University of Alberta

Students' Perception of the Mechanisms for Conceptual Change in Physics

By

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Introduction

From my experience and discussions with teachers having similar experiences, a problem that physics teachers continually address in their classes is the difficulties students have in conceptualizing physics. They can reiterate examples they have seen, and can memorize the mathematical processes, but because they lack a deeper conceptual understanding, when it comes to applying their learning to new (but related) topics they do not make the connections necessary to do as well as they believe they should. Zhou (2002) provides a good explanation of conceptual 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 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." (p. 2)

An initiative seemingly gaining favour with physics teachers attempting to promote conceptual growth is the use of a new computer technology – Java based simulation applets. These are a series of computer programs that simulate real physical systems and allow the students to physically see how systems react to different variables and then go further by making the connections with graphical and mathematical analysis. Students bring to the computer their own conceptualization of how the "real world" systems work and through interacting with the simulations they begin to form a deeper understanding of how their own experience ties to the experimental and theoretical perspectives they are being presented with in class. The Modular Approach to Physics (MAP) is a series of computer simulations that mimic situations in the world and allow the user to anticipate and analyze the simulated results of a number of real world systems that are commonly discussed and analyzed in physics class. The simulations were developed specifically to augment students' conceptual understanding. Research done on MAP by Zhou (2002) and other work done on similar Java based simulations (Hwang, 2000), has demonstrated that these simulations, used at appropriate times within the lesson, do in fact aid students' conceptual growth in physics. These studies have chosen pre-test vs. post-test and MAP vs. non-MAP quasi-experimental methodologies to evaluate the effectiveness of Java simulations on students conceptual growth. It is interesting to note though, that they were only effective when used in conjunction with other material presented by the teacher within the lesson. When used as a stand alone tool, the MAP applets were not effective (Zhou, 2002).

While working through the research on MAP and other Java simulation initiatives, I found myself asking three questions that the existing research seemed to fall short of asking.

Question 1: How do you measure conceptual growth in physics?

Conceptual growth as Zhou (2002) defines it is an accommodation (to borrow from Piaget) process by which students' existing way of visualizing / understanding is replaced with a more "accurate" version that enables them to formulate the "right" answer. The successful integration of this new paradigm ultimately is conveyed through the students' increased test scores. I would argue that the very nature of tests limits the ways in which students' conceptual development occurs. They become outcome oriented and want to know what they need to be able to do and know to do well on the test. They distrust the ability of visualization and conceptualization to help them score higher, and thus revert to more traditional and proven effective memory based approaches.

It is not the purpose of this research to argue the merits of tests. Nor do I deny that ultimately much of our perception of students' success is through their ability to do well on tests. However, to use that as the sole source of evaluation of students' conceptual growth in physics is to deny that conceptualization by its very nature is a holistic, virtually 3-dimensional awareness and perhaps can best be measured by more than a test looking for specific solutions to problems.

Question 2: What is the students' perception of their own conceptual development in Physics?

In none of the literature that I found have I seen an attempt to establish what is occurring to the student (from their own perspective) when it comes to attempts to increase their conceptual ability in physics using simulations. Too often, I believe, they are seen as the passive recipients of various new initiatives and environments – with the relative success being gauged by their score on a test. The essence of constructivism is the willingness to allow students to bring their own experience with them into the classroom and find ways to create an environment that motivates them to construct the knowledge and perspective deemed desirable. Is it not important to use the students' own perception of the process to evaluate its success? A description by the students, detailing how they feel their own conceptual growth has occurred, should be an integral part of any evaluation of initiatives designed to improve this – including simulations like MAP.

As a result I have chosen to let the students themselves tell me what they are experiencing and what they consider significant with regards to growth in their conceptual understanding. From this I hope to distil any significant trends, opinions or actions that researchers and teachers working with these students might consider.

Question 3: Do physics students value using computers in physics, and more specifically, are initiatives such as designing computer simulations to foster conceptual understanding (like the Modular Approach to Physics) perceived by the students as helpful?

"We must integrate technology into our classrooms" has become the mantra of schools and school divisions worldwide. Often the school divisions' rationales are not even complete before the implementation begins in their rush to get on board with the rest of the western world, and are completed as the projects themselves progress (Commonwealth Secretariat, 1991). Initially these integrations often have the intent of producing highly skilled computer users, but they tend to evolve into promoting increased student test scores and "computer literacy" (Commonwealth Secretariat, 1991). Depending on the body of research reviewed, there are many conflicting opinions on how effective technology integration really is – do the gains merit the ongoing time and monetary costs associated? Further research on computer simulation's role in specific areas like conceptual development in physics may help to inform these decisions. If initiatives like MAP have a role to play in students' conceptual understanding I would like the students to be the origin for its significance and not have it arise as a result of a directed series of questionnaires or surveys. This desire for the students to be the origin for the theories and trends discussed has led me to using grounded theory as my methodology in this research.

As a result of these questions listed above, I have decided to focus this research on what physics students' perceive as valuable contributions to their conceptual understanding, and what value (if any) they place on computers and more specifically, the MAP applets that some will have been exposed to.

Question: What is the students' perception of their conceptual development in physics?

- To what extent are they aware of progression or improvement in their conceptual understanding?
- What classroom activities and environments do students value with regards to their conceptual development?
- Do students perceive that MAP has an impact on their conceptual development?

