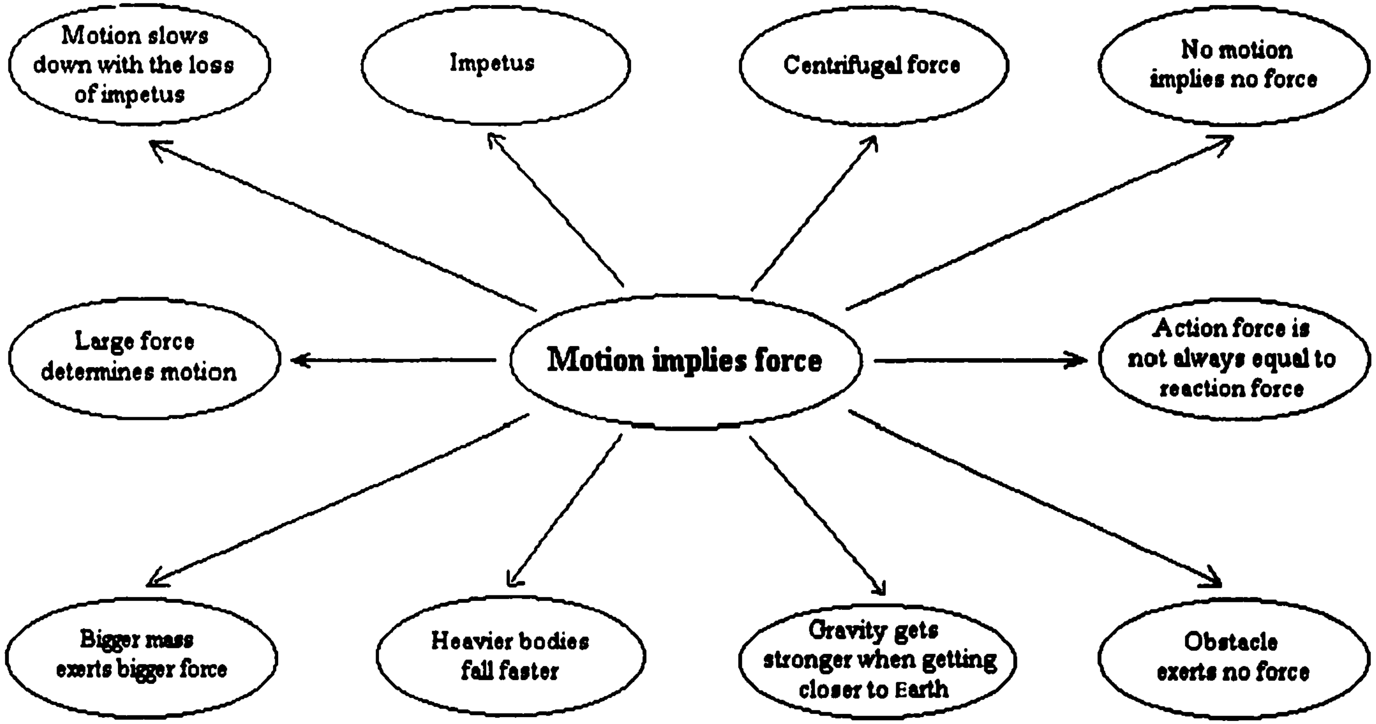


Figure 6-6 A pattern of students' preconceptions

Table 6-3

Correlation Among Preconceptions in Dynamics

Correlation among preconceptions

		P7	P8	P9	P10	P11
P7	Pearson Correlation	1.000	.163**	.162**	.294**	.336**
	Sig. (2-tailed)	.	.003	.004	.000	.000
	N	328	328	308	290	328
P8	Pearson Correlation	.163**	1.000	.331**	.194**	.202**
	Sig. (2-tailed)	.003	.	.000	.001	.000
	N	328	328	308	290	328
P9	Pearson Correlation	.162**	.331**	1.000	.171**	.232**
	Sig. (2-tailed)	.004	.000	.	.004	.000
	N	308	308	308	288	308
P10	Pearson Correlation	.294**	.194**	.171**	1.000	.405**
	Sig. (2-tailed)	.000	.001	.004	.	.000
	N	290	290	288	290	290
P11	Pearson Correlation	.336**	.202**	.232**	.405**	1.000
	Sig. (2-tailed)	.000	.000	.000	.000	.
	N	328	328	308	290	329

**. Correlation is significant at the 0.01 level (2-tailed).

Most students who had the core preconception in the pre-test did not change their mind in the post-test. For example, 64% of the control students in the Term-A post-test still believed that a boy who is swinging freely experiences a force in the direction of the motion. Therefore, it is no wonder that other preconceptions did not change much. Students' everyday cognition concerning dynamics phenomena survived through the course. This led to the poor performance of students in both the pre and post conceptual tests. For example, in the control group, students' average scores of 16.3 and 17.6 out of 33 for the pre-test and post-test, respectively, are below the conceptual threshold, 60% correct, set up by Hestenes and Wells (1992). Below this threshold, a student's grasp of Newtonian concepts is insufficient for effective problem solving.

Some implications for science teaching can be drawn with respect to the above features of the students' cognition. Since students think through analogies, applying an

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

analogy can be a valuable teaching strategy. Analogies help us understand new material based on our knowledge about something else. However, analogies do not mean "equal to" or "same as". They will break down at some points. A boundless extension of an analogy can cause wrong conceptions. The instructor needs to help students to realize where and when the analogy breaks down. When two forces act on an object with a zero initial speed, the object will move in the direction of the bigger force. A social policy analogy can be used to clarify this concept. A stronger political party with a larger number of members determines the direction of social policy and development. Similarly, the larger force determined the direction the object will move. But if the initial speed of the object is not zero, the social analogy is not applicable. The object may move in the direction of the smaller force. Since perception plays an important role in students' cognition, a variety of visualization methods, such as demonstrations and computer simulations, can be helpful for students to construct understanding. University physics courses are primarily abstract and this is perhaps why students feel physics is hard to learn. A demonstration and simulation can make the concept and physical process visible and therefore are helpful. Linking abstract theory and concept to students' real life experience can make the abstract material "visible" and meaningful and therefore is welcomed by effective physics instruction. Since some preconceptions appear to be more fundamental than others, these preconceptions need to be treated with more attention. For the core preconception – motion implies force, its opposite counterpart in Newtonian physics is the 1st Law. Unfortunately, the 1st Law was only briefly described in the courses observed. Instead, most of class time was devoted to the 2nd Law and its application. The teachers were interested in various problem settings of applying the 2nd Law, and forgot to conceptually strengthen the 1st Law through teaching the 2nd Law.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

6.5 Why Preconceptions Are so Hard to Change

Many others' studies and my own have adequately documented the difficulty of conceptual change. Why are students' preconceptions so hard to change? I think there are three reasons. The first reason lies in the fact that students' preconceptions are much closer to their experiences than scientific concepts are. Students' preconceptions are formed within their everyday life environment and are situation-dependent. In most cases, these preconceptions have sufficient power to interpret students' life experiences. In contrast, scientific concepts are abstracted from experiences and are generalized. Therefore, scientific concepts are much more abstract and relatively further from what students see and hear.

The second reason, which is related to the first one, is that the transition from preconceptions to scientific notions requires great intelligence. In the history of physics, for quite a long time physicists such as Newton and Descartes did not agree with each other on the concept of force, kinetic energy, momentum, and so on. Descartes took momentum as the fundamental concept of motion. Newton however put the concept of force at the centre of dynamics. In Newton's fundamental work *Principia*, there still existed confusion in the use of the force concept. Newton called applied force *moving force* and inertia *intrinsic force, resisting force, or inertia force.* He even called acceleration *accelerating force.* According to Galileo, a force could be measured by the velocity change the force creates in a given time interval, but Leibnitz thought a force should be estimated by the height to which a force could lift an object. From the view of classical physics, we know that Galileo was talking about impulse and Leibniz about work. Both impulse and work are different concepts from force but reflect the effect of a force over a period in time or a distance in space. The struggle of these excellent physicists over the concepts of force and motion is an indicator of the difficulty that students have in grasping these concepts.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The third reason is our instruction. Our instruction often takes the following format: We do a demonstration, and to interpret this demonstration, we introduce a new concept. This process has a similar logic to students' everyday thinking. Students pick up a model that can interpret what they experience. The metaphorical and phenomenological feature of preconceptions reflects the inconsistency in students' thinking. We need to address the consistence of science that represents the merit of science over students' everyday cognition by generalizing the scientific concepts to more cases. We need to teach students that successful explanation of a special case is not enough for a hypothesis to become a theory.

With respect to these three factors that contribute to the difficulty of conceptual change, we as educators can apply our influence on the first one and the third one. Introducing more real-life problems may help us move science closer to students' life experiences and make students feel more comfortable with science. Linking scientific concepts to as many phenomena as possible and demonstrating the consistence of science and inconsistency of everyday science may work for the third factor and help students appreciate the marvels of science.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

CHAPTER 7

DATA ANALYSIS AND DISCUSSIONS: EFFECTIVENESS OF MAP AND SUGGESTIONS FOR TEACHER EDUCATION

In the last chapter I reported my findings regarding students' preconceptions in physics and the characteristics of students' cognition. In this chapter I will report my findings about the effectiveness of the MAP project and provide suggestions for today's teacher education. In the first four sections I will analyse the data obtained from the conceptual test and the attitude survey and discuss the impact of the MAP project on students' conceptual learning and attitudes toward physics. In the fifth section, I will describe my findings about the relationship of problem solving and conceptual learning and the features of students' approaches to problem solving. In the last section, based on numerous resources including evaluation results, my class observations, my communications with teachers and students in the classroom and in my clinic, and so on, I will give my suggestions for the improvement of teacher education.

7.1 Sample

The evaluation of the MAP project started several years ago with a pilot test (Zhou, Martin, Brouwer and Austen, 2000). More formal investigations followed in three subsequent terms within a calendar year: Term-A, Term-B, and Term-C (Table 7-1). In total, ten classes, approximately eight hundred students were involved in our investigation (Table 7-2). These students were registered in two introductory physics courses at a Canadian university. One course is algebra-based and the other one is calculus-based. Students involved in the investigations of Term-A and Term-B were from the algebra-based course (classes: C1, C2, C3, C4, T1, T2, and T3). Students involved in the Term-C investigation were from the calculus-based course (classes: C and T).

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 7-1

Class Numbers Involved in the Evaluations

	Term-A	Term-B	Term-C
Control classes	4	0	1
Treatment classes	2	1	1

Table 7-2

Student Numbers in Each Class

	Term-A						Term-B	Term-C	
	C1	C2	C3	C4	T1	T2	T3	C	T
Number of students	81	76	99	105	88	103	26	89	71

Note: C1-4 are the control classes and T1 and T2 are the treatment classes in Term-A. T3 is the treatment class in Term-B. C and T represent the control and treatment classes respectively in Term-C.

7. 2 Conceptual Test Results and Data Analysis

7.2.1 Conceptual Test Data

I administered the Force Concept Inventory (FCI)-Plus to each control and treatment class at the start and end of the course. Students were allowed about thirty minutes to write the test except for the Term-B class which was allowed only twenty minutes because of the intensive class plan. This may account for the low pre-test score of the Term-B class. Class means out of 33 are listed in Tables 7-3 and 7-4. Classes in Table 7-3 were algebra-based classes, while classes in Table 7-4 were calculus-based

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

classes whose students had a stronger background in math and science than students from the algebra-based classes.

Table 7-3

Class Averages on FCI-Plus (Term-A and Term-B)

	Term-A								Term-B
	C1	C2	C3	C4	Cw	T1	T2	Tw	T3
Pre-test	16.8	16.6	15.4	16.5	16.3	15.8	15.4	15.6	11.5
Post-test	18.3	17.6	16.6	18.1	17.6	18.4	18.0	18.2	22.1

Note: Cw and Tw denote the whole control and treatment groups in Term-A respectively.

Table 7-4

Class Averages on FCI-Plus (Term-C)

	C	T
Pre-test	17.8	17.7
Post-test	20.5	23.0

7.2.2 g Theory and g Values

To investigate and compare the effectiveness of instructional methods, we need a measurable and comparable variable primarily determined by the studied teaching methods. This variable should not be influenced much by other factors such as students' knowledge level when they started the course. The existence of this kind of variable allows us to test instructional methods in a wide range of class levels. Through a

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

longitudinal study, Hake (1998) constructed a statistical measure: normalized gain, which he called g.

Hake (1998) did a detailed study of FCI results by investigating 62 introductory physics courses involving over 6,000 students at school, college, and university levels. He categorized these 62 classes into two groups: 14 classes with interactive engagement (IE) methods and 48 classes with traditional (T) methods. Traditional classes were defined as those relying primarily on passive lectures, recipe labs, and algorithmic problem exams. IE classes were defined as those designed at least in part to promote conceptual understanding through interactive engagement of students in head-on (always) and hands-on (usually) activities which yielded immediate feedback through discussion with peers and/or instructors. Hake defined the *absolute gain* as the class average of post-test score minus the average of pre-test score, and the *maximum possible gain* as the full mark minus the average of the pre-test score. After plotting the absolute gain against the average pre-test score, Hake found that points representing the traditional classes fell along the T line with various pre-test scores while those for IE classes appear along the IE line (Figure 7-1). That is to say, the absolute gain had a roughly linear relationship with the average pre-test score among the classes with a similar instructional approach. These lines of absolute gain vs. average pre-test score pass through the point (100, 0) with an assumption that the full mark is 100. The dashed line represents ideal cases in which absolute gains are equal to possible gains.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

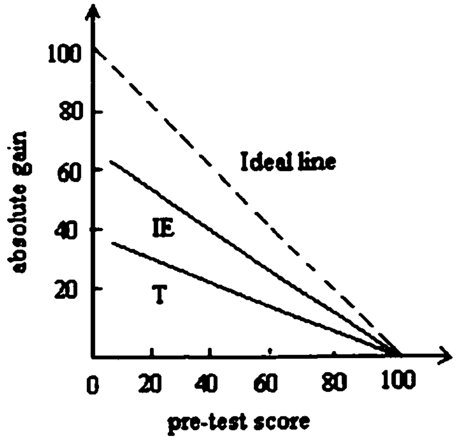


Figure 7-1. Schematic of Hake's plot.

Hake defined the ratio of the absolute gain over the maximum possible gain as the *normalized gain*, represented by the letter *g*, which was the absolute value of the slope of the line graph.

$$g = \frac{\text{absolute gain}}{\text{maximum possible gain}} = \frac{\overline{X}_{post} - \overline{X}_{pre}}{100 - \overline{X}_{pre}}$$

The g value remained roughly the same for the classes with a similar instructional approach regardless of the different pre-test scores. Hake calculated the correlation coefficient of g with the pre-test score and got a very low value (0.02). In contrast, the correlation coefficient of the post-test score and the pre-test score was 0.55, and the correlation coefficient of the absolute gain and the pre-test score was -0.49. Clearly, compared with the post-test score and the absolute gain, the ratio g was more suitable for comparing course effectiveness over diverse groups with a wide range of initial levels. Hake (1998) therefore inferred that "a consistent analysis over diverse student populations in high schools, colleges, universities is obtained if a rough measure of the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

average effectiveness of a course in promoting conceptual understanding is taken to be the average normalized gain <g>" (p. 64).

My test results of Term-A and Term-B are reported in Table 7-5. The test result of Term-C is reported in Table 7-6.

Table 7-5

The g Values for the Control and Treatment Classes (Term-A and Term-B)

Term	Term-A								Term-B
Class	C1	C2	C3	C4	Cw	T1	T2	Tw	T3
g	0.093	0.064	0.067	0.095	0.078	0.151	0.148	0.149	0.529 (0.36)*

* Adjusted value.

Table 7-6

The g Values for the Control and Treatment Classes (Term-C)

Class	C	T
g	0.176	0.345

The data demonstrate two points: (a) g value is quite independent of instructor within the traditional format of instruction. The four independent control classes in Term-A produced close g values; and (b) every treatment class produced a bigger g than the control classes. The g value of the Term-B class seems an outlier. This is because the Term-B class was only allowed twenty minutes to write FCI-Plus in the pre-test instead of thirty minutes. Twenty minutes is not enough for this test. This can be seen in the low pre-test score of the Term-B class. If we adjust the pre-test score 11.5 to be 16.1, which is

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the average of the pre-test scores of all the Term-A classes, including the control and the treatment classes, the g value of the Term-B class will be 0.36. This value is still bigger than g values of the Term-A control classes. Among the four treatment classes, the Term-B and Term-C classes did much better than the two in Term-A. A possible explanation will be explored later.

The results from my research were compared to similar studies. In Hake's (1998) statistical results, the traditional classes produced g values in the range of 0.12 to 0.28, with an average of 0.23. In my research all four control classes, which represented traditional instruction, produced g values less than 0.10. These g values were also smaller than the g values reported by Redish et al. (1997) and Redish and Steinberg (1999) — 0.18 (1997) and 0.16 (1999). This seems to raise some concern over the effect of traditional instruction in developing conceptual understanding in physics at the university where I carried out my research.

7.2.3 Effect Sizes of Control and Treatment Classes

Effect size (Δ) is most often used to describe the difference between the means of experimental ($\overline{X}_E$) and control ($\overline{X}_C$) groups. It is simply the z-score of the mean of the experimental group referenced in the frequency distribution of the control group; that is, the effect size is equal to $\overline{X}_E - \overline{X}_C$ expressed in standard deviation units:

$$\Delta = \frac{\overline{X}_E - \overline{X}_C}{S_C},$$

where S_C is the standard deviation of the control group. In our study situation, if we take both teaching in a traditional way and teaching with MAP as two kinds of treatments and take students who do not take the course as a virtual control group, the effect size can be used to compare the effectiveness of the traditional class and the MAP class. We assume the virtual control group has no change on their test results through time. The pre-test

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

then can be treated as the post-test score of the virtual control group. The effect size for each class therefore can be obtained through the following equation:

$$\Delta = \frac{\overline{X}_{post} - \overline{X}_{pre}}{S_{pre}},$$

The effect sizes for the classes involved in my study are shown in Table 7-7.

Table 7-7

<u>Effect Sizes of the Control and Treatment Classes</u>

	Cw	Tw	T3	C	T
Mean increase	1.3	2.6	10.6 (6.1)*	2.7	5.3
Standard deviation of pre-test	6.3	6.6	5.3 (6.6)*	7.3	7.2
Effect size	0.21	0.39	2.0 (0.91)*	0.37	0.74

* Adjusted values.

Note: Cw and Tw represent the control and treatment groups respectively in Term-A. T3 represents the treatment class in Term-B. C and T represent the control and treatment classes respectively in Term-C.

For the same reason mentioned above, the effect size of the Term-B class is an outlier. If we take the adjusted average pre-test score (16.1) for the Term-B class and 6.6 as the standard deviation, the effect size of the Term-B class will be 0.91. Clearly, the treatment group/class has a larger effect size than does the control group/class.

7.2.4 T-Test Results

The most popular measurement in educational evaluation is probably the t-test. It is used to answer the following kinds of questions: Is the treatment effective? Do girls read better than boys? Does anxiety level influence test performance? Tables 7-8 to 7-12

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

are the t-test outputs of SPSS for my evaluation (refer to Appendix F for more detailed t-test results). A brief interpretation of the results is presented after each set of tables. The alpha level for all the t-tests was set up as 5%.

Table 7-8

Independent T-Test for Pre-test Results (Term-A)

Independent Samples Test for the pretest

			PRETEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		.166	
	Sig.		.684	
t-test for Equality of Means	t		1.147	1.131
	df		502	340.752
	Sig. (2-tailed)		.252	.259
	Mean Difference		.68	.68
	Std. Error Difference		.60	.60
	95% Confidence Interval of the Difference	Lower	-.49	-.50
		Upper	1.85	1.87

Table 7-9

Independent T-Test for Post-test Results (Term-A)

Independent Samples Test for the posttest

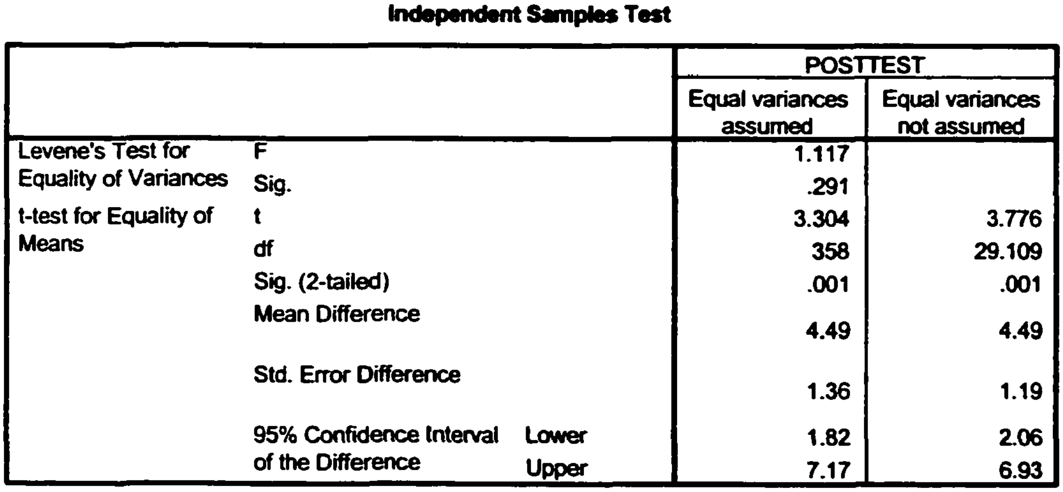
			POSTTEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		.031	
	Sig.		.860	
t-test for Equality of Means	t		-.995	-.994
	df		511	360.062
	Sig. (2-tailed)		.320	.321
	Mean Difference		-.61	-.61
	Std. Error Difference		.61	.62
	95% Confidence Interval of the Difference	Lower	-1.82	-1.82
		Upper	.60	.60

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

As illustrated in Table 7-8, in the pre-test of Term-A, the significant level ('Sig. (2-tailed)') of the mean difference between the treatment group (Tw) and the control group (Cw) on FCI-Plus was 0.252. This value is much bigger than the prescribed statistically significant level 0.05. That is to say, the treatment and control groups were at a similar level in terms of conceptual understanding when they started the course. After the course, the significant level of the mean difference was 0.320 (Figure 7-9), which is much bigger than the prescribed value of 0.05 as well. Therefore, the two groups were still at the similar level after the course. The use of MAP by the treatment group did not result in a significant difference from the control group in Term-A.

Table 7-10

Independent T-Test on Post-test Results for the Control Group in Term-A and the Treatment Class in Term-B



Independent Samples Test

			POSTTEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		1.117	
	Sig.		.291	
t-test for Equality of Means	t		3.304	3.776
	df		358	29.109
	Sig. (2-tailed)		.001	.001
	Mean Difference		4.49	4.49
	Std. Error Difference		1.36	1.19
	95% Confidence Interval of the Difference	Lower	1.82	2.06
		Upper	7.17	6.93

Since there was no control group in Term-B, I took the control group in Term-A (Cw) as a reference group. The Table 7-10 shows the t-test output of the post-test for the Term-B treatment class (T3) and the Term-A control group (Cw). The significant level of

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the mean difference is 0.001. This value is much smaller than the prescribed value of 0.05. I therefore conclude that the Term-B treatment class produced a mean which was significantly better than the Term-A control group.

Table 7-11

Independent T-Test for Pre-test Results (Term-C)

Independent Samples Test

			PRETEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		.460	
	Sig.		.499	
t-test for Equality of Means	t		.042	.042
	df		146	140.277
	Sig. (2-tailed)		.967	.967
	Mean Difference		5.03E-02	5.03E-02
	Std. Error Difference		1.20	1.20
	95% Confidence Interval of the Difference	Lower	-2.32	-2.32
		Upper	2.42	2.42

Table 7-12

Independent T-Test for Post-test Results (Term-C)

Independent Samples Test

			POSTTEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		1.771	
	Sig.		.185	
t-test for Equality of Means	t		-2.228	-2.262
	df		137	129.110
	Sig. (2-tailed)		.028	.025
	Mean Difference		-2.53	-2.53
	Std. Error Difference		1.14	1.12
	95% Confidence Interval of the Difference	Lower	-4.78	-4.74
		Upper	-.28	-.32

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

The Tables 7-11 and 7-12 illustrate t-test results for the pre-test and post-test in Term-C respectively. The significant level of the mean difference between the treatment class (T) and the control class (C) was 0.967 for the pre-test and 0.028 for the post-test. By comparing these two values with the prescribed value of 0.05, I concluded that the treatment and control classes in Term-C had the same starting level in physics conceptual understanding, but the two classes had a significant difference in conceptual understanding after the course. The treatment class performed significantly better on the FCI-Plus test than the control class.

7.3 Attitude Test Data

In the whole control group (Cw) of the Term-A test, 66% of students thought physics was interesting to them; 43% of the students thought that physics was hard to learn; and 92% viewed science (including physics) as a major force in the development of society at the start of the course. Unfortunately, these three numbers were 62%, 45%, 86% respectively, at the end of the course. In the whole treatment group (Tw) of Term-A, these three percentages were 70%, 40% and 90% respectively at the start of the course and 64%, 42% and 84% at the end of the course (Table 7-13). That is, students' attitudes toward physics went down in Term-A after the course. The same thing happened in Term-C as illustrated by Table 7-13. This result is consistent with the report of Redish and Steinberg (1999). Based on survey results from more than 1,500 students from six colleges and universities, they found that "the percentage of students with favorable attitudes tends to deteriorate as a result of traditional instruction" (p.6). Why did more students think physics was hard to learn and lose their interest and trust in physics after the class? This is another question worth further discussion later.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 7-13

Attitude Test Results (Term-A and Term-C)

			Percentage of students thinking physics was interesting (%)	Percentage of students thinking physics was hard to learn (%)	Percentage of students viewing science as a major force for social development (%)
Term-A	Cw	Pre-test	66	43	92
		Post-test	62	45	86
	Tw	Pre-test	70	40	90
		Post-test	64	42	84
Term-C	C	Pre-test	91	37	97
		Post-test	84	43	88
	T	Pre-test	98	33	96
		Post-test	91	46	89

Note: The FCI-Plus and the attitude test were administrated together. Since the Term-B class did not have enough time to write the tests at the start of the course and most students did not respond to the attitude questions, the pre attitude test data for the Term-B class were not reliable. Therefore the attitude data for the Term-B class were excluded from this table.

In the survey of student attitude about video labs, I found that 63% of the students liked video labs more than traditional labs, but there was a significant percentage (21%) who did not like them, and 17% did not show a preference. This gives us an unclear picture of this topic. The group interviews supplied more information on students' preferences. Interviewees said that they liked some video labs, those which visualized the physical process and promoted thinking; but they did not like some others, those which appeared to be too rigidly organized and gave them little freedom in carrying out the experiment and designing their own analysis. Many of these students thought that the computer had done too much for them. In one student's words, "The computer allows you to be lazy." Interviewees suggested a combined version of traditional lab and video lab. They would like a traditional section (warming-up section) before the video lab section. They felt that "the thing is too far from you as long as it is input into the computer. You cannot see—I mean feel or touch—what is going on there." Video laboratory activities should supplement rather than replace regular hands-on laboratory activities. This reminds me of the importance of hands-on experiments in teaching and learning. New media cannot replace them all.

7.4 Discussions and Conclusions

7.4.1 Is MAP Effective in Promoting Conceptual Learning?

Control classes consisted of traditional instruction and treatment classes utilized MAP in their instruction. Treatment classes created a larger g value and effect size than control classes. Therefore, I conclude that MAP successfully helped students learn physics concepts. The t-test results also support this conclusion. For the Term-C test, the treatment class produced a significantly higher mean in the post-test than the control class did, even though the treatment and control classes started at the same level before the course. Since we have no reason to reject the assumption that the Term-B treatment class and the Term-A control group had the same level of performance on FCI-Plus before the course, the statistically significant t-test result for the post-test between these two groups points to the same conclusion. Although the t-test results in the Term-A test do not show a significant difference between the treatment and control groups in the post-test at an alpha level of 0.05, the changes of class means in the pre-test and post-test probably

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

support this conclusion as well. The average pre-test score of the treatment group was lower than that of the control group, but the order was reversed in the post-test.

One might be suspicious of this conclusion because treatment classes had different instructors from the control classes. One would wonder whether the difference comes from the instructors or from the MAP use. In this regard, I would argue in the following way. The five instructors for the control classes were assistant, associate, or full professors. They have many years teaching experience. In contrast, the instructors for the treatment classes in Term-A and Term-C were postdoctoral fellows who had only one or two years teaching experience. These teachers' lack of teaching experience did not stop their classes from doing better. The contributor, I am fairly sure, was MAP. The instructor of class T3 was an associate professor. He had no more teaching experience than his equivalent instructors in the control group.

To further investigate this matter, I did the following measurement. I assigned five numbers (1 through 5 to the five scales in an ascending order) to the two five-scale multiple-choice questions (questions 3 and 4 in appendix D) surveying the frequency of students accessing MAP applets and the number of applets students visited after class, and scored students on these two questions separately. Within the T3 and T classes, I studied the relationship between the personal normalized gain (personal gain over the possible personal gain) in the conceptual tests and the frequency of the students accessing MAP or the number of MAP applets they visited after class. The correlation coefficients are positive for the T3 class, although not large—0.286 for the accessing frequency and the conceptual gain and 0.316 for the number of visited applets and the conceptual gain. For the T class, these two coefficients are 0.225 and 0.278 respectively.

The results of the in-class survey provide further evidence for my above conclusion since most treatment students reported MAP helped them learn physics concepts (Figure 7-2). In the Tw group of Term-A, 46% of students reported that MAP helped them a great deal with learning concepts; 27% said MAP helped them a little bit;

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

16% did not gain benefits from MAP at all; and the remaining 11% were uncommitted. In the T3 class of Term-B, 96% of students reported that MAP helped them learn concepts a great deal; 4% said that it helped only a little bit; no students found no benefit using MAP at all; and no students were uncommitted. In the T class of Term-C, 52% of students reported MAP helped them understand concepts a lot; 17% said MAP helped them only a little bit; 7% did not get benefits from MAP at all; and the remaining 24% were uncommitted. In the after-class group interview, we heard similar student comments: "The applet helps. It allows you to see what is going on," "Anything visual, in my opinion, helps," and "The applets help us do the transformation [from the physical situation to physics language]."