This thesis begins with a discussion of what a grounded theory design is and why I have chosen it for this research. I follow this with a description of the research environment and include both my research plan and an approximate interview guide. It is necessary to discuss conceptual change next, and I will be quite extensive in defining it in reference to my own and the literature's perspectives (including established problems and common alternative conceptions). I will follow next with the data collected by this research, which is broken into four categories; non-context-specific factors, physics specific factors, the nature of students, and hands-on activities. Next will be a discussion of the research questions in the context of the data, which will be followed by conclusions drawn from analyzing the literature on this topic as well as the derived thesis or core category. I will finish with a few applications and some discussion of further research that this research suggests. Included at the end, of course, is the references section as well as appendices A through C.

Grounded Theory

Grounded theory as a methodology formally began with a paper published by Barney Glaser and Anselm Strauss in 1967 entitled Discovery of grounded theory: Strategies for qualitative research. It was based on the simple idea that in order to truly develop a theory rooted in the data it is necessary to allow the participants themselves and the data they provide to be the source of it. Since its original 'discovery' by Glaser and Strauss, grounded theory has undergone much debate and change. This academic pairing was not to last however, and by the early 1970's Glaser and Strauss stopped working together and went off to pursue what each believed was the best way to use grounded theory as a methodology. Strauss and Corbin (his new research partner), in response to concerns about validity and reliability of the data, followed a more prescriptive process in which the data gathered from the participants was fit to predetermined categories and then analyzed with a systematic coding process (Strauss and Corbin, 1998). Systematic designs are based on the structured creation of categories and subsequent placing of data within these headings. Relationships between the existing categories can be seen and a theory regarding the process being studied can be drawn (Creswell, 2002). Glaser remained focused upon emergent conceptualizations (as denoted by categories and their properties) which are accomplished through many steps woven together by a constant comparison process (Glaser, 2002). Researchers utilizing an emergent design model, choose to let the research create the categories and then further to establish the links between the categories (Creswell, 2002). This dichotomy in perspective has been the source of much debate between Glaser and Strauss & Corbin as to which is the 'right' way to use grounded theory as a methodology. Most researchers who have used grounded theory as their methodology since 1967 have tended to follow either Glaser or Strauss depending on their own perspective and needs (Babchuk, 1997).

I readily agree with the idea that the source of your theories should be grounded in the data that the participants provide, but upon reflection I realized that neither of these researchers put forth a way of conducting a grounded theory study that I agreed with. Strauss & Corbin are much too prescriptive to allow the participants to truly drive the theory, seemingly more concerned with theory verification than theory creation. Glaser, although proposing a more emergent design which I do agree with, seems obsessed with technical jargon and finding a way to make qualitative, subjective data seem more quantitative. I do not believe that either the participants or the researcher can ever remove themselves from the research far enough for the theory to be bias free, as Glaser would seem to imply.

Charmaz (2000) has suggested an alternative to the perspectives of Glaser and Strauss & Corbin, an approach she has labelled a 'Constructivist grounded theory design'. Constructivist designs are more focused on the subjective meanings given by the participants. They are much more narrative with a focus on the feelings, experiences, meanings and beliefs of the participants as well as (to a lesser degree) the researcher. This constructivist approach pairs nicely with work done by Bob Dick in which he suggests a method for interviewing that is emergent in design and is clearly focused on accurately portraying the experiences of the participants while using the constant comparative method grounded theory is characterized by (Dick,1990). It is Charmaz's constructivist approach that I have chosen as the basis for using grounded theory to study conceptual change in physics students.

Regardless of the specific design, grounded theory has 5 key characteristics that researchers incorporate into their designs (as defined by Creswell, 2002). It is my hope that by addressing each characteristic separately, within the context of my research, I will help establish that grounded theory is the best approach I can use.

Studying a Process

Grounded theorists can study a single idea, but more often grounded theory is the study of a process that is of interest. For instance in my research, I do not want to study conceptual change as an idea, rather I am interested in the process that leads students to increased conceptual ability in physics. After establishing the process, the focus shifts to allowing the participants (through the interview process) to establish the actions and interactions influencing the defined process. These are then defined as categories by the researcher and act as the basic framework whereby themes and patterns can be distilled from the data.

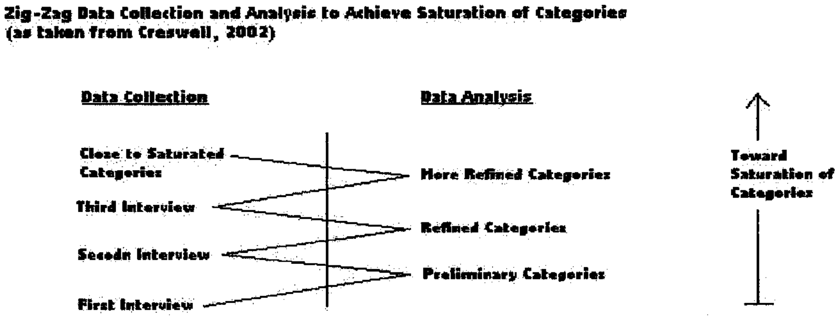
Using Theoretical Sampling

As summarized by Creswell (2002), grounded theory uses a data collection technique unique among qualitative methods. Data is collected sequentially but is also analyzed simultaneously. The entire sampling process is driven by the emerging theories that become evident through the data analysis, and influences the direction and categorization of further data collection. In other words, this process is driven by the participants and the creation of a theory. This is the essence of why I have chosen grounded theory. As a physics teacher and now researcher I have a feel for, but no clear idea of what processes are involved in students' conceptual growth in physics. However, very shortly after beginning the interview process, patterns began to emerge that allowed me to distil the theories that drove the focus of further interviews. I did not want to enter this research with any preconception of how this process occurred. By interviewing physics students, a theory emerged that demonstrated how students saw their own conceptual growth and whether MAP was a part of that.