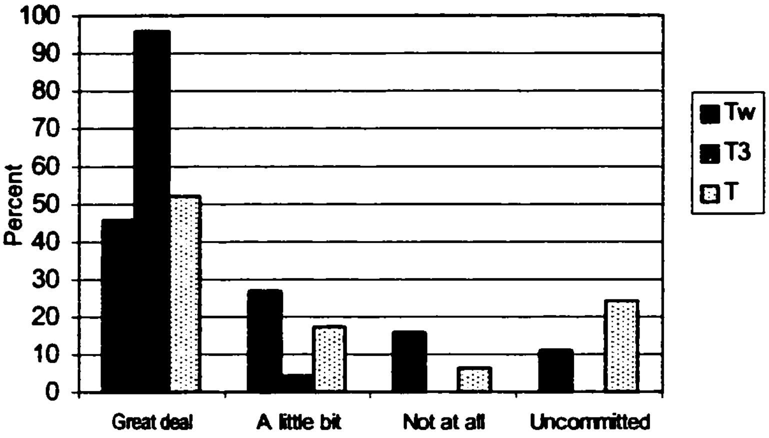


Figure 7-2. Students' self-report on how they benefited from MAP.

7.4.2 Under What Conditions Is MAP Effective?

The Term-B treatment class produced a g value over two times larger than the two treatment classes in Term-A and almost all students felt MAP was helpful. This dramatic difference leads me to question why this happened. To answer this question, I will look into the instructional processes of the treatment classes. Based on class observation,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

important differences could be detected between the T3 class and T1 and T2 classes on the strategy of teaching concepts and how MAP applets are used. The T3 instructor received his doctoral degree in science education, and he was quite familiar with the student preconception theory. Whereas the T1 and T2 classes generally had a traditional format of instruction, which stressed traditional problem solving, the T3 class was different. The T3 instructor could properly address preconception issues and promote student involvement in the construction of concepts. The interaction between the instructor and the students was more frequent and effective. In one of the T1 and T2 classes, for instance, the instructor asked students to predict which direction the ball would go after cutting the string. When the first responding student gave the right answer, the instructor moved ahead right away. It would appear that for him the purpose of questioning students was to get a right answer rather than students' understanding. For the same question, however, the T3 instructor held on for a while after a student gave the correct answer. He questioned more students until most of the possible student concepts were addressed, and then he worked on these students' concepts one by one.

The T3 instructor was one member of the MAP team. He understood the purpose of each applet. He used applets in quite a different way from the other two instructors. Except for a limited number of cases, the T1 and T2 instructors used applets as new information-presenting tools. Through applets, students could see what happened, but they were not encouraged to make predictions. Applets were primarily used as examples of knowledge application. In contrast, the T3 instructor could smoothly orchestrate applets. He quite often used applets to organize the lecture and involved students in thinking. He could use the same applet for different topics associated with it. For instance, the T3 instructor used the "collision" applet in teaching Newton's 3rd law and the motion of the mass centre. In addition, through the attached functions of auto data collecting, graphing, and integrating the area under a graph, the T3 instructor used this applet to help students visualize the impulse-momentum theorem. He discussed the

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

energy loss, the categories and many more aspects of collisions. Instead, the T1 and T2 instructors used this applet only to help students visualize the process of collision and presented quantitative questions for students to solve (assigning initial velocities to balls and asking for the final velocity).

One of the two treatment class instructors in Term-A was also the instructor of the treatment class in Term-C. Exploring his two sessions is even more informative for us to understand the conditions under which MAP is effective. In the Term-A test, his class was not significantly different from the control classes, but in the Term-C test his class was significantly better than the control class. To investigate the reason, I interviewed this teacher after Term-C. One part of the recorded dialogue went like this:

> *R: In [Term-A] your class did better than control classes, but the difference was not significant. In [Term-C], however, the difference [between your class and the control class] turned out to be significant. Can you figure out any possible reasons for these different results?*
>
> *T: We had better students in [Term-C]. They were highly motivated. They knew they would use what they were learning.*
>
> *R: You are right. But I compared your classes with other classes from the same background. In [Term-A] I compared your algebra-based class with other algebra-based classes. In [Term-C] I compared your calculus-based class with another algebra-based class.*
>
> *T: I mean, better students can learn more. I put the MAP site onto the course web site. Students could access them anytime they wanted to.*
>
> *R: You mean better students will get more when we supply them with a chance?*
>
> *T: Yes.*
>
> *R: This is one possible reason. Do you think there is any difference in the way you used MAP in [Term-C] compared with [Term-A]?*
>
> *T: Of course. When you first used it, you did not know what it was for. I used applets more often in the beginning of the class in [Term-C]. If I used applets after the theory, students would not pay attention to them. They already knew what would happen.*
>
> *R: They are not curious anymore.*

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

T: No.

He was honest when he described his different ways of using MAP applets in two terms. According to my class observation records, in Term-A he taught new concepts in a traditional way and used applets after he taught the concept. On the contrary, in Term-C he quite often used applets in the exploratory stage of conceptual construction. Here is an example. There is an applet about friction (Figure 7-3) which was developed for teaching such concepts as static friction, maximum static friction, and kinetic friction. Students can use the computer mouse to pull the force probe. At the beginning, the probe has a reading, but the books do not move because of the static friction. When students pull harder and the reading increases to one point (maximum static friction), the pile of books starts to move; and suddenly, the probe's reading drops down to a smaller value (kinetic friction). Students can turn on the free body diagram. This diagram allows students to see the change of friction during the whole process (Figure 7-4). Through increasing or decreasing the number of books, the applet can also be used to investigate the relationship between the friction and the normal force. This applet is an excellent helper for constructing knowledge of friction. In Term-C the teacher launched this applet at the very beginning when he taught friction. Through this applet, he successfully demonstrated students' life experiences with friction, such as pulling a table on a floor; visualized the force change in the process; and offered students detailed ingredients to construct relevant concepts and knowledge. On the contrary, in Term-A this teacher used the same applet to verify what he said about friction.

The above analysis leads me to conclude that MAP is more functional in a constructivist's teaching environment. The computer applets are not very useful by themselves. They work best only when they are included in the right spots in teaching. It is no wonder that the same project can have different results when used by different teachers. They teach in a different style and use applets in a different way.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Figure 7-3. An applet about the friction force.

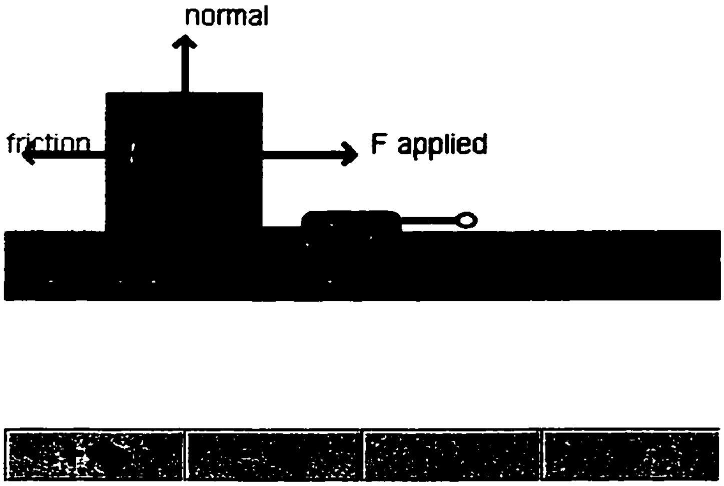


Figure 7-4. Friction applet with the free body diagram turned on.

7.4.3 Why Our Instruction Tends to Degrade Students' Attitude Toward Physics

Although I was surprised when I first saw the attitude data, it was indeed not unusual for our traditional teaching. According to my class observation, the following vivid description would apply to the classes studied in Term-A:

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

> We require the students to buy textbooks of encyclopedic dimensions, and then we use lecture time to present what is printed in the text. We write the material on the blackboard, and students copy it into their notebooks. If we are lucky they can follow the first 15 minutes of the lecture. If they lose the thread somewhere—and this is bound to happen sooner rather than later—note taking becomes completely blind: "I'll think about it later." Unfortunately, the thinking is not always happening, and many students resort to memorization of the equations and algorithms copied in their notebooks (Mazur, 1996, p.1).

A great part of the lecture time was occupied by giving examples; and, more worrisome, the examples were given in similar formats and were too detailed in derivation. Students were kept busy copying what was on the board into their notebooks, and they had limited time for thinking. As Mazur (1996) said, "Many bad study habits are a direct result of the lecture system" (p.1). When Dr. Brouwer tried his new way of teaching (which was to let students suggest a method for problem solving and then do it the way the student suggested; if it leads to an incorrect solution, analyse where we went wrong), some students were puzzled and commented, "Dr. Brouwer, why don't you just do the problem the right way? We don't have to learn how not to do it" (Brouwer, 1995b, p. 293). When half of the university students who took three semesters of traditional physics instruction stated, "All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems" (Redish & Steinberg, 1999, p.7), the people to blame should not be our students. A number of quantitative examples follow every introduced formula, and the exam asks students to solve similar questions. This has led students to think that learning physics is learning to use the formulas. In this case, it is unlikely to expect students to take as the goal "an understanding of the limitation of those formulas or the relation of the formula to fundamental principles and concepts" (Redish & Steinberg, 1999, p.7).

Students focus on the recipe for traditional problem solving. Unfortunately, no single strategy works for all questions if they do not have a deep conceptual and qualitative understanding of the physics process and concepts. When, just after a lecture,

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

a student pointed to the board and told me sadly, "I can 'understand' what is on here, but I have problems with assignments and exams. I did poorly on the midterm," I knew what she meant by the word *understand*. She could follow the derivations of the sample question the teacher gave on the board, but she did not in fact understand the question. She did not know much about the following questions: What is the nature of the phenomenon in the question? How many steps does the whole process involve? How could the process be represented qualitatively in physics language? When students remember the recipe and put their faith in it, but it does not work in the critical moment (as in an exam), what do the students feel? Frustrated! How boring physics must be when it is portrayed as a set of recipes that do not even work all the time! What an unfair treatment it is to the colorful aspects of physics! No wonder our students come into class with interest and thirst for physics, but leave with a feeling of annoyance.

Fortunately, in certain modified learning environments student attitudes do show movement in the favorable direction. Redish and Steinberg (1999) reported that, in the workshop physics they studied, students showed a slight improvement in the cognitive attitudes on learning physics. Consistent with this finding, in the post attitude test, a much higher percentage (88%) of students in the T3 class thought physics was interesting and a much higher portion of students (95%) had a favorable attitude toward physics than Cw and Tw groups in Term-A. Redish et al. suggested that it was the guided group investigation that might contribute to the improvement of student cognitive attitudes in the workshop physics. I think some features of the T3 class instruction might be the reasons why more students loved and trusted physics in the T3 class, including the frequent in-class interaction between the teacher and the student, applying physics to real-life problems, and linking classical physics to modern physics.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

7.5 Conceptual Understanding and Problem Solving

7.5.1 Correlation Between Conceptual Understanding and Problem Solving

Conceptual learning and problem solving are two of the main goals of science instruction. When scholars advocate more emphasis on conceptual learning, others wonder whether this will happen at the cost of student ability in problem solving.

I quantitatively investigated the correlation between conceptual-learning and problem-solving achievements by comparing the FCI-Plus results and the combination of the midterm and final exam scores for each treatment class in Term-A, Term-B and Term-C tests. The correlation coefficients for the four treatment classes (T1, T2, T3 and T) are 0.481, 0.564, 0.678, and 0.539 respectively. All four numbers are significant at the 1% level (Tables 7-14, to 7-17). Mazur (in press) reported that the peer instruction approach improves student mastery of both conceptual reasoning and quantitative problem solving simultaneously. Consistent with this report, my results show that conceptual teaching and learning do not necessarily happen at the cost of teaching using problem solving.

Table 7-14

Correlation of Conceptual Learning and Problem Solving (T1)

Correlations

		TOTAL	POSTTEST
TOTAL	Pearson Correlation	1.000	.481**
	Sig. (2-tailed)	.	.000
	N	84	82
POSTTEST	Pearson Correlation	.481**	1.000
	Sig. (2-tailed)	.000	.
	N	82	82

**. Correlation is significant at the 0.01 level (2-tailed).

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 7-15

Correlation of Conceptual Learning and Problem Solving (T2)

Correlations

		TOTAL	POSTTEST
TOTAL	Pearson Correlation	1.000	.564**
	Sig. (2-tailed)	.	.000
	N	97	93
POSTTEST	Pearson Correlation	.564**	1.000
	Sig. (2-tailed)	.000	.
	N	93	96

**. Correlation is significant at the 0.01 level (2-tailed).

Table 7-16

Correlation of Conceptual Learning and Problem Solving (T3)

Correlations

		TOTAL	POSTTEST
TOTAL	Pearson Correlation	1.000	.678**
	Sig. (2-tailed)	.	.000
	N	25	25
POSTTEST	Pearson Correlation	.678**	1.000
	Sig. (2-tailed)	.000	.
	N	25	25

**. Correlation is significant at the 0.01 level (2-tailed).

Table 7-17

Correlation of Conceptual Learning and Problem Solving (T)

Correlations

		TOTAL	POSTTEST
TOTAL	Pearson Correlation	1.000	.539**
	Sig. (2-tailed)	.	.000
	N	66	57
POSTTEST	Pearson Correlation	.539**	1.000
	Sig. (2-tailed)	.000	.
	N	57	58

**. Correlation is significant at the 0.01 level (2-tailed).

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

7.5.2 Features of Students' Problem Solving

Based on my experience in my physics clinic and as an assignment marker, I find that students' troubles in problem solving result from several disadvantages. First, students do not have the necessary skills for physics problem solving. They do not know where they should start. "So many variables; how can I know which variable I need to find out from which process?" Susan complained when she came to my clinic for help. For the question involving two masses hanging through a fixed pulley, students do not know how to set up the coordinate system. "Do we need to know which one is bigger, M1 or M2, for us to decide if the acceleration is upward or downward?" one student asked in the class when the teacher set up the coordinate upward. He did not know that the setup of a coordinate was not absolute at all, but was determined by convenience. Second, language is an obstacle for some students in problem solving. They have difficulty in understanding what the question is asking. They often fail to notice the known variables hidden in the text. The following is one example. A boy climbs onto a board sitting on two supports and walks to one end. The question asks students to find out how far the boy is from the end when the board starts to tip. Some students failed to know that "start to tip" means that one normal force exerted by the two supports is equal to zero. Third, students have problems with calculation, especially for the extremum questions. They don't know how to find the maximum or minimum value from an equation. Fourth and most important, students do not conceptually understand the process in the question. This problem is clearly demonstrated by students' assignments. They start the adventure with numbers instead of a qualitative analysis. They change to different equations when they discover that the equation with which they started does not work. I could often see students cross out lines and start a new trial on the assignment book. When I asked Sara what she tries to do when she has a question to solve, she said:

> *I start with numbers. Substitute the numbers into the equation. If it works, I am glad, but quite often it does not work. I get frustrated. When I get frustrated, I*

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

> *cannot concentrate on the question. Although I try a second time, it is often no use. I get even more frustrated. Finally I have to give up it.*

I knew that she meant variables by "numbers," and I said:

> *R: Your strategy may work when the question has only one or two numbers. If the question has more than two numbers, it very likely does not work.*
>
> *S: Exactly. I can solve the simple questions in the book, but I always have trouble with the complex questions such as questions in assignments.*

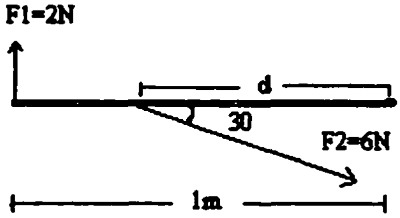


Figure 7-5. A lever in equilibrium with two forces acting on it.