Analyzing through comparative procedures

In order to attain "saturation of categories" it is necessary to revisit the data many times and from it define the parameters of further data collection. Saturation is the point at which the participants have no more to say and an overall pattern can be seen in the data such that clear agreement emerges between all or most of the people interviewed, and where their differences are explained (Dick, 1990). Eventually it should be possible to come to the conclusion that no more categories will surface that are relevant to your focus (saturation). This continual comparison between data and categories "grounds" the emerging theories (taken from the comparison of the categories) in the data from which it originates. If I conceptualize the interviews and refinement of categories as hierarchical, by continually "zigzagging" between them, I hope the impressions and opinions will originate from the students, and simultaneously allow me to see the broader themes and theories tying them all together. Figure 1 below (taken from Creswell, 2002) summarizes the comparative nature of grounded theory nicely.

Figure1: The Comparative Nature of Grounded Theory



Selecting a Core Category

Once category saturation is reached, the researcher must select a core category that will act as the basis for the theory. It should be central, be apparent in virtually all the data, be logical and as it develops, expand the explanatory power of what is occurring in your data. It acts as the central basis on which the theory is built. This should not occur as a revelation after saturation is reached, rather it will be a category that establishes itself early and continually is returned to by the participants. As a central category it should situate itself naturally at the center of what the participants are relating to you (likely without knowing it).

Generating a Theory

Typically the theories that are formulated from the core category and its connection to the raw data and other categories are "Middle range theories" (Creswell, 2002). That is, it is not a sweeping theory that can be applied to many people and situations (due to the specificity of the data upon which the theory is grounded). Nor is it trivial in the sense that it is limited to only one class or set of individuals. It is a theory of process and as such has applicability to individuals that mirror similar contexts. In the specific instance of my research, the emerging theories can be applied to the conceptual growth of students taking high school physics. I do not expect that the scope of this study will allow me to make valid conclusions about students' conceptual growth in other subjects. Likewise I believe the theories that emerge are applicable to their conceptual development in more than the specific unit of study that the students are engaged in while being a participant in my research.

Why not other Research Approaches?

As stated at the outset of this paper, a lot of the work that has been done with conceptual change used a quasi-experimental approach. Any conclusions as to the success of one initiative or another at increasing conceptual ability in physics was assessed predominantly through comparing pre-test and post-test scores on tests designed to measure relative achievement and thus infer changes to the students' conceptual ability in physics. The qualitative aspects of these studies were to provide the context for how the teacher was to integrate these initiatives in the classroom. Because of the apparent lack of student perspective and perception with regards to their own conceptual growth in physics, I have chosen not to use quantitative data in my research. This precludes the use of experimental, quasi-experimental, mixed method, or correlation designs, which are based on the collection of quantitative data. Which qualitative methodology to work within subsequently became my focus.

Because the students' perspective and opinions are important to me, a research approach that uses interviews as the primary data collection vehicle seems most appropriate. Additionally however, I did not want to bias my research with the preconceived belief that any particular technique is effective at increasing students' conceptual ability in physics. I have no personal stake in reaching a particular conclusion or claim. This means that I do not have a quantifiable hypothesis by which to guide my research and conclusions. The students themselves must be the source of the insights I derive.

Survey designs collect much of the same information that I am interested in. They describe motivations, opinions and group characteristics which might be useful for drawing conclusions about effective ways to increase student conceptual ability in physics. Further, they allow sampling of much larger groups of people. However, I chose grounded theory instead of a survey design for two reasons. First, I have no clear cut belief or hypothesis about conceptual change to work from, and therefore designing an appropriate survey would be difficult. Second, an interview process and the ability to use verbal and somatic cues in addition to the data helps me interpret the significance of the data collected (and perhaps these cases are actually part of the data set). Within my study, a survey would be too impersonal and subject to other limitations related to return rate and survey design.

Ethnographic and phenomenological designs also use interviews and observation extensively. They are particularly good at identifying social interaction and the context for the individual in the group dynamic. However, my focus is not on the group dynamic and its interactions and motivations. I am focused on individual student opinion, perspective and growth. The group perhaps creates the environment within which conceptual change develops and the above approaches might help to describe it. However, I do not believe them to be as effective as grounded theory at letting the individuals relate their experiences which subsequently forms the basis of the theory. Whereas ethnographic and phenomenological designs require the researcher to enter the research with a loosely defined notion or even a preconceived hypothesis, I would like the participants to be the source of my theory

Narrative design was also attractive to me as an approach to studying student conceptual growth in physics. It is particularly good at plumbing the depths of an individual's motivations and perspectives on issues. However, I believe it to be too narrow for my study. I would like to be able to draw more sweeping conclusions about conceptual change in physics. Additionally, so much of the "context" of narrative designs consists of descriptions of an individual and their broad approach to life – not of something as specific as their conceptual growth in physics.