For a very simple situation illustrated by Figure 7-5, students are asked to find the distance d. The following equation is often the first line of students' solution: $2\times 1-6\times d\sin 30^0=0$. They skip the step of $F_1l_1-F_2l_2=0$, which represents qualitative understanding. One day Jennifer came to my clinic for her assignment. She came to ask the following question: A moving car plows into a stationary car and then the two cars move together as a unit. Students are asked to find out how much the common velocity is just after the collision.

> *R: Tell me what you did for this question please.*

This is my routine in my clinic. For whatever question students have, I always encourage them to express their thinking to me first so that I can find out where they went wrong. On the other hand, thinking aloud supplies students with an opportunity to realize their errors.

> *J: I know I need to use the conservation law of momentum.*

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Then she wrote down the equation $p_1 = p_2$ on a scrap of paper and told me how she found the answer:

> *R: Great!*
>
> *J: But, it does not make sense to me.*
>
> *R: What do you mean?*
>
> *J: Do you think the momentum conserves in a completely inelastic collision? I believe it conserves in an elastic collision. Two balls collide and separate.*

So I did the deduction of the conservation of momentum which had been done by the instructor in the class, and I reminded her that we did not assume anything about the collision (whether the balls stick together or separate) when we did the deduction. She nodded, but I could see she was still struggling to understand.

> *J: When a ball hits another ball like this [she drew a graph: moving pendulum 1 hit initially static pendulum 2], if the balls exert equal forces on each other, the net force is zero. How can the balls move?*
>
> *R: Can you say that again?*
>
> *J: I think ball 1 will exert a bigger force on ball 2. The net force keeps them moving forward.*

Aha! Here is the problem. She distrusted Newton's 3rd law and thought that force was needed to keep the pendulum moving.

> *R: Do you think we have to have force for motion?*
>
> *J: Don't we? I apply a force on the pen. If the force is bigger than the friction, the pen moves.*

I could not remember how many times students had done this kind of demonstration to present an argument. Similarly, I used a demonstration to convince her. I pushed the pen hard and said:

> *R: Even though I stop pushing, it keeps moving for a while.*
>
> *J: Because you give it initial velocity.*

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

R: Yes, the initial kinetic energy keeps it moving. It finally stops because of the friction.

J: Okay.

R: For the case of the ball collision, the system has initial kinetic energy. During the collision, the system loses some, but not all of it. The remaining kinetic energy keeps the two balls moving forward together.

J: I see.

R: The two balls exert equal forces on each other. That is Newton's 3rd Law. Over 60% of students incorrectly think ball 1 exerts a bigger force on ball 2.

J: I am glad to hear that.

From this interview record, we can see that the traditional assignment may be useless for some students even though they reached the right answer. They do the assignment by modeling the example that the teacher gave in class, with little understanding. They pick up the equation they learned in the class. They know this because the equation learned in class is supposed to be used in the follow-up assignment.

Here is another typical example. After he taught the centre of gravity in one class, a teacher included the following question in the follow-up assignment. A person sitting with one leg outstretched so that it makes an angle of 30.0° with the horizontal. The weight of the leg below the knee is 45.0 N with the centre of gravity located below the knee joint (figure 7-6). The leg is being held in this position because of the force M applied by the quadriceps muscle, which is attached 0.10m below the knee joint. Students are asked to obtain the magnitude of M. David came to the clinic for this assignment. He wanted me to clarify the concept of the centre of gravity for him. But his real question was, "How can I use this equation [the definition of the centre of gravity] in this question?" I was fooled for a while by his question. The possible explanation for his question is that he did not understand the concept of the centre of gravity at all. Because he saw the phrase "centre of gravity" in the question, his first response to these words was to figure out how to use the equation.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

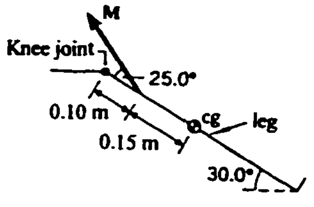


Figure 7-6. A drawing about a person sitting with one leg outstretched.

7.6 Suggestions for Teacher Education

When I was sitting in the classroom and watching the communication between the teacher and students, I often felt that some of our university teachers might not be ready to teach although they might know a great deal about the subject matter. They seemingly did not know how to encourage students to participate in the class, they did not pay enough attention to what students learned from the class, they were not aware of the importance of metacognition, and they did not show enough enthusiasm for the new instructional technology. Based on the evaluation results, my class observations, and my communications with teachers and students, I will provide suggestions for today's college teacher education (might be valuable for teacher education at the secondary level as well) in four areas: more pedagogical knowledge, more interest in appropriate use of new instructional technology, more meta-cognitive knowledge and skills, and a more conceptual way of teaching problem solving.

7.6.1 More Pedagogical Knowledge

In Alberta, Canada, students must receive a teaching certificate before they teach in schools. To get this certificate, students need to have a minimum of forty-five credits from a faculty of education. However, people can become college or university lecturers

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

without any education training. They hold high academic degrees in a subject area, but they do not know much about what is going on in cognitive or pedagogical studies. Teaching without pedagogical knowledge quite often relies on the knowledge structure of the subject, which receives much criticism from cognitive study, or is based on personal learning experience. Redish (1994) reminded us of the danger of this latter kind of teaching: "Our (physics teachers') own personal experiences may be a very poor guide for telling us what to do for our students" (p.10). Physics teachers normally have more than 10 years of special training in physics and make up a very small number in school classes. The experiences of a small group with intensive special training could not inform us much about the learning of students who make up the larger part of the class. Redish cited his own story as a footnote to his argument:

> I will never forget one day a few years ago when a student in my algebra-based introductory physics class came in to ask about some motion problems. I said: "All right, let's get down to absolute basics. Let's draw a graph." The student's face fell, and I realized suddenly that a graph was not going to help him at all. I also realized that it was going to be hard for me to think without a graph and to understand what was going through the student's mind (p.10).

In my research I found that teachers without educational training may have quite different perspectives on teaching from those with educational training accepted by cognitive scholars. On the way from the class to the office, the following dialog occurred between one of the Term-A treatment class teachers and the researcher:

> *T: Is it boring? It is old stuff for you, [the teacher asked me].*
>
> *R: No. You know I am not learning physics now. I am learning how students learn and how teachers teach, especially on concepts.*
>
> *T: Unfortunately, not much is on concepts for this course; lots on problem solving.*

This informal talk clearly exposed the teacher's perspective of conceptual learning and teaching. His comment was quite far from the cognitive study results which tell us that students have great difficulty in learning mechanical or heat concepts. We

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

could not expect them to put much emphasis on concept teaching as intensive studies have suggested.

7.6.2 More interest in New Instructional Technology

New instructional technology, especially computer-based multimedia, has been stepping into the classroom. Teachers need to accept this. We tend to teach the way we were taught. This fundamental resistance to new things stops us from fully exploring the function of new approaches. In addition, the T3 instructor was one of the MAP designers and T1 and T2 instructors used MAP for the first time in Term-A. Therefore, the difference between the T3 instructor and the T1 or T2 instructor in attitudes toward MAP was obvious and expected. Sitting in the class, I could clearly feel the passion the T3 instructor had for the MAP applets. Applets were an essential part of his lecture design. They were integrated with demonstrations, blackboard draft and drawing, and other components. In the cases in which the computer crashed and applets could not be downloaded, the teacher showed patience and tolerance with technology by commenting that "Well, sometimes technology has problems." I had a very different feeling in the treatment classes of Term-A. The instructors often failed to run applets correctly. They did not know where and how the applets were supposed to be used effectively. They sometimes asked students to predict, but failed to show the difference between the prediction and the actual result. The applets were used as a kind of decoration in the traditional framework of instruction rather than as a part of the rail leading to the construction of knowledge. In the cases in which the computer crashed, the instructor continued his teaching with a comment of "We'd better get rid of it."

Relating the difference of instructors' attitudes toward MAP to students' attitudes is interesting. In the in-class survey, 88% of the T3 class students reported that they liked MAP a great deal, and 12% liked it a little bit; no students disliked it. In contrast, only 50% of Tw (T1 and T2) students reported that they liked MAP a great deal, and 27% of

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

the students liked it modestly; 9% did not like it at all. The remaining 14% were not committed. These percentages were structurally similar to the student-reported effectiveness of MAP in terms of helping them to learn concepts (Table 7-18). Obviously, T3 class students liked MAP more and benefited more from MAP than Tw students. Given the difference between the T3 instructor and the Tw instructors in their attitudes toward MAP, I tend to conclude that the teachers' attitudes could greatly impact students' attitudes and, through it, impact students' learning. If we want students to benefit from new technology, our teachers must like it first.

In Table 7-18, the T class lies somewhere between the Tw group and the T3 class in terms of students' attitudes toward MAP and the level at which students benefited from MAP. This provides further evidence for the conclusion above considering that the appreciation of the T class instructor toward MAP improved with experience but was not yet as positive as the T3 instructor. As described in the previous section, the T class instructor used MAP for the second time in Term-C and used it more effectively than he did in Term-A. It is reasonable to assume that he had a stronger appreciation of MAP in Term-C because of his prior experience with the applets. However, it is difficult for him to become as committed to MAP as the T3 instructor since he was not one of the MAP designers.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table 7-18

Structural Similarity Between Survey Results on How Students Liked MAP and on How Students Benefited From MAP

Survey results on how students liked MAP (%)				
	A great deal	A little bit	Not at all	Uncommitted
Tw	50	27	9	14
T3	88	12	0	0
T	61	7	9	24
Survey results on how students benefited from MAP (%)				
	A great deal	A little bit	Not at all	Uncommitted
Tw	46	27	16	11
T3	96	4	0	0
T	52	17	7	24

7.6.3 The Idea of Meta-Teaching

As we discussed in Chapter 3, meta knowledge is important in learning. Physics instructors observed, however, for the most part did not show their readiness for meta teaching. In the following vignette we can see an example of unsuccessful communication between a teacher and a student caused by the teacher's failure to address the nature of instruction.

The class began with a displacement vs. time (x-t) graph (Figure 7-7). Students were asked to think about what the velocity vs. time (v-t) graph looks like, then the acceleration vs. time (a-t) graph. No students responded to this question. The instructor drew Figures 7-8 and 7-9 and gave an oral explanation of what he was doing. Basically, the explanation was such that the slope of the x-t graph was velocity and the slope of the v-t graph was acceleration.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

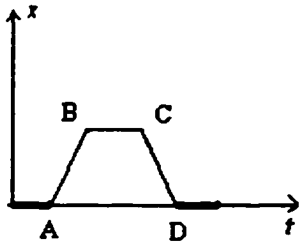


Figure 7-7. x-t graph

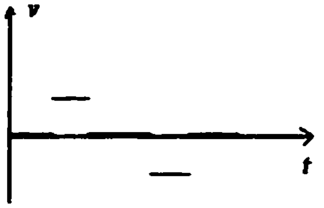


Figure 7-8. v-t graph

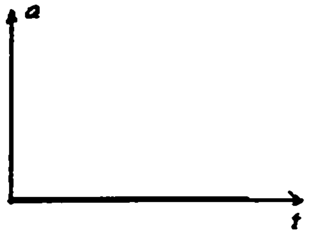


Figure 7-9. a-t graph

Then the class moved to the derivation of the five equations of motion with uniform acceleration. One example of problem-solving followed. The question described a spaceship that was accelerated by g from the Earth to the moon. At the middle point the acceleration turned to –g. The distance was given between the Earth and the moon. Students were asked to calculate the time the spaceship would take to arrive at the moon.

> *T: Symmetry is helpful here. We can just calculate the time for the halfway, then double the value. [The teacher is explaining the solution.]*
>
> *S: What is the acceleration at the middle point?" [A female student interrupts the class.]*
>
> *T: We do not consider the middle point for this question.*

Then the class moved on to another example. The class time was over when the calculation was almost done, and students were busy leaving the classroom. I turned to the girl who asked the above question and decided to interview her. I became anxious when students poured into the aisle between her and me, but I comforted myself by saying to myself, "I can interview her sometime later." Fortunately, she had no intention of leaving. After the aisle was clear, she approached the platform. The instructor was answering some students' questions, and I went there too. It was now her turn. She asks questions about the v-t and a-t graphs that the instructor had presented at the beginning of the class.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

She asked, "If the acceleration is zero, how can the car start to move at point A, then stop at point B, and then move again at point C? What happened at points A, B, C, D?" The instructor responded,: "This is an ideal situation. In real life the graphs should be like this." The teacher quickly drew Figures 7-10 , 7-11, and 7-12 on the board.

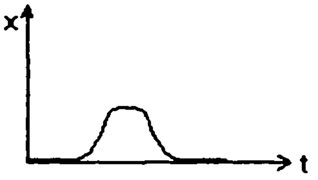


Figure 7-10. x-t graph

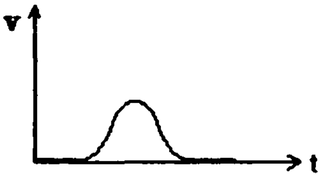


Figure 7-11. v-t graph

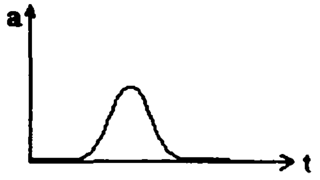


Figure 7-12. a-t graph

Although the teacher made mistakes on the v-t and a-t graphs, he touched on the point, ideal situation. Unfortunately, I could tell from the student's face that she was not convinced. The following class was about to begin, and students came into the classroom. The instructor had no time to realize his mistake and observe the student's feelings about his explanation. We stepped out of the classroom. The student was waiting to warm her lunch in the lounge, and I took a few seconds to prepare myself, then I said:

> *R: Just now you asked questions about the x-t graph.*
>
> *S: Yes. Were you convinced? I was not convinced. [She continues,] When we throw up a ball, at the top the ball stops, but the acceleration is still there. Otherwise, the ball cannot change from going up to falling down. How can the car start to move from stop without acceleration?*

So far, I have been quite clear about her cognitive difficulty.

> *R: Your thinking is right!*

I wanted to let her know that her understanding was correct. Wasn't it? She was a good student and learned well. She could link all of the questions together: the spaceship example, the x-t graph, and the ball thrown up into the air. My comment made her eyes

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

bright, but I could see that she wanted to question. I continued before she asked her question because I knew what she was going to ask must be about the difference between her thinking and the teacher's graphs.

> *R: In the real-life question, we do need time for the car to be accelerated from stop to a certain speed. But this question is an artificial question. It is designed to test your special knowledge about the relation among displacement, velocity, and acceleration. It is not focused on the turning points A, B, C, D. All the questions we will see in class will be somewhat artificial. There is a gap between education and real life.*

Then I drew Figures 7-13, 7-14, and 7-15 for the real life situation.

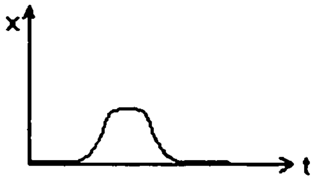


Figure 7-13. x-t graph

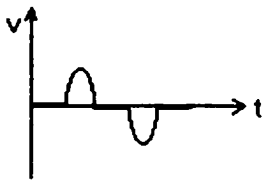


Figure 7-14. v-t graph

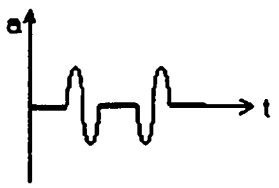


Figure 7-15. a-t graph

This vignette tells us much. For effective teaching, the teacher needs to think the way that students think, rather than forcing his/her ideas on the student. It is important to encourage students by affirming their correct reasoning. But there are not the points I want to draw from this vignette; I want to address the importance of meta teaching. We have many moments when we should teach students something, but we miss them. For example, in the class, when Carol asked a question about the spaceship, it was a good time to teach students something about teaching and learning. Helping students to become familiar with the special way that a discipline addresses problems and to be able to figure out the questioner's intention can be very important for students' success in school. This meta knowledge is helpful for students to understand what happens in the classroom and to become more sophisticated and self-regulated learners.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

At this moment a story about myself comes to mind. In the first term of the first year of my high school, my physics teacher assigned students a problem to work on. The question tells students the initial speed and the acceleration of a car when it climbs a hill, and they are asked to find the time required for the car to reach the top. This is a very simple kinematics question. However, I fell into a trap by continuing to think of the effect of gravity: The gravity will slow down the car! I did not know why the question had the car on the slope instead of on a flat road, and when I asked my teacher for an explanation, he told me, "You need not consider gravity here" and "You will learn this in the next chapter." But his explanation did not address my curiosity.

7.6.4 Conceptual Way to Teach Problem Solving

Problem solving is important not only because it is an essential step for students to practice what they learn, but also because it is a valuable way to teach for understanding. In the history of science, scientists created and developed theory while they solved a variety of problems, theoretical and practical. Problem solving therefore has two dimensions: applying knowledge and creating understanding. The popular strategy in science education—namely, the project approach—is on the right track in terms of the second dimension. Unfortunately, in our traditional teaching, problem solving is most often employed for knowledge application only. After almost every equation, teachers give students examples of problem solving in detail. Teachers write down all the steps of derivation on the blackboard, and students are kept busy copying them in their notebooks. These examples function as models for assignments. In one class in which I sat, the instructor announced a *recipe* (the teacher's word) for solving dynamics problems, including free body diagrams, equations, and calculations.

To teach problem solving for deep understanding calls for a different format of instruction, a more conceptual way of teaching problem solving. Compared with teaching problem solving by modeling, the conceptual way does not focus on the recipe for

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

problem solving, but rather on understanding the problem. It does not start with a free body diagram, but with the conceptual description and qualitative understanding of the process. It is open to students' questions or ideas, instead of hurrying to cover more examples. It extends the problem into a big context instead of constraining it within a traditional textbook style. In the following Table 7-19, I show, what I believe to be, the differences between the two approaches for teaching problem solving.

Table 7-19

The Differences Between Two Ways of Teaching Problem Solving

	Modeling way of teaching problem solving	Conceptual way of teaching problem solving
Focus of teaching	Recipe for problem solving	Understanding of the process of the problem
Function of teacher	Supply a model of problem solving	Teach for understanding
Process of teaching	No interruption, cover more examples	Open to students' questions or ideas
Format of teaching	Highly formatted	Flexible
Role of students	Copy what the teacher writes on the blackboard	Actively participate in problem solving
Problem solver	The teacher only	Teacher and students
Context of problem	Traditional format of textbook questions	Link to real-life context
Number of problems	Many	A few

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Following are some effective and non-effective examples I collected from the classes in terms of teaching for deeper understanding. One non-effective example happened in a class of circular motion. The teacher swung a ball and asked the students what force the ball exerted. Among other answers, one voice said, "Weight." "We do not consider weight now. We will discuss it later." the teacher replied and continued the class. But the teacher never came back to this question later in the course.

Another non-effective example happened in a class of rotational motion. The teacher was working on an example of problem solving which described a ball rolling down an incline without slip. The problem is to find the velocity of the ball when it gets to the bottom of the incline. "Since there is no friction, we could apply the conservation of energy," the teacher said. He wrote down the equation on the blackboard and started to substitute values into the equation.

> *If there is no friction, how can the ball roll down without slip? [a student questioned the teacher].*
>
> *The friction is small. It is negligible [the teacher replied and then continued the calculation].*

When students ask questions, teaching them at these moments can be much more effective than the traditional presentation. In these two examples I felt regret for the missed opportunity to teach something. In the first example we miss an opportunity to explain a fundamental principle of physics—simplifying real-life phenomena to physics problems: What kinds of factors can we ignore in what kinds of situations and for what kinds of purposes? In the second example the student was correct. We miss an opportunity to correct our own mistake. I wrote in my notebook after the class, "When can our teaching be driven by students?"

One effective example happened in a different teacher's class on circular motion in which the teacher discussed a problem of driving a car on a banked road. The teacher did not write down the question (including numbers) on the blackboard at the start. He asked, "How many of you have driven on Fox Drive?" Many students raised their hands. Then the teacher reminded them of the section of the Whitemud Freeway to Fox Drive (banked and curved) and qualitatively discussed with them why the road is banked and why there are speed limits on these banked sections. Finally, the teacher listed some numbers and did the calculations for the speed limit.

Another effective example happened in a class about collision. The question described a golf ball bouncing down a flight of steel stairs. Assuming all of the collisions with the stairs are elastic, the question asks students to find the height the ball can bounce from the bottom of the stairs. The answer was found to be that the height of the bounce is the same as the vertical height of the staircase. The teacher, however, did not stop there. He reminded students of the difference between this answer and their experience. Students had never seen a case in real life that agreed with this solution. A discussion of the assumptions in this question followed.

For these two examples, problem solving is not constrained within the traditional format, but is posited in the real-life context. In the first case the instructor successfully encouraged students to think through an unusual way of problem solving. If the teacher wrote this real-life question in textbook format on the blackboard, the instructional result would not have been as successful because formatting encourages people to follow fixed steps and think less. In this case, students would first try an equation and not think qualitatively. In the second case, the problem solving is extended into evaluation of the solution. Through this evaluation, students get to know how physics works and what its limitations are. It is hoped that this can reduce the number of students who think that physics is useless.

In my physics clinic I applied the conceptual way of problem solving. I took a few steps to help students with problem solving:

1. I encouraged students to tell me what they did with the question.
2. I detected where students went wrong.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

3. I challenged students' wrong ideas.
4. I guided students with step-by-step questions.
5. I reviewed the process.

If students had no idea how to answer a question, I never simply told them how to do it. I believe that students should be the problem solvers; the teacher is a facilitator. I always challenged students to think questions through step by step. Students were excited when they solved the question by themselves with my questioning. I told students that a good process of problem solving generally includes the following steps:

1. Read the question carefully.
2. "Picture" the process.
3. Conceptually/qualitatively analyse the process.
4. Set up equations.
5. Do the calculation.
6. Evaluate the result.

My norm is to make sure that students begin problem solving with a qualitative understanding of the process. In mechanics we too often persuade students to start with a free body diagram. But if they do not understand the physical process, they have trouble drawing the diagram. Even if they draw the diagram, they may not know how to deal with questions involving maximum or minimum values.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

CHAPTER 8

SUMMARY AND REFLECTIONS

8.1 Summary

As I described in Chapter 1, this study includes two related parts. In the first part, including Chapter 2 and Chapter 3, based on the literature review and reflections on my own experiences, I explored the process of conceptual change and discussed the effective format of instruction to promote conceptual change. In the second part, including Chapter 4, Chapter 5, Chapter 6, and Chapter 7, I investigated the effectiveness of computer-simulation-based applets on fostering conceptual change. This part covers my evaluation design, data collection, findings, and discussions.

Taking Piaget's theory about psychological development as a theoretical foundation, constructivists since the 1970s have paid considerable attention to students' preconceptions, which represent students' intuitive understanding of the world prior to formal instruction. Ongoing studies have demonstrated that students' preconceptions spread along the spectrum of science. In some instances students' preconceptions are in keeping with scientific concepts. In most cases, however, there are huge differences between students' notions and school science. Because one of the goals of science education is to promote the appreciation of scientific notions, we should ask the question: How can we help students move from intuitive conceptions to scientific ones? This is my central research topic.

Many studies, including my own (Chapter 6), have documented that students' preconceptions can survive through many years of traditional instruction. For example, according to my study, over 50% of university students from physical science departments still believe that a truck exerts a bigger force on a car than the force the car exerts on the truck during a head-on collision. This is a very common concept among

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

elementary and secondary school students. Since the 1980s scholars have investigated the process of conceptual change and proposed diverse approaches to foster conceptual change, among which Posner's model and the POE approach are the most popular. Paralleling Kuhn's conditions for the occurrence of scientific revolutions, Posner et al. (1982) stated that some conditions must be fulfilled before any conceptual change can occur. These conditions are (a) there must be a dissatisfaction with the old concept, (b) a new concept must be intelligible, (c) a new concept must appear initially plausible, and (d) a new concept should suggest the possibility of a fruitful research program. Corresponding to this model, the POE approach stresses the discrepancy between students' cognition and the actual fact. It requests that teachers give students opportunities to present their predictions, which may lead to cognitive disequilibration.

Posner's model correctly addresses the importance of cognitive conflict for conceptual development but forgets something that is also important. Pintrich, Marx, and Boyle (1993) criticized Posner's model as a "cool" or "isolated" model because it ignores the social and non-rational dimensions of learning. This model assumes that when students become dissatisfied with their original beliefs, they will try to find alternative ones that are intelligible, plausible, and fruitful. It stresses to readers that reasoning happens within the mind of the individuals. As I discussed in Chapter 3, both Piaget's and Vygotsky's theories refute this position. Piaget took the interaction with others as an essential source for constructing social knowledge and as an important source of occasions that cause cognitive disequilibration for constructing mathematical and logical knowledge. Vygotsky went even further by stating that all the knowing occurs in the interpersonal level first before it moves to the intrapersonal level. Many experimental studies also address the importance of peer collaboration. Researchers reported that collaborative learning provides a supportive environment that encourages students to share and examine their conceptions. Group learning not only helps the less knowledgeable students in the group, but also benefits the knowledgeable students. The

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

assumption of Posner's model that students approach their classroom learning with a rational goal of making sense of the information and then coordinate it with their prior conceptions may not be accurate either. Students come to school with different motivations. Their values, beliefs, attitudes, and so on can greatly influence their learning through controlling the selections of topics to which they will open their minds. Therefore, not all the events that are "well designed" by teachers for cognitive disequilibration work for all students. The cultural concern in science education might provide a third standing point to examine the disadvantages of Posner's model. Scientific concepts, in some cases, have conflicts with cultural views that greatly influence all aspects of people's lives. The phrase *change concept* as a goal of teaching seems too arbitrary and ambitious. On one hand, it does not show enough respect to the cultural heritage; on the other hand, it underestimates the difficulty of the task. These disadvantages of Posner's model lead me to think of a more sophisticated model for science education, which is called Post-Posner's model. In this model, supplying discrepant events and introducing a new intelligible, plausible, and fruitful concept are not everything. Instructors should motivate students to work together and promote the appreciation of scientific concepts. Metacognition is treated as a serious component of the teaching. What I mean by this model is explicitly illustrated in the argument format of science instruction that I proposed in Chapter 4. This new format of science instruction includes six steps: (1) presenting problem context; (2) eliciting preconceptions; (3) creating cognitive conflict; (4) introducing scientific notions; (5) defending the scientific concepts; and (6) evaluating. This argument format of instruction takes conceptual change as a result of argumentation in the classroom community, rather than simply replacing students' conceptions with scientific ones such as replacing a worn-out part of a machine with a new part. In the process of argument, both students' conceptions and scientific ones are examined, investigated, and evaluated; metacognition is addressed;

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

and students are highly involved in the construction of knowledge. Regarding the advantages of argument, Driver et al. (2000) suggest:

> In science, we contend that there is a mounting body of evidence that approaches of the teaching and learning of science, based on conceptual challenge and the presentation of anomalous data, are of themselves ineffective. Rather, it is our view that conceptual change is dependent on the opportunity to socially construct, and reconstruct one's own personal knowledge through a process of dialogic argument. Such occasions, rare as they are, do occur in science lessons when students are given the opportunity to tackle a problem in a group, or where, in a whole class situation, the teacher orchestrates a discussion to identify different lines of thought and invites students to evaluate these and move toward an agreed outcome (p. 298).

In the second part of my study I investigated the effectiveness of a computer-simulation-based project (MAP) in fostering conceptual learning. The impact of MAP on students' attitudes toward physics was also investigated. The important role of a cognitive conflict for conceptual change has been well accepted. To invoke a cognitive discrepancy, teachers can use demonstrations or phenomena that require students to explain or make a prediction. Interactive computer simulations can also be used for this purpose. They have the additional advantage that students can freely explore the microworld of the program by challenging the parameters and variables and visualizing immediately the consequences of their manipulations of the program and compare them with their own conceptions. With this assumption in mind, in the MAP project our group has built up a set of highly interactive simulations that address students' common preconceptions. Through these simulations, students can make a hypothesis, test it, and reconcile any discrepancy between their ideas and the observation in the micro-world. When students work together on these simulations, they have opportunities to examine different hypotheses and test them. As such, it is possible for these simulations to foster conceptual change. This is the desire of the MAP team and is also the hypothesis of the second part of my study.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

My intensive investigation of the MAP project lasted three terms and involved ten classes, about eight hundred students. I integrated quantitative and qualitative methods for this study. In more detail, I administered the Force Concept Inventory (FCI)-Plus and an attitude survey to each class before and after a course to investigate the impact of MAP on conceptual learning and students' attitudes. I interviewed students to gain deeper insight into students' conceptions and attitudes. I did class observation to explore under what conditions the MAP project works more effectively, which is the exploratory question in this part of my study. In addition, diagnosis in my physics clinic, review of students' assignments, and collection of students' writing through email provided me with substantial information for my study as well.

In my study, all the treatment classes produced a larger normalized gain (g value) in conceptual understanding tests than did the control classes, although the instructors of the treatment classes were generally less experienced in teaching compared with those of the control classes. I therefore conclude that MAP is capable of helping conceptual teaching and learning. The data analysis based on effect size and t-test tells us the same thing. Among treatment classes, their means on FCI-Plus were quite different. To investigate the reason, I analysed my class-observation scripts and discovered that students in the classes whose instructors often used MAP applets at the exploratory stage of a new concept produced a bigger g value than did those students whose instructors used applets at the stage of knowledge application. One teacher's experiences of using MAP in two terms provided very convincing evidence regarding the above conclusion. In the first term he used MAP to teach a physics course. He primarily used MAP applets as examples of problem solving, and his class mean was not significantly different from the mean of the control class. However, in his second trial with MAP he quite often used applets to construct new concepts, and his class produced a significantly different mean compared with the control class.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

I did not find any evidence to say that MAP can influence students' attitudes. In the evaluations of Term-A and Term-C, for both the control and the treatment groups, the percentage of students who thought physics was hard to learn increased after the course; the percentage of students who thought physics was interesting and the percentage of students who believed that physics was a major force for social development decreased. This result was consistent with the statement of Redish and Steinberg (1999) that the percentage of students with favorable attitudes tends to deteriorate as a result of traditional teaching.

8.2 Conclusion

In the theoretical part of my study, based on the literature review and reflection on my experience, I proposed an argument format for science education. According to this approach, teaching should start from where students are. They should be given enough opportunities to express their ideas and approaches to the learning tasks and defend and examine their positions through argument with others in the classroom. Instead of forcing students to buy scientific concepts, the instructor moves to the position of persuading them to appreciate science. Therefore, appreciation of scientific concepts is a result of argument in the classroom. My argument format of science instruction suggests that the events that are applied to foster conceptual change, including simulations, could be used better in the construction or invention stage of a new concept than in the application stage. It is in the construction stage that the instructor creates a space for students to input their ideas and argue with the instructor and classmates. The second part of the study, the evaluation of MAP, supplies evidence for my theoretical study in some sense. Consistent with my theoretical suggestion, I discovered that computer-based simulations work more effectively when they are used in the exploratory stage of a new concept than when they are used in the stage of knowledge application. Technology is not functional by itself for

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

teaching and learning. Only when it is designed and used properly can technology help in education.