If I was currently teaching Physics 20 or 30, and wanted to evaluate conceptual change in my classroom, I would have likely chosen an action research design. However, as an outside researcher trying to distil the perspectives of the students themselves, action research was inappropriate. I am not focussed on "fixing" a perceived problem in my class. I am attempting to identify what students value with regards to their own conceptual development in physics and infer from that what may be the stumbling blocks to their overall success in the subject. And once again, the desire to allow the students to guide my research and the theories that emerge precludes action research designs. Action researchers must enter with a hypothesis they are attempting to verify or refute.

Summary

There has been some work done on evaluating whether the Modular Approach to Physics (MAP) has been effective at achieving its mandate – to increase students' conceptual ability in physics (Zhou, 2002). Predominantly this work has used a quasi-experimental approach in which the success of MAP has been evaluated using test score comparisons between groups using MAP and groups not using MAP. I have chosen to focus on an apparent gap in the research – consideration of the students' own perspectives on their conceptual growth in physics and whether they consider MAP to significantly aid that process. For this I have chosen a grounded theory approach, due to its unique ability to allow the participants to guide the creation of the categories and theories that they feel are significant. Specifically, a constructivist grounded theory design is the most applicable, given my preference for receiving students' opinions and impressions. Other research designs were not chosen predominantly for two reasons. First, any design that is based on the collection of numeric data would not provide the vehicle for student opinion that is important to this study. This includes experimental, quasi-experimental, correlation and mixed designs. Second, the desire to let the students themselves drive the theory and conclusions heavily favours grounded theory design. Other qualitative approaches use interviewing as a methodology but do not have the focus I believe important to understanding the significance of the students' own opinions with regards to conceptual growth. Grounded theory allows the students the freedom to share their own perspective and then have that serve as the "grounding" for the theory that emerges.

Description of Research Environment

Using a Constructivist Design

This study for me is about giving the students a voice with regards to what they consider significant in the growth of their conceptual understanding in physics (conceptual growth). As such I did not want to become concerned with test scores and a description of specific acts and facts. The subjective beliefs and views of the student are what I believe has been missing from the research conducted on conceptual growth in physics, especially as it pertains to the integration of computer technology in that process. Through a series of successively more refined interviews with the students as individuals and as a group, my hope was to determine any significant commonalities within the participants' experiences (who ultimately are being asked by teachers for the same outcome – increased conceptual understanding in physics), and from this to address the question 'what is the students' perception of their own conceptual development in physics?' Because I am interested in whether computer technologies (like the MAP initiative) are valued and believed by the students to aid their conceptual development, my initial research design was set up to contrast students who had been exposed to the MAP applets with students who had not.

Research Plan

The process began with my co-organization of a professional development opportunity for physics teachers across Alberta on the integration of MAP into their physics classes. During this in-service in which teachers were exposed to how applets could be used to aid students conceptually, I asked teachers to aid in my research by allowing interviews with students from their Physics 30 classes. Physics 30 is the highest level of physics a high school student in Alberta can take (not counting university equivalent courses like IB or AP physics) and I focused on Physics 30 students for two reasons. First, they would be more mature than students in lower grades and would be more apt to embrace the interview process. Second, and even more importantly, they have had 2 years of previous exposure to instruction in physics and are likely to have a more developed sense of what 'works' for them conceptually than a student just beginning to take physics. From this inservice I had a number of teachers agree to allow me to work with their students, and from this list I selected two schools where I thought I would have my best chances for getting the data I needed.

St. John's (pseudonym) is a high school in the Edmonton Catholic School division and has a student population of approximately 1100 students in grades 10-12. At St. John's I worked with Joel, a teacher with 7 years of experience teaching physics from grade 10 through 12. Joel taught two Physics 30 classes in blocks of 1 hour and 20 minutes each, and participants were drawn equally from each class. Both courses were for one semester. The second school was Composite High School (Comp High – also a pseudonym) in the Edmonton Public School Division, with approximately 2185 students in grades 10-12. At Comp High I worked with Daniel, a physics teacher of 12 years. Daniel taught two Physics 30 classes in blocks of 1 hour and 8 minutes each, with one class running the whole year and the other a semestered class. Only one participant from the semestered class took part in the study.

After speaking with both teachers it was decided that Daniel at Comp High would begin to use MAP applets with his students in Physics 30 as an extra teaching strategy, while Joel at St. John's would hold off using them during the course and supplement his review at the end of his course with the use of the MAP applets. Since the interview process was complete before the end of the semester, this effectively created the environment I favoured which was approximately half of the participants getting some exposure to computer technology (the applets) during their physics course and the other half not getting any.

In September I spoke with the Physics 30 classes of each teacher and explained to them that I was interested in determining what they valued the most with regards to their conceptual development in physics. I gave each student an information sheet and permission slips (see appendices A & B), and asked them to return them to their teacher within one week if they were interested in participating in the study. In the end I had 6 students at Comp High and 7 students at St. John's agree to participate in the study, making a total of 13 participants of which 8 were girls and 5 were boys. All the participants were white Caucasian, except for two – one Pakistani and one African Canadian.

At both schools the interviews took place in the staff conference room, which was ideal in that it allowed the interview to proceed with few distractions of noise or interruption, and provided an environment that the students found relatively unthreatening and comfortable. The first round of interviews, done individually between each participant and me, were approximately 20 – 40 minutes long and were done during the students' free periods or after school. Notes were taken during the interviews and I followed each with further observations and thoughts about the participant and their comments. Initially the interviews were recorded, but I found from experience that the recordings were not overly helpful in contributing substantively to the interview notes and were distracting for the participants. I decided that in subsequent interviews I would not record them and would rely on my notes and observations during the interview. Participants were noticeably more relaxed and focused on the questions in subsequent interviews. It was my goal in the first round of interviews to develop a rapport with the students and also to allow them to speak as freely as possible on what they thought was important with regards to their own conceptual development in physics, without asking questions that were too specific.

> "... the starting point [in an interview] is a question which is almost content-free. This is your warranty that the answers came from the respondent, and did not arise simply because your questions created a self-fulfilling prophecy." (Dick, 1990 pp. 9)

From the first round of interviews I was able to discern from the students' comments a number of commonalities and themes and began to form a network of concepts from them. These comments then became the source for the questions that drove the second round of interviews.

The second round of interviews was once again done individually, however, the questions were much more directed and required the students to address some of the comments they made in the first interview as compared to the common concepts and categories that began to emerge from the participants as a whole. This round of interviews was done approximately one month after the first round so that the students had an opportunity to be exposed to more of the strategies being used by each teacher and also to allow me to draw from the data what the overlap and differences were between the participants. By the end of the second round of interviews there was little new data being offered by the students with much of what was being said overlapping with comments that each had made previously, with the exception of a small number of emerging concepts.

After the second round I began to sense that saturation was being reached, but wanted to ensure that nothing new would emerge from the participants. I chose to use a group interview for the third and final interview, thinking that perhaps in the process of having them describe their ideas and defend them to the group in each school that any discrepancies with what they had previously maintained would be drawn out. Because of the group nature of the interview, I decided to give the last series of questions to the participants ahead of time, so that they would have a chance to reflect on what they wanted to say when confronted by the responses of their classmates. All of the questions given to the participants in the third interview were reiterations of ideas and concepts that had been derived from the participants in previous interviews (See Appendix C). These questions proved to be a very effective tool for contrasting the comments of each participant with both what they had said before and what the group as a whole established as important.

Timeline

Date	Action
April 2003	Submit Ethics and CAPS applications
June 2003	Ethics and CAPS approvals
Mid August 2003	MAP Teacher In-service (King's College)
Late August 2003	Approach Teachers / Schools
Early September 2003	Approach Students
September 2003	1st Interview with Students
September/October 2003	Data analysis
October-December 2003	Follow-up interviews and further data analysis

Interview Guide

Because this research uses grounded theory, the interview questions and direction of the interview itself was largely determined by the students themselves and as such it is not possible to list all the questions that were used over the course of the various interviews. Having stated this, in retrospect I am now able to list some of the questions that I had the participants focus on during the interview process. Again let me reiterate that by the very nature of using grounded theory as my methodology, the interviews were largely driven by the students input and responses, and it was not until the third interview that I was able to use very directed and scripted questions with the participants (see Appendix C).

First Interview

- If you remember from when I spoke with your whole class, I am interested in how you believe you undergo permanent conceptual growth in physics. What do you think I mean by that?
- Could you explain to me what a typical class in physics is like?
- As you progress through a unit, typically the ways you are evaluated changes, becoming more discussion based – focusing on applications of what you have learned and why. What sort of things helps you prepare for this new way of being evaluated?
- How would you increase your confidence in physics and how well you are doing?
- Have you ever had a “Eureka” moment?

Second Interview

- Would you say your conceptual ability is the same, better or worse than it was when you first began to take Physics in Grade 10? How do you know that? What proof do you have?
- Give me an example of an activity or moment in one of your physics classes that you believe was intended to address your conceptual ability?
- If you were given sole charge of your learning in physics, what sorts of activities would you choose for your lessons in order to improve your conceptual understanding?
- Explain what effect (if any) the following have on your conceptual understanding.
  - Textbooks
  - Computers / Internet
  - Homework
  - Problems (calculator or written based)
  - Other class members
- What do you think the teacher (or you) removes from physics because of time pressure? How does that affect your conceptual understanding?
- How much of what you do in physics is because you have to (it is a hoop to jump through)? What is left? Has this always been the case?
- Many people have said that they see physics as 'math with notes'. There is a perception that physics has an analytic component (problem solving with math) and a conceptual component (problem solving with ideas). Do you think this separation exists? If yes, how would you go about bringing the two halves together to help you understand better? Or would it?

Third Interview

- See Appendix C

Conceptual Change

Historical Origins

The 70's was a decade of beginning for the study of conceptual change. Piaget's cognitive stage theory which detailed how students construct their knowledge through a process of assimilation and accommodation was being quite widely accepted and applied in education. In *The Structure of Scientific Revolutions* (1962 & 1970), Kuhn, in addition to observing how science evolves, began to voice for science the pedagogic observations of many teachers who saw cognitive development in their students being heavily influenced by social context and constructions. Driver and Easley (1978), after reviewing the literature, stated that more attention needed to be given to the personal / private conceptions held by students concerning science content than had been in the past. These were some of the foundations for the study of both constructivism and conceptual change in students, and they began a language and focus of research that has dominated science education circles for the past thirty years.

Context

As a beginning teacher of the academic high school sciences here in Alberta in the early 90's, I was strongly motivated to learn the rules of the game that I was about to play. I felt I owed my students the ability to anticipate what they might find interesting and useful and to present the material in such a manner that they were motivated to participate with me in the class and not just act as passive recipients of the information I was giving them. However, being responsible for only 50% of the their grade (the other 50% coming from the external diploma exam), I was also motivated to anticipate what aspects of the course needed most emphasis so as to improve my students' chances of doing well on their external exam.