Computer simulations, as demonstration and phenomena that require students to explain or make a prediction, can be used as a device for fostering conceptual change. They work more effectively when used in a constructivist's teaching environment, which allows students to be the constructors of knowledge. Students' attitudes toward physics are somewhat independent of the use of simulations. Although most of the studied students showed a preference for the use of simulations in physics classes, this does not necessarily mean that simulations have an impact on students' attitudes toward physics. The use of simulations seemingly did not change students' attitudes toward physics in my research.

8.3 Reflection

8.3.1 Curriculum and Instruction

Teaching should be pre-organized by the teacher but driven by students' understanding. This is the voice of my study. However, my experience in curriculum design and textbook writing in China told me something different. Curriculum design still follows Tyler's (1949) Rationale, which states that four fundamental questions must be answered before developing any curriculum:

1. What educational purposes should the school seek to attain?
2. What educational experiences can be provided that are likely to attain these purposes?
3. How can these educational experiences be effectively organized?
4. How can we determine whether these purposes are being attained?

Four linear steps are normally included in curriculum development: first, defining objectives of the new curriculum; second, selecting and creating learning experiences that will most effectively help students achieve these objectives; third, organizing those

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

learning experiences pragmatically; and, finally, evaluating the effect of using the new curriculum. Students' voices are not really taken into account in any one of these steps. The objectives are formulated by a group of scholars based on their understanding of social needs and students' psychological-development status. Learning experiences are logically organized to meet the objectives. The content-oriented exam is the principle method to evaluate the application of the curriculum. Textbooks in China are still knowledge-oriented. Chinese textbook writers have several criteria in mind for content selection and presentation, including knowledge structure, potential use of knowledge in work, students' capabilities of understanding, students' prior knowledge, and students' learning difficulties. However, to follow these criteria is very difficult when they write a textbook for students all over China. Because there is a dramatic difference in education between regions in China, the criteria of content selection and presentation associated with students—namely, students' cognitive ability, their prior knowledge, and their learning difficulties—actually become useless. Textbook writers have to refer to the abstract "average" level of students. As a result of this, the textbook is suitable neither for urban children nor for rural children. The instruction is still teacher centred. Teachers are always in a hurry to cover the content that they have prepared, and students' questions and inquires are often treated in a perfunctory manner. When students ask questions during the lecture, they will very likely get a reply as follows from the teacher: "I will discuss that with you after the class" or "Come to see me in my office after the class." The teacher does not want to be interrupted during the lecture. If a number of students become puzzled by the new content, the teacher will alter his or her interpreting approaches; that is, students may influence the way their teacher presents the prepared content, but they can never change the topics. Should we not do something to change this situation? And what can we do? In Chapter 3 I gave an example to reform our textbook, but we have much work to do in this direction.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

8.3.2 The Role of Technology in Science Education

A couple of months ago I began to work for an evaluation team. We have a client asking us to evaluate its underdeveloped instructional technology project. It is an expensive project involving many types of new technologies, such as a chat room, whiteboard, and computer-mediated conferencing. After a month's work together, we eventually realized that the project team was more enthusiastic about the cutting edge technology than about our inquiry into the use of technology. Its concern is how to make the project more advanced in technology than other companies' products.

My study indicates that technology cannot be, in itself, effective in education. The same MAP project was not so effective when used in Term-A, but it was very effective in Term-B and Term-C. The comparison of the ways that the MAP project was used by different teachers shows that the MAP project is more effective in a constructivist's teaching environment. Computer-based simulations supply a new possibility of facilitating the argument between scientific concepts and alternative concepts so that they make teaching and learning more effective. Based on this view, the most important issue in instructional technology is how to orchestrate various types of methods to achieve the best effect, rather than how to use the latest technology.

8.3.3 Teacher Education

As I described in Chapter 7, some teachers are not ready for constructivist teaching. They do not have enough pedagogical knowledge and are not familiar with new instructional technology. Sitting in these teachers' classes, I could not tell the difference between what I heard and saw here and what I had heard and seen in my university classes 15 years before. The teacher completely controls the class. The content is presented in a logical sequence, and examples of problem solving are abundant in the lecture that supply models for students to follow.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

In my argument format of instruction, the picture of teaching is quite different from this. Although the topics are premeditated by the teacher, the class agenda should be driven by students' understanding. Conceptual teaching receives enough attention. Qualitative questions replace some of the quantitative questions. Problem solving is taught through a conceptual way instead of a modeling way, which I differentiated in Chapter 7. Overall, teachers should always remind themselves that it is the students who are constructing knowledge, and students should have opportunities to express their ideas. Otherwise, argument cannot happen in class.

Technology opens new opportunities to improve teaching and learning, but some teachers do not like it or do not know how to apply it. They tend to teach in a traditional way in which they feel easier and safer to operate. In my study I found that these teachers did not change their teaching style at all with the use of technology. MAP applets were presented as examples of problem solving and, as one result of this, these teachers' students showed a lower level of interest in MAP and benefited less from MAP than did students whose teachers liked MAP. My conclusion is that if we want students to like technology and receive benefit from it, teachers must like it first and use it effectively. We cannot blame our teachers for their passive attitude toward technology because technology is always changing; furthermore, how to effectively use new technology in instruction is even more subtle and difficult to grasp than the new technology itself. The question we need to solve is what can we do for these teachers so that they can become effective users of the new instructional technology.

8.4 Recommendations for Further Studies

8.4.1 Gender Difference

For the investigation of the Term-A group, I applied a t-test for the gender difference in physics course achievement based on the pre-test and post-test results on FCI-Plus (Appendix G). The control and treatment groups have approximately the same

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

numbers of males and females. The t-test results showed male students had significantly higher means than female students did in all cases (pre-test and post-test, control and treatment groups). The gender gaps in conceptual understanding decreased after the class, but still remained significantly large. Male and female students have different attitudes toward physics as well. Male students have a seemingly greater appreciation of physics than do females. For instance, in the post attitude test, for both treatment group (Tw) and control group (Cw), more male than female students felt that physics was interesting, and fewer male students than female thought that physics was hard to learn (Appendix H). I also found that the correlation among dynamic preconceptions was not parallel between males and females. Some significant correlations for males were not significant for females. The other way around was true too (Appendix I). This finding might suggest somewhat of a difference exists between the two genders' cognitive development.

Further studies could be designed to investigate the following questions: Why are there so many differences between males and females in the physics area? What causes the difference in correlation patterns of males' and females' preconceptions? What can we do to reduce the gap?

8.4.2 Collaborative Learning

Peer collaboration involves more than one student working together on a task that neither could do on his/her own prior to the collaborative engagement. Studies have documented the importance of peer collaboration in learning. Damon and Phelps (1989) contended that peer collaboration provides a supportive environment that encourages students to experiment with and test new ideas and thereby critically re-examine their own conceptions. They asserted that the engagement of peer collaboration is rich in mutual discovery, reciprocal feedback, and frequent sharing of ideas. Crook (1994) suggested that peer collaboration offers three cognitive benefits: articulation, conflict, and co-construction. He argued that in peer collaboration students have to make their intuitive

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

and emerging ideas explicit and public. For the sake of the joint activity, students need to articulate their opinions, predictions, and inter-presentations. The pressure to communicate well with their partners helps them gain greater conceptual clarity. Conflict arises when partners disagree with each other in their ideas and approaches to the task. This conflict forces students into reflection on their own ideas, their partners' ideas, and the task. When partners discuss all the possible ideas and finally reach an agreement, they are co-constructing understanding. In their study on problem solving, Heller, Keith, and Anderson (1992) found that better problem solutions emerged through collaboration than were achieved by individuals working alone. They also argued that the collaboration in solving context-rich problems enhanced students' conceptual understanding of course materials.

From my interviews with students, I discovered that collaborative learning did not happen in our classrooms. Linda, John, and David are three good students whom I interviewed in Term-C. When I asked them about their learning habits, Linda said that she learned more by herself and preferred an equivalent partner for group learning. John and David told me that they also learned by themselves, and they believed that group learning was less efficient. When I marked students' assignments, I did find that some students had worked together. Unfortunately, their getting together meant for some of them that they copied other's assignments without any reflection. These facts suggest further research on the following questions: Why do our good students refuse collaborative learning? How can we promote fruitful peer collaboration in our classroom? Damon and Phelps (1989) claimed that peer collaboration is particularly useful for tasks that require new insights, conceptual shifts, and the development of deep knowledge structure, but that it is not very effective for tasks that rely on formulated and given procedures. Heller and Hollabaugh (1992) found that student groups were more likely to use effective problem solving strategies when given context-rich problems (good examples of context-rich problems can be found in Stinner 1997) to solve than when

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

given standard textbook problems. These findings point to the direction for further studies on collaborative learning: Check the content we are teaching, the approaches we are applying to teaching, the tasks we ask students to do, and the requirements we set up to evaluate students' work. In one word, *investigate* whether what we are doing in teaching favors individual learning or collaborative learning.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

REFERENCES

Adams, P. E., & Tillotson, J. W. (1995). Why research in the service of science teacher education is needed. *Journal of Research in Science Teaching, 32,* 441-443.

Anderson, C. W., & Smith, E. L. (1987). Teaching science. In V. Richardson-Koehler (Eds.), *Educators' handbook: A research perspective* (84-111). New York: Longman.

Atkinson, M., & Burton, J. S. (1991). Measuring the effectiveness of a microcomputer simulation. *Journal of Computer Based Instruction, 18*(2), 63-65.

Ausubel, D. P. (1968). *Educational psychology: a Cognitive View* (1st ed.). New York: Holt, Rinehart and Winston.

Bajracharya, H., & Brouwer, W. (1997). A narrative approach to science teaching in Nepal. *International Journal of Science Education, 19*(4), 429-446.

Bar, V., & Zinn, B. (1998). Similar frameworks of action-at-a-distance: Early scientists' and pupils' ideas. *Science and Education, 7*(5), 471-491.

Bar, V., Zinn, B., & Rubin, E. (1997). Children's ideas about action at a distance. *International Journal of Science Education, 19*(10), 1137-1157.

Berg, T., & Brouwer, W. (1991). Teacher awareness of student alternate conceptions about rotational motion and gravity. *Journal of Research in Science Teaching, 28*(1), 3-18.

Beyer, B. K. (1988). *Developing a Thinking Skills Program.* Boston: Allyn and Bacon.

Brouwer, W. (1995a). Towards a more conceptual way of teaching physics. *Physics in Canada, 51*(1), 56-61.

Brouwer, W. (1995b). The physics lecture. *Physics in Canada, 51*(5), 290-295.

Brouwer, W. (2000). Using historical vignettes to illustrate the nature of scientific discovery. *Alberta Science Education Journal*, 33(1), 13-18.

Brouwer, W., Austen, D., & Martin, B. (1999). The unpopularity of physics lectures. *Physics in Canada, 55*(6), 361-370.

Carey, S. (1986). Cognitive science and science education. *American Psychologist, 41,* 1123-1130.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Carlsen, D., & Andre, T. (1992). Use of a microcomputer simulation and conceptual change text to overcome student preconceptions about electric circuits. *Journal of Computer-Based Instruction, 19,* 105-109.

Chambers, S. K., & Andre, T. (1997). Gender, prior knowledge, interest, and experience in electricity and conceptual change text manipulations in learning about direct current. *Journal of Research in Science Teaching, 34*(2), 107-123.

Champagne, A. B., Gunstone, R. F., & Klopfer, L. E. (1985). Effecting changes in cognitive structures among physics students. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 163-186). New York: Academic Press.

Champagne, A., & Klopfer, L. (1980). *Technical report.* Pittsburgh: University of Pittsburgh.

Clark, R. E. (1994). Media will never influence learning. *Educational Technology Research and Development, 42*(2), 21-29.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics, 50*(1), 66-71.

Crook, C. (1994). *Computers and the Collaborative Experiences of Learning.* London: Routledge.

Damon, W. & Phelps, E. (1989). Critical distinction among three approaches to peer education. *International Journal of Education Research,* 13, 9-19.

Davis, A. B., Sumara, D. J., & Kieren, T. E. (1996). Cognition, co-emergence, curriculum. *Journal of Curriculum Studies, 28*(2), 151-169.

Driver, R. (1989). Students' Conceptions and Learning of Science. *International Journal of Science Education.* 11, 481-90.

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to conceptual development in adolescent science students. *Studies in Science Education, 5,* 61-84.

Driver, R., Guesne, E., & Tiberghien, A. (Eds.) (1985). *Children's ideas in science.* Milton Keynes: Open University Press.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84,* 287-312.

Driver, R., & Warrington, L. (1985). Students' use of the principle of energy conservation in problem situation. *Physics Education, 20*(4), 171-176.

Duschl, R. A., Ellenbogen, K., & Erduran, S. (1999, March). *Promoting argumentation in middle school science classroom: A Project SEPIA evaluation.* Paper presented

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

at the annual meeting of the National Association for Reach in Science Teaching, Boston.

Dweck, C. S., & Leggett, E. L. (1988). A social cognitive approach to motivation and personality. *Psychological Review, 95*(2), 256-273.

Erickson, G. L. (1979). Children's conceptions of heat and temperature. *Science Education, 63,* 221-230.

Erickson, G. L. (1980). Children's viewpoints of heat: A second look. *Science Education, 63,* 221-230.

Erickson, G., & Agurirre, J. (1984). Students' conceptions about the vector characteristics of three physics concepts. *Journal of Research in Science Teaching, 21*(5), 439-457.

Fodor, J. A. (1975). The language of thought. Cambridge, MA: Harvard University Press.

Gall, M. D., Borg, W. R., & Gall, J. P. (1996). *Educational research: An introduction* (6th ed.). New York: Longman.

Gopnik, A. (1996). The scientist as child. *Philosophy of Science*, 63(4), 485-514.

Gunstone, R., & White, R. (1981). Understanding of gravity. *Science Education, 65*(3), 291-299.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66, 64-74.

Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. *American Journal of Physics*, 60(7), 627-636.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics*, 60(7), 637-644.

Hestenes, D., & Wells, M. (1992). A mechanics baseline test. *The Physics Teacher, 30*(3), 159-166.

Hestenes, D., Wells, M., & Swackhammer, G. (1992). Force concept inventory. *The Physics Teacher, 30*(3), 141-158.

Hewson, M. G., & Hewson, P. W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies in science learning. *Journal of Research in Science Teaching, 20*(8), 731-743.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Hewson, P. W., Tabachnick, B. R., Zeichner, K. M., & Lemberger, J. (1999). Educating prospective teachers of biology: findings, limitations, and recommendations. *Science Education, 83,* 373-384.

Hiebert, J. (1986). *Conceptual and procedural knowledge: The case of mathematics.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Huffman, D., & Heller, P. (1995). What does the Force Concept Inventory actually measure? *The Physics Teacher, 33,* 138-143.

Hunter, B. (1983). *My Students Use Computers.* Reston, Va.: Reston Publishing Co.

Janesick, V. J. (1998). *"Stretching" exercises for qualitative researchers.* Thousand Oaks, CA: Sage.

Jegede, O. J., & Okebukola, P. A. O. (1991). The effect of instruction on socio-cultural beliefs hindering the learning of science. *Journal of Research in Science Teaching, 28*(3), 275-285.

Jonassen, D. H. (1996). *Computer in the classroom: Mindtools for critical thinking.* Englewood Cliffs, NJ: Merrill.

Karplus, R. (1977). *Science Teaching and the Development of Reasoning.* Berkeley: University of California Press.

Kirkpatric, H., & Cuban, L. (1998). Should we be worried? What the research says about gender differences in access, use, attitudes, and achievement with computer. *Educational Technology, 38*(4), 56-61.

Kohlberg, L. & Mayer, R. (1972). Development as the Aim of Education. *Harvard Educational Review*, 42(4), 449-496.

Kozma, R. B. (1994). Will media influence learning? Reframing the debate. *Educational Technology Research and Development, 42*(2), 7-19.

Krueger, R. A. (1988). *Focus groups: A practical guide for applied research.* Newbury Park, CA: Sage.

Kuhn, D. (1993). Science as argument. *Science Education, 77,* 319-337.

Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). *The Development of Scientific Thinking Skills.* London: Academic Press.

Kuhn, T. (1970). *The structure of scientific revolutions.* Chicago: Chicago University Press.

Larkin, J. H., & Reif, F. (1979). Understanding and teaching problem solving in physics. *European Journal of Science Education, 1*(2), 191-203.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Lawson, A. E. (1988). A better way to teach biology. *The American Biology Teacher, 50*(5), 266-278.

Leont'ev, A. N. (1981). The problem of activity in psychology. In J. V. Wertsch (Ed.), *The concept of activity in soviet psychology* (37-71). Armonk, NY: Sharpe.

Lijnse, P. (1990). Energy between the life-world of pupils and the world of physics, *Science Education, 74*(5), 571-583.

Logan, R. K. (1995). *The Fifth Language: Learning a Living in the Computer Age.* Toronto: Stoddart Publishing Co.

Marion, R., Hewson, P. W., Tabachnick, B. R., & Blomker, K. B. (1999). Teaching for conceptual change in elementary and secondary science methods courses. *Science Education, 83,* 275-307.

Mazur, E. (1996). *Science lecture: a relic of the past?* [On-line]. Available: http://mazur-www.harvard.edu/mazur-www/Library/pubs.taf?id=90&function=detail. Also: *Physics World, 9,* 13-14.

Mazur, E. (1997). *Peer instruction: A user's manual.* Englewood Cliffs, NJ: Prentice Hall.

Mazur, E. (in press). Peer instruction: Eight years of experience and results [On-line]. Available: http://mazur-www.harvard.edu/mazur-www/Library/pubs.taf?id=263&function=detail

McCloskey, M. (1983). Intuitive physics. *Scientific American, 248,* 114-122.

Merrill, P. F., Hammons, K., Vincent, B. R., Reynolds, P. L., Christensen, L., & Tolman, M. N. (1996). *Computers in Education* (3rd ed.). Boston.: Allyn and Bacon.

Minstrell, J. (1982). Conceptual development research in the natural setting of the classroom. In M. Rowe (Ed.), *Education in the 80's: Science* (129-143). Washington, DC: National Educational Association.

Mitchell, I., & Baird, J. (1986). Teaching, learning and the curriculum--1: The influence of content in science. *Research in Science Education, 16,* 135-140.

Musheno, B. V., & Lawson, A. E. (1999). Effects of learning cycle and traditional text on comprehension of science concepts by students at differing reasoning levels. *Journal of Research in Science Teaching, 36*(1), 23-37.

Nolen, S. (1988). Reasons for studying: Motivational orientations and study strategies. *Cognition and Instruction, 5,* 269-287.

Novak, J. (1977). *A theory of education.* Ithaca, NY: Cornell University Press.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

O'Donnell A., & Dansereau D. (1993). Learning from lectures: Effects of cooperative review. *Journal of Experimental Education, 61*(2), 116-125.

Oppenheimer, T. (1997). The computer delusion. *The Atlantic Monthly, 280*(1), 45-62.

Osborne, J. (2000, February). Promoting argument in science classroom: a rhetorical perspective. Lecture in Faculty of Education, University of Alberta, Edmonton.

Osborne, R., & Freyberg, P. (1985). *Learning in science: The implication of children's science*. Auckland: Heinemann.

Paris, S. G., & Winograd, P. (1990). How metacognition can promote academic learning and instruction. In B. F. Jones & L. Idol (Eds.), *Dimensions of thinking and cognitive instruction* (pp. 11-52). Hillsdale, NJ: Lawrence Erlbaum Associates.

Patton, M. Q. (1990). *Qualitative education and research methods* (2nd ed.). Newbury Park, CA: Sage.

Perner, J. (1994). Cognitive development: overview. In T. Husen, & T. N. Postlethwaite (Eds.), *The international encyclopedia of education* (2nd ed., 852-57). Oxford: Elsevier Science.

Piaget, J. (1954). *The construction of reality in the child* (M. Cook, Trans.). New York: Basic Books.

Piaget, J. (1970). *Genetic epistemology*. New York: Columbia University Press.

Piaget, J. (1973). *To understand is to invent*. New York: Viking Press.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child* (H. Weaver, Trans.). New York: Basic Books.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change. *Review of Educational Research*, 63(2), 167-99.

Pintrich, P. R., & De Groot, E. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology, 82*, 33-40.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 221-227.

Redish, E. F. (1994). The Implications of Cognitive Studies for Teaching Physics [On-line]. Available: http://www.physics.umd.edu/rgroups/ripe/papers/cogsci.html. Also: *American Journal of Physics*, 62(6), 796-803.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1997). *On the effectiveness of active-engagement microcomputer-based laboratories* [On-line]. Available: http://www.physics.umd.edu/rgroups/ripe/papers/mbl/mbl1.html. Also: *American Journal of Physics, 65,* 45-54.

Redish, E. F., & Steinberg, R. N. (1999). *Teaching physics: Figuring out what works* [On-line]. Available: http://www.physics.umd.edu/rgroups/ripe/papers/PT/pt.htm. Also: *Physics Today, 52,* 24-30.

Reif, F., & Larkin, J. H. (1991). Cognition in scientific and everyday domains: Comparison and learning implication. *Journal of Research in Science Teaching, 28*(9), 733-760.

Reiner, M. (1998). Through experiments and collaborative learning in physics. *International Journal of Science Education, 20*(9), 1043-1058.

Richardson, V. (1997). *Constructivist approaches to teacher education.* Thousand Oaks, CA: Corwin Press.

Romberg, T. A., & Carpenter, T. P. (1986). Research on teaching and learning mathematics: Two disciplines of scientific inquiry. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed.; pp. 850-873). New York: Macmillan.

Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General, 104,* 192-233.

Ruse, M. (1989). Making use of creationism: A case study for the philosophy of science classroom. *Studies in Philosophy and Education, 10*(1), 81-92.

Salomon, G., & Globerson, T. (1987). Skill may not be enough: The role of mindfulness in leaning and transfer. *International Journal of Educational Research, 11*(6), 623-637.

Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Education Research, 20*(3), 2-9.

Schlenker, R. M., & Perry, C. M. (1983). The molar concept: A Piagetian-oriented learning cycle. *Journal of College Science Teaching, 12*(6), 431-434.

Sechrest, L. (1979). *Unobtrusive measurement today.* San Francisco: Jossey-Bass.

Siegel, H. (1995). Why should educators care about argumentation? *Informal Logic,* 17(2), 159-76.

Serway, R. A., & Beichner, R. J. (2000). Physics: For scientists and engineers with modern physics (5th ed.). Philadelphia: Saunders College.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Shlechter, T. M., & Bessemer, D. W. (1992). Computer-based simulation system and role playing: An effective combination for fostering conditional knowledge, *Journal of Computer-Based Instruction, 19*(4), 110-114.

Sjoberg, S. & Lie, S. (1981). Technical Report, University of Oslo.

Smith, E. E., & Medin, D. L. (1981). *Categories and concepts*, Cambridge, MA: Harvard University Press.

Stinner, A. (1994). The large context problem approach: providing a contextual base and a theoretical structure to guide the teaching of high school physics. *Physics in Canada*, 50(1), 45-51.

Stinner, A. (1997). From intuitive physics to star trek: Large context problems for an investigation of motion on earth and in space. *Physics in Canada*, 53(1), 23-33.

Stinner, A. (2000a). Hitching on an asteroid: A large context problem. *Physics in Canada*, 56(1), 27-42.

Stinner, A. (2000b). Lord Kelvin and the age-of-the-earth debate: the rise and fall of Kelvin's calculations of the age of the Earth and the Sun. *Physics in Canada*, 56(6), 321-330.

Stinner, A. & Williams, H. (1993). Conceptual change, history, and science stories. *Interchange*, 24(1/2), 87-103.

Sudman, S. (1976). *Applied sampling*. New York: Academic Press.

Tao, P-K, & Gunstone, R. F. (1999). Conceptual change in science through collaborative learning at the computer. *International Journal of Science Education, 21*(1), 39-57.

Taylor, R. (1980). *The computer in the school: Tutor, tool, tutee*. New York: Teachers College Press.

Tennyson, R. D. (1996). Concept learning. In T. Plompand & D. P. Ely (Eds.), *International encyclopedia of educational technology* (2nd ed.; pp. 52-55), New York: Pergamon.

Thagard, P. (1992). *Conceptual revolutions*. Princeton, NJ: Princeton University Press.

Tyler, R. (1949). *Basic Principles of Curriculum and Instruction*. Chicago: University of Chicago Press.

Uhlenbeck, G. E. (1976). Fifty years of spin: Personal reminiscences. *Physics Today, 29*(6), 43-48.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. *European Journal of Science Education, 1*(2), 205-221.

Von Glaserfeld, E. V. (1993). Questions and answers about radical constructivism. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 23-38). Washington, DC: AAAS Press.

Von Glaserfeld, E. V. (1995). A constructivist approach to teaching. In L. P. Steffe, & J. Gale (Eds.), *Constructivism in education* (3-15). Hillsdale, NJ: Lawrence Erlbaum Associates.

Von Wright, J. (1992). Reflection on reflection. *Learning and Instruction, 2,* 59-68.

Vygotsky, L. S. (1962). *Thought and language.* Cambridge, MA: MIT Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.). Cambridge, MA: Harvard University Press.

Vygotsky, L. S. (1981). The genesis of higher mental functions. In J. V. Wertsch (Ed.), *The concept of activity in soviet psychology* (144-188). Armonk, NY: Sharpe.

Wang, T., & Andre, T. (1991). Conceptual change text versus traditional text and application questions versus no questions in learning about electricity. *Contemporary Educational Psychology, 16*(2), 103-116.

Webb, N. M. (1982). Student interaction and learning in small groups. *Review of Educational Research, 52,* 421-445.

Wentzel, K. R. (1991). Social and academic goals at school: motivation and achievement in context. In M. L. Maehr & P. R. Pintrich (Eds.), *Advances in motivation and achievement* (Vol. 7, 185-212). Greenwich, CT: JAI Press.

Whisnant, D. M. (1983). Learning cycle in the general chemistry laboratory. *Journal of College Science Teaching, 12*(6), 434-435.

Whitaker, R. J. (1983). Preconceptions about trajectory motion. *American Journal of Physics, 51*(4), 352-357.

White, R. T. (1988). *Learning science.* Oxford, UK: Basil Blackwell.

White, R. & Gunstone, R. (1989). Metalearning and Conceptual Change. *International Journal of Science Education*, 11, 577-86.

White, R., & Gunstone, R. (1992). *Probing understanding.* London: Falmer Press.

Wyndham, J. (1958). *The chrysalids.* Markham, ON: Penguin Books.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Zhou, G. Q., Martin, B., Brouwer, W., & Austen, D. (2000). Computer-based physics and student preconceptions. *Alberta Science Educational Journal, 32*(2), 23-35.

Zietsman, A. I., & Hewson, P. W. (1986). Effect of instruction using microcomputer simulations and conceptual change strategies on science learning. *Journal of Research in Science Teaching, 23,* 27-39.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX A

LETTER INVITING STUDENTS TO A DISCUSSION ON PHYSICS INSTRUCTION

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Discussion About Physics Instruction

____________________:

Congratulations on your successful finish of this term's physics course. As an evaluator of the MAP project, I warmly invite you to a discussion about computer use in physics instruction. Your opinions and suggestions are very important to improve MAP. Please fit this event into your time schedule.

The discussion will begin at 11:00 AM on this Friday in coffee room 445, Physics building. The discussion will last about one hour. After the discussion, we will invite you to a Chinese restaurant for lunch.

Please think about the following questions for the discussion:

1. How do you like the MAP applets in the lecture?
2. Do you think the applets are useful to understand physics concepts?
3. How do you like the video lab compared with traditional lab?
4. What kind of suggestions do you have about the designs of applets and video lab?

Please inform me at 433-9918 (home) or 492-8364(office) or guoqiang@gpu.srv.ualberta.ca if something happens to stop you from coming to the discussion.

Hope you can join us!

Guoqiang Zhou

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX B

LETTER INVITING STUDENTS TO WRITE COMMENTS ON PHYSICS INSTRUCTION

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

talkmap@hotmail.com

Dear students:

We, the instructors and researchers, are working hard to make physics instruction more interesting and more effective. That is why MAP on-line materials were developed. To better do our job, we cordially invite you to write any comments to the above address at any convenient time on MAP and your physics course. Your responses are very valuable for our research and teaching practice. Here are some suggested topics:

1. **Do you like MAP?**
2. **Do the applets of MAP help you understand physics?**
3. **List one or more examples to support your above responses.**
4. **List several applets you most like.**
5. **What do you think of physics, difficult to learn? Useful? Makes sense to you? Etc.**
6. **What do you recommend for physics instruction?**

Your writing will be used for research purposes only. Your name and any other identity will be kept confidential.

Thanks for your cooperation! Good luck with your study!

Dr. XXXXX	Guoqiang Zhou
Course instructor	Graduate Student

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX C

ATTITUDE TEST

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

1. I am taking this physics course because:
    - (a) physics is a compulsory course for my program.
    - (b) physics is useful for my future job.
    - (c) my parents or friends recommended me to take it.
    - (d) physics helps me understand how the world works.

For the following statements, please choose the right response.

2. I like to learn physics with computer.

a. very true b. true c. uncertain d. not true e. not at all true

3. Physics is interesting for me.

a. very true b. true c. uncertain d. not true e. not at all true

4. Physics makes sense to me.

a. very true b. true c. uncertain d. not true e. not at all true

5. Physics is hard to learn.

a. very true b. true c. uncertain d. not true e. not at all true

6. Science is a major force of the development of our society and our life.

a. very true b. true c. uncertain d. not true e. not at all true

7. I wish to pursue a career in physics or a physics-related field.

a. very true b. true c. uncertain d. not true e. not at all true

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX D

IN-CLASS SURVEY

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Survey

Instructions

1. You have about 10 minutes to write this survey.
2. Please mark **your name and student ID** on the answer sheet.
3. Return your answer sheet and the questionnaire to your instructor.

All data will be used for research purposes only. Your name and any other identification will be kept confidential.

Thanks for your cooperation!

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

For the following statements, please choose only one response.

1. I like the applets in the online program of Modular Approach to Physics (MAP).

   (a) a lot (b) sort of (c) a little bit (d) not at all (e) uncertain

2. MAP applets helped me understand concepts.

   (a) a lot (b) sort of (c) a little bit (d) not at all (e) uncertain

3. On average, I access the MAP applets.

   (a) very often: after each class, or two or more times a week.

   (b) often: about once a week.

   (c) occasionally: less than once a week.

   (d) very seldom: less than once a month.

   (e) not at all.