I had some success with both of these concerns; however, one frustration I continually experienced (and shared with many other colleagues) was the apparent inability of some of my students to make connections between the contexts we were using in class to illustrate concepts, and the contexts that were being used on the diploma exam. In an attempt to address this problem I became involved with the construction and marking of the Physics 30 and Biology 30 diploma exams in Alberta. Through discussion, I learned that this inability to transfer their knowledge from class to test was categorized by my peers as a "conceptual ability" problem. They hypothesized that not all the students could change from their own (private) alternative conceptions to the (public) scientific conceptions, which they needed to succeed on the exam. Similar problems existed in all the sciences, but it seemed that physics was somewhat unique in the prevalence of this problem. Over the course of my teaching career I began to discover the areas of the physics curriculum with which students had the most difficulty, and to explore ways that might help them to make the connections between their own experiences and class discussions. Without realizing it, I was personally engaged in a process that was receiving much focus in educational research circles in the 80's and 90's – how do we promote conceptual change from the students' common sense / alternative conceptions to the scientific conceptions they require to do well in science? As diSessa & Sherin (1998) rather bluntly ask – "what changes in conceptual change and how do I facilitate that process?"

> "Teaching and learning science have become increasingly complicated tasks. It seems that everyone connected with science education wants students to understand science content at some deeper, unspecified, level." (Beeth & Hennessey, 1996, p. 4)

There is considerable literature on the topic of creating conceptual change in students. Duit (1993) reported that over 3000 empirical studies on various aspects of students' conceptions were published over 25 years. In the ten years since Duit's article there has continued to be much research conducted on conceptual change, but interestingly, there have been few new conclusions made beyond the observation / truism that it remains a problem both for teachers and their students. In an extensive literature review on conceptual change, Martinez (2001) concluded that from 1975 to 2000, very little had changed in conceptual change theory. Getting students to change from their intuitive, practical alternative conceptions of the world to more scientifically applicable conceptions continues to be a problem for teachers and a focus for research. "…children do not recognize the difference between scientific and general ideas about the world" (Dickinson & Flick, 1997, p. 3). This continuing concern prompts me to ask: *Is it reasonable for teachers to expect all students to undergo significant, permanent conceptual growth in science?*

What is conceptual change?

In order to understand / appreciate the conclusions / concerns of teachers and researchers it is necessary to define specifically what is meant by a *concept, conceptual change, alternative conceptions and scientific conceptions.*

What should we count as a concept? Labelling something does not give any indication of how different people perceive that concept and apply it to their own lives. A young child will apply the concept of 'dog' initially to any four legged, hairy organism they encounter – including cats, sheep and so on. Through making mistakes and being subjected to new labels and organisms, that child's concept of 'dog' will narrow until he/she is able to differentiate between concept differences as subtle as dog and wolf. What focuses our understanding of different concepts is the context and explanations we receive as we progress through life. When attempts are made to apply different explanations for concepts that have already been filed away as "understood" (as we do in science) then, potentially, students will resist by relying on their own experiences with these concepts. It is thus quite difficult to give a definition for 'concept' that is accepted by all researchers. In fact there are many articles that focus exclusively on establishing a definition of what a concept is (diSessa & Sherin, 1998). For instance, Keil (1979) suggests that a concept is limited to the fundamental part of its usage that exists across all contexts (as an example, only the atomic form of carbon exists across all of it permutations, like charcoal and diamonds, and therefore Keil would suggest that the concept of carbon must be limited to its atomic structure). However, for this paper, I will use the definition established by Zhou (2002): A concept is a class of objects, symbols, and events that are grouped together in some fashion by shared characteristics and find their meaning within a theoretical context. Thus conceptual change becomes a change in the cognitive structures or schema (as well as the networks that connect these cognitive structures) that students build their concepts into. At a practical level, this would translate into students fitting new and relearned concepts into a framework that more closely resembles the more scientific, publicly promoted understanding proposed by their teachers.

In order to establish where conceptual change starts and stops, it also becomes necessary to establish what concepts students have before being taught – their alternative conceptions - and what concepts the teacher desires to have them learn – the scientific conceptions. Again, there is considerable literature describing different ways to label this pre-post progression. Some of the labels that have been used are “preconceptions”, “alternative conceptions”, “personal / private knowledge”, “misconceptions”, “naïve science”, “children’s scientific intuitions”, “children’s science”, “common sense concepts” and even “spontaneous knowledge” (see Eryilmaz, 2002 for a review of the origins of each of the descriptive terms). For this paper I share the belief of Dykstra, Boyle & Monarch (1992) that “alternative conceptions” best describes the conceptions that students have upon entering the science classroom. They are alternative to those the teacher hopes to teach the students. They are not wrong in the sense that the word “misconceptions” suggests, since they have served the student well in his/her everyday life. Nor do they exist only before class as “preconceptions” suggests, since students continue to carry these conceptions with them through class and often after class as well. Learning the “scientific conception” is one of the goals of science instruction. Students are encouraged to reach levels of comprehension that will allow them to apply their unique understanding of science to natural and technological phenomena they encounter that are incorrectly explained using their alternative conceptions.

In 1982, Posner, Strike, Hewson and Gertzog proposed a conceptual change model (CCM), which became a common starting point for much research that followed it. Posner et al listed four conditions required for conceptual change to occur:

(1) "There must be dissatisfaction with existing conceptions."
(2) "A new conception must be intelligible."
(3) "A new conception must appear initially plausible."
(4) "A new concept should suggest the possibility of a fruitful research program." (p.214)

Posner and his colleagues quite openly cited Kuhn (1970) and many times in their work they refer to him as the source of their model. "A major source of hypotheses concerning this issue [conceptual change] is contemporary philosophy of science." (Posner et al, p. 211).

When the above four conditions are compared with Kuhn's description of how science progresses through scientific revolutions, the similarity is striking. Kuhn detailed the appearance of anomalies that lead to scientists' dissatisfaction with the old paradigm (similar to 1 above); the appearance of a new paradigm that offers scientists a choice (similar to 2 above); and the merits of the new paradigm allowing more accurate predictions, more problem solving and more compatibility with the subject matter (similar to 3 & 4 above). The similarity between the origins of constructivism and conceptual change theory has led to much parallel work / research in the two fields. Conceptual change in science education is fundamentally or, at least usefully, homologous to the dynamic of change in professional science communities (Duschl, Hamilton, & Grandy, 1992). Thus, having a working knowledge of how science communities have changed, and why, gives some insight into how conceptual change is believed to occur.

Posner's conceptual change model was considered a seminal work in the field of conceptual change because it was the first to propose a mechanism by which teachers could attempt to create conceptual change in their students. It has since been criticized many times (most notably as a purely cognitive model which ignores social and contextual factors), but still serves as a foundation from which many studies regarding conceptual change originate.

Since the publishing of Posner et al's Conceptual Change Model, other models have begun to emerge that both acknowledge its contributions as well as modify that model to include some social constructivist leanings. For instance, Driver & Easley (1978, p. 68) specifies the type of teaching required to promote conceptual change in students:

> - Providing opportunities for pupils to make their own conceptions about a particular topic area explicit so that they are available for inspection;
> - Presenting empirical counter examples;
> - Presenting and reviewing alternative conceptions; and
> - Providing opportunities to use scientific conceptions.

In much of the literature detailing mechanisms utilized to promote conceptual change, the most common instructional strategy is to confront students with 'discrepant' events that contradict their existing conceptions (Tao & Gunstone, 1999). Students must be placed in a situation that creates conflict between their alternative conception and a problem situation that the alternative conceptions cannot be used to solve. Essentially the students' existing schemas of the world are pressed for their adequacy, consistency, and explanatory power and then the scientific conceptions are introduced and shown to be better at providing a more defensible, acceptable prediction or explanation for the problem (Macbeth, 2000). This conceptual conflict has been advocated as being effective at promoting conceptual change in students.

There is some evidence to suggest, however, that the type of conceptual change undergone by each student is not uniform. Dykstra, Boyle and Monarch (1992) propose a more progressive conceptual change from differentiation through class extension to reconceptualization. Niedderer & Goldberg (1994) similarly suggest that there is an intermediate step between the students' alternative conceptions and the scientific conceptions desired by the teacher. Even more recently, while studying students' conceptual changes in evolution, Demastes, Good & Peebles (1996) identified four patterns of conceptual change:

1) Cascade of changes (one conceptual change begins a sequence of changes – like dominoes falling);
2) Complete changes (scientific conception replaces alternative conception abruptly);
3) Incremental changes (slow progression from alternative through intermediate to scientific conception);
4) Dual constructions (students maintain two distinct logical conceptions applied in different contexts).

Variation can also be seen in the reaction of students to the conflict between their alternative conceptions and the discrepant events with which they are presented. Tao & Gunstone (1999), summarizing the work of a number of researchers, report that students are not uniform in their reaction when faced with discrepant events:

- Bright, enthusiastic students welcomed conceptual conflicts, but unsuccessful students ignored or tried to avoid them;
- Some students failed to recognize that there was a conceptual conflict;

- Some students recognized the conflict but chose to avoid it by passively relying on others in their class;
- Some students resolved the conflict only partially;
- Some students resolved the conflict by stubbornly continuing to use their alternative conceptions.

Variation in response to any initiative designed to address an issue in our classrooms is commonplace. That students respond differently to the attempts to use conceptual conflict to promote conceptual understanding will surprise very few teachers. But does this mixed response suggest a larger problem? Is there some fundamental barrier that students in science must overcome to undergo some form of conceptual change from their alternative conceptions to the scientific conceptions we would like them to have? This paper will review some evidence to suggest that there are basic problems with this goal of promoting conceptual change in science and that, perhaps, we as teachers also need to be realistic when we set out to modify the conceptions of our students.

Alternatives to Conceptual Change

How susceptible to change are the alternative conceptions that students have? Searle & Gunstone (1990) performed a longitudinal study of seven students to determine how well their scientific conceptions (taught to them prior to University) carried over to an entry level physics course at university. Despite the small sample, the result is suggestive of the longer term implications of the conceptual change difficulty students have. Of the seven students studied, only one could be shown to have any significant maintenance of the scientific concepts previously "learned"; the remainder had reverted to levels of understanding more characterized by the application of alternative conceptions. Their conclusion was that alternative conceptions are strongly held by students and highly resistant to change or replacement by instruction, and students' positive attitude toward their physics course did not correlate with increased conceptual ability. Zhou (2002) makes a similar statement about how hard it is to permanently change students' alternative conceptions to scientific conceptions. He quotes a study in which 93% of a high school physics class had a conception of motion considered naïve and not acceptable prior to taking physics, and 80% continued to make the same mistake after *successful* completion of the course. Zhou also refers to work which shows that students were taking high school physics because they felt they had to and not because they wanted to. He further demonstrates that externally motivated students tend to employ superficial cognitive strategies, focused entirely on passing the exam and getting the marks they need to move on to what they actually desire. Motivating these students to develop a deeper conceptual understanding is difficult.

Tao & Gunstone (1999) studied twelve Grade 10 science students to determine the efficacy of conceptual conflict in fostering conceptual change and how this conceptual change is realized. They concluded that conceptual conflict did not always produce conceptual change, and that for it to be effective it needed to be paired with an opportunity for students to reflect and reconstruct their conceptions. Even more striking was Tao & Gunstone's second assertion, in which they state that "Students vacillated between alternative and scientific conceptions from one context to another during instruction. Their conceptual change was context dependent and unstable" (p. 872). As a physics teacher I often observed students who were able to apply scientific conceptions within the context of the class and topic studied, but even switching to another room could result in confusion about how to apply the conceptions they had previously learned. Their scientific conceptual ability was somehow tied to what they spatially and mentally associated with what they had just learned. Changes to those associations diminished their ability to use their newly learned scientific conceptions and they would revert to their alternative conceptions.

> "Conceptual change… is a slow process during which students achieve contextually based change in a range of contexts, and based on these conceptions they may reorganize and systematize their cognitive structure and acquire conceptual change across the contexts. Context-independent conceptual change is exceedingly difficult, and students may fail at any intermediate stage during the process" (Tao & Gunstone, 1999, p. 876).

Macbeth (2000) offers a simple explanation for why students have so much difficulty permanently switching from their alternative conceptions to the scientific conceptions we would like. Students begin science instruction with a wealth of life experience that serves them well for successfully navigating and anticipating what the world presents. Students do not need to know Newton's laws of motion to operate their bicycle nor be able to anticipate what will happen if they hit a wall with that bike. Students' Aristotelian perspectives serve them as well as it did the people before Newton and his discovery of the laws of motion. Physics may be unique in how students' conceptions can actually hinder the learning of the subject.

> "What must be taught cannot easily be found elsewhere, and worse, what *is* found elsewhere inveighs against the aims of science instruction. The resistance to change that science educators find in their students' naïve and incommensurable ways of seeing and thinking about the natural world is thus both an obstacle and distinguishing mark for science education." (Macbeth, 2000, p. 234, emphasis in original)

Students' life experiences are often used as foundations for the writing of a poem in English or the evaluation of a social effect in social studies, and although we seek to make similar connections with students' lives in science, this often helps foster the maintenance of the very alternative conceptions we seek to 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." (Zhou, 2002, p. 43)

Dykstra, Boyle & Monarch (1992) share a similar perspective to Monarch but take a decidedly constructivist approach to the problem. They argue that presenting a student with Newtonian arguments will do little to develop scientific conceptual understanding because it makes little sense in the context of his / her own beliefs. They believe that the focus in physics should not be on the scientific concepts desired to be conveyed to the students, but rather "should focus on *students'* beliefs about the world, which means that such beliefs have to be identified" (p. 619, emphasis in original). Dykstra et al go on to describe how students can 'get by' and even be successful by memorizing formulas and problem solutions with no awareness of the underlying situation-independent conceptions, simply because they are not being evaluated on their conceptual understanding but rather on their performance.

Adams & Chiapetta (1998) studied junior high honour students entering their first high school physics class in order to evaluate the effect that the students' beliefs about the nature of science (and their attitudes toward physics class) had on their conceptual development. They came to three conclusions. First, that physics students in general did not find that the study of physics was relevant to their everyday experiences and, therefore, were reluctant to try to tie the scientific conceptions they were learning in class to the experiences they were having outside of class. Second, the students who did demonstrate high conceptual change were more likely to have a logical view of the world and also a view that closely resembled the teacher's own view of the nature of science. Third, that the students who demonstrated high conceptual change were able to develop an internally consistent understanding of the content. Interestingly that content was often constructed as isolated knowledge that operated separately from their alternative conceptions back in their everyday worlds. In other words students had constructed two worlds – a "physics world" in which they had a good scientific conceptual ability, and a "real world" in which they used their already present alternative conceptions.

Research on conceptual change in students is quite uniform in its belief that changing students' alternative conceptions to more scientifically acceptable conceptions is a difficult process, and making that change permanent is even more so. It is affected by evaluation practices, context, ability, motivation, teacher ability and belief as well as many other factors, yet none of the studies reviewed suggest stopping research into how to best facilitate conceptual change.

Data

Since this is a grounded theory study, the data collection process was driven by the students, and their responses during previous interviews became the backbone of what I asked them in subsequent interviews. I wanted to provide the opportunity for the students to tell me exactly what they believed was important without my expectations or biases influencing them beyond setting the general topic area for them to discuss, i.e. conceptual development in physics. What I learned in the early interviews is that the students were not qualified to give me a truly objective and personal comment on what is best for them with regards to their conceptual development for two reasons. First, the very nature of approaching students of a selected demographic (Physics 30 students) within their classrooms overshadowed my study since I was associated with their teacher