4. Among the MAP applets associated with Phy144, I have visited:

   (a) almost all of them.

   (b) more than half of them.

   (c) less than half of them.

   (d) only several.

   (e) zero.

5. I like MAP video labs more than traditional labs:

   (a) very true (b) true (c) not true (d) not at all true (e) uncertain

6. I study hard because I want to make sense of what the instructor taught me.

   (a) very true (b) true (c) not true (d) not at all true (e) uncertain

7. I study hard because I want people to think I am smarter and do a better job than others.

   (a) very true (b) true (c) not true (d) not at all true (e) uncertain

8. I study hard because I want to get a good mark.

   (a) very true (b) true (c) not true (d) not at all true (e) uncertain

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

9. I study hard because I want to learn more for my future plans.

(a) very true (b) true (c) not true (d) not at all true (e) uncertain

10. I feel like an active participant in this course.

(a) very true (b) true (c) not true (d) not at all true (e) uncertain

11. I try to understand each topic of this course.

(a) very true (b) true (c) not true (d) not at all true (e) uncertain

12. I go back over things I did not understand.

(a) very true (b) true (c) not true (d) not at all true (e) uncertain

13. I ask myself some questions to make sure the learning makes sense to me.

(a) very true (b) true (c) not true (d) not at all true (e) uncertain

14. I try to match what I learned in this class with what I had learned before.

(a) very true (b) true (c) not true (d) not at all true (e) uncertain

15. I try to relate what I learned in this class to my life experiences.

(a) very true (b) true (c) not true (d) not at all true (e) uncertain

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX E

INVITATION LETTER AND CONSENT FORM

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Invitation Letter

Dear students:

I am a graduate student in physics education. With the desire of making our physics instruction more effective for conceptual learning, I warmly invite you to join my research, which is to investigate the effectiveness of the Modular Approach to Physics program on students' conceptual growth.

To participate in my research, you will be administered pre and post conceptual understanding tests. Some of your performance in the lectures and labs may be recorded. About four of you will be invited to interviews for your understanding of physics. Each interview will last about fifteen minutes. All data I get from you will be used for research purposes only and will not influence your mark for this course. Your name will not appear in any reports. You may also opt out of this research at any time without any kind of penalty.

Your participation is very important for my research. Your kind consideration will be greatly appreciated.

Sincerely

Guoqiang Zhou

Consent Form

I,________________________, have read the above letter inviting my participation in a study which explores the effectiveness of Modular Approach to Physics. I agree to participate with the understanding that:

1. I may withdraw from the research at any time without penalty.
2. I may request that all or part of the data collected be omitted.
3. My name will not be used in any reports.
4. My data will not influence my mark for this course.

Signature: ________________________ **Date**: ____________________.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX F

DETAILED TABLES OF AND BRIEF CONCLUSIONS FROM THE T-TEST RESULTS ON CONCEPTUAL UNDERSTANDING TESTS

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table F1

Independent T-Test for Pre-test Results in Term-A

Group Statistics for the pretest

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
PRETEST	control group	329	16.28	6.25	.34
	treatment group	175	15.60	6.56	.50

Independent Samples Test for the pretest

			PRETEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		.166	
	Sig.		.684	
t-test for Equality of Means	t		1.147	1.131
	df		502	340.752
	Sig. (2-tailed)		.252	.259
	Mean Difference		.68	.68
	Std. Error Difference		.60	.60
	95% Confidence Interval of the Difference	Lower	-.49	-.50
		Upper	1.85	1.87

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table F2

Independent T-Test for Post-test Results in Term-A

Group Statistics for the posttest

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
POSTTEST	control group	335	17.59	6.62	.36
	treatment group	178	18.20	6.64	.50

Independent Samples Test for the posttest

			POSTTEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		.031	
	Sig.		.860	
t-test for Equality of Means	t		-.995	-.994
	df		511	360.062
	Sig. (2-tailed)		.320	.321
	Mean Difference		-.61	-.61
	Std. Error Difference		.61	.62
	95% Confidence Interval of the Difference	Lower	-1.82	-1.82
		Upper	.60	.60

Conclusions from Tables F1 and F2: In both pre-test and post-test in Term-A, the mean difference of the treatment and control groups on FCI-Plus was not significant. That is to say, students in both groups were at the same level in conceptual understanding both at the start and the end of the course.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table F3

Dependent T-Test for the Control Group in Term-A

Paired Samples Statistics for the control group

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PRETEST	16.37	310	6.19	.35
	POSTTEST	17.75	310	6.73	.38

Paired Samples Correlations for the control group

		N	Correlation	Sig.
Pair 1	PRETEST & POSTTEST	310	.740	.000

Paired Samples Test for the control group

			Pair 1 PRETEST - POSTTEST
Paired Differences	Mean		-1.38
	Std. Deviation		4.68
	Std. Error Mean		.27
	95% Confidence Interval of the Difference	Lower	-1.90
		Upper	-.85
t			-5.179
df			309
Sig. (2-tailed)			.000

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table F4

Dependent T-Test for the Treatment Group in Term-A

Paired Samples Statistics for the treatment group

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PRETEST	15.74	162	6.42	.50
	POSTTEST	18.06	162	6.76	.53

Paired Samples Correlations for the treatment group

		N	Correlation	Sig.
Pair 1	PRETEST & POSTTEST	162	.774	.000

Paired Samples Test for the treatment group

			Pair 1
			PRETEST - POSTTEST
Paired Differences	Mean		-2.31
	Std. Deviation		4.45
	Std. Error Mean		.35
	95% Confidence Interval of the Difference	Lower	-3.00
		Upper	-1.62
t			-6.626
df			161
Sig. (2-tailed)			.000

Conclusion from Tables F3 and F4: Both treatment and control groups in Term-A had a significant increase in conceptual understanding. This means that both teaching with MAP and teaching with a traditional method had significant effect on conceptual teaching and learning.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table F5

Independent T-Test on Post-test Results for the Control Group in Term-A and the Treatment Group in Term-B

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
POSTTEST	3	25	22.08	5.67	1.13
	control group	335	17.59	6.62	.36

Independent Samples Test

			POSTTEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		1.117	
	Sig.		.291	
t-test for Equality of Means	t		3.304	3.776
	df		358	29.109
	Sig. (2-tailed)		.001	.001
	Mean Difference		4.49	4.49
	Std. Error Difference		1.36	1.19
	95% Confidence Interval of the Difference	Lower	1.82	2.06
		Upper	7.17	6.93

Conclusion from Table F5: The mean difference on FCI-Plus between the Term-B treatment class and the Term-A control group was significant.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table G6

Independent T-Test for Pre-test Results in Term-C

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
PRETEST	1	82	17.79	7.31	.81
	2	66	17.74	7.19	.89

Independent Samples Test

			PRETEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		.460	
	Sig.		.499	
t-test for Equality of Means	t		.042	.042
	df		146	140.277
	Sig. (2-tailed)		.967	.967
	Mean Difference		5.03E-02	5.03E-02
	Std. Error Difference		1.20	1.20
	95% Confidence Interval of the Difference	Lower	-2.32	-2.32
		Upper	2.42	2.42

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table F7

Independent T-Test for Post-test Results in Term-C

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
POSTTEST	1	81	20.47	6.84	.76
	2	58	23.00	6.25	.82

Independent Samples Test

			POSTTEST	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		1.771	
	Sig.		.185	
t-test for Equality of Means	t		-2.228	-2.262
	df		137	129.110
	Sig. (2-tailed)		.028	.025
	Mean Difference		-2.53	-2.53
	Std. Error Difference		1.14	1.12
	95% Confidence Interval of the Difference	Lower	-4.78	-4.74
		Upper	-.28	-.32

Conclusion from Tables F6 and F7: The treatment and control groups were at the same level in physics conceptual understanding at the start of the course in Term-C, but the two groups had a significant difference in conceptual understanding after the course. The treatment group did much better than the control group.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table F8

Dependent T-Test for the Treatment Group in Term-C

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	POSTTEST	22.87	52	6.11	.85
	PRETEST	17.58	52	6.84	.95

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 POSTTEST & PRETEST	52	.632	.000

Paired Samples Test

			Pair 1
			POSTTEST - PRETEST
Paired Differences	Mean		5.29
	Std. Deviation		5.60
	Std. Error Mean		.78
	95% Confidence Interval of the Difference	Lower	3.73
		Upper	6.85
t			6.816
df			51
Sig. (2-tailed)			.000

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table F9

Dependent T-Test for the Control Group in Term-C

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	POSTTEST	20.43	75	6.93	.80
	PRETEST	17.97	75	7.47	.86

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	POSTTEST & PRETEST	75	.828	.000

Paired Samples Test

			Pair 1
			POSTTEST - PRETEST
Paired Differences	Mean		2.45
	Std. Deviation		4.25
	Std. Error Mean		.49
	95% Confidence Interval of the Difference	Lower	1.47
		Upper	3.43
t			4.996
df			74
Sig. (2-tailed)			.000

Conclusion from Tables F8 and F9: Both the treatment and control classes had a significant growth in conceptual understanding in Term-C.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX G

T-TEST RESULTS ON GENDER DIFFERENCE IN PHYSICS COURSE

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table G1

T-Test for Gender Difference in the Control Group (Cw) in Term-A

Group Statistics

	GENDER	N	Mean	Std. Deviation	Std. Error Mean
PRETEST	male	165	18.59	6.25	.49
	female	136	13.30	4.77	.41
POSTTEST	male	168	19.57	6.77	.52
	female	131	15.19	5.48	.48

Independent Samples Test

			PRETEST		POSTTEST	
			Equal variances assumed	Equal variances not assumed	Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		16.402		9.162	
	Sig.		.000		.003	
t-test for Equality of Means	t		8.104	8.314	6.013	6.171
	df		299	297.326	297	296.585
	Sig. (2-tailed)		.000	.000	.000	.000
	Mean Difference		5.29	5.29	4.37	4.37
	Std. Error Difference		.65	.64	.73	.71
	95% Confidence Interval of the Difference	Lower	4.00	4.04	2.94	2.98
		Upper	6.57	6.54	5.81	5.77

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table G2

T-Test for Gender Difference in the Treatment Group (Tw) in Term-A

Group Statistics

	GENDER	N	Mean	Std. Deviation	Std. Error Mean
PRETEST	male	89	17.13	6.98	.74
	female	76	13.68	5.35	.61
POSTTEST	male	86	19.65	6.87	.74
	female	78	17.03	5.90	.67

Independent Samples Test

			PRETEST		POSTTEST	
			Equal variances assumed	Equal variances not assumed	Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		5.074		4.456	
	Sig.		.026		.036	
t-test for Equality of Means	t		3.516	3.589	2.612	2.631
	df		163	161.240	162	161.546
	Sig. (2-tailed)		.001	.000	.010	.009
	Mean Difference		3.45	3.45	2.63	2.63
	Std. Error Difference		.98	.96	1.01	1.00
	95% Confidence Interval of the Difference	Lower	1.51	1.55	.64	.66
		Upper	5.39	5.35	4.61	4.60

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX H

GENDER DIFFERENCE IN ATTITUDES TOWARD PHYSICS

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

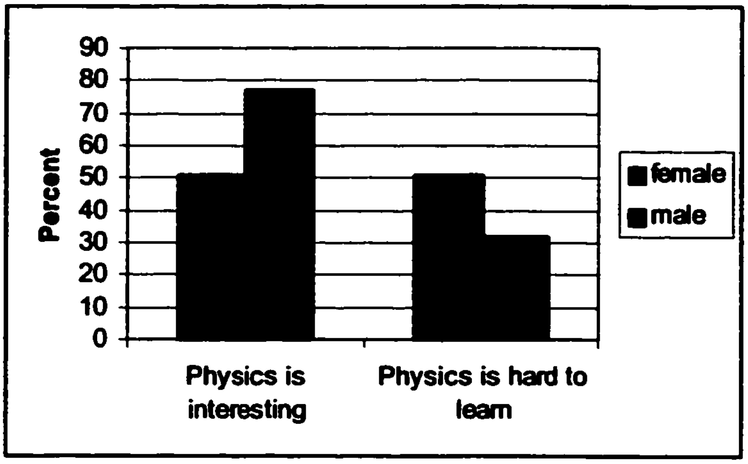


Figure H-1. **Attitude difference between males and females (Tw)**

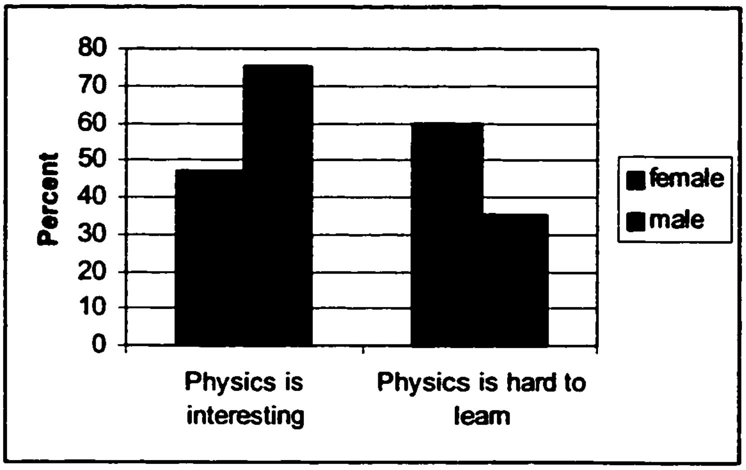


Figure H-2. **Attitude difference between males and females (Cw)**

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

APPENDIX I

A COMPARISON OF PRECONCEPTIONS' CORRELATION BETWEEN MALE AND FEMALE STUDENTS

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table I1

Correlation of Preconceptions for Males

Correlations

		P7	P8	P9	P10	P11
P7	Pearson Correlation	1.000	.132	.022	-.108	.238*
	Sig. (2-tailed)	.	.168	.829	.296	.012
	N	110	110	103	95	110
P8	Pearson Correlation	.132	1.000	.282**	.085	.246**
	Sig. (2-tailed)	.168	.	.004	.411	.010
	N	110	110	103	95	110
P9	Pearson Correlation	.022	.282**	1.000	-.111	-.064
	Sig. (2-tailed)	.829	.004	.	.285	.523
	N	103	103	103	94	103
P10	Pearson Correlation	-.108	.085	-.111	1.000	.233*
	Sig. (2-tailed)	.296	.411	.285	.	.023
	N	95	95	94	95	95
P11	Pearson Correlation	.238*	.246**	-.064	.233*	1.000
	Sig. (2-tailed)	.012	.010	.523	.023	.
	N	110	110	103	95	111

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Table I2

Correlation of Preconceptions for Females

Correlations

		P7	P8	P9	P10	P11
P7	Pearson Correlation	1.000	.147	.251**	.351**	.312**
	Sig. (2-tailed)	.	.083	.004	.000	.000
	N	139	139	133	127	139
P8	Pearson Correlation	.147	1.000	.319**	.187*	.148
	Sig. (2-tailed)	.083	.	.000	.035	.082
	N	139	139	133	127	139
P9	Pearson Correlation	.251**	.319**	1.000	.188*	.391**
	Sig. (2-tailed)	.004	.000	.	.035	.000
	N	133	133	133	126	133
P10	Pearson Correlation	.351**	.187*	.188*	1.000	.400**
	Sig. (2-tailed)	.000	.035	.035	.	.000
	N	127	127	126	127	127
P11	Pearson Correlation	.312**	.148	.391**	.400**	1.000
	Sig. (2-tailed)	.000	.082	.000	.000	.
	N	139	139	133	127	139

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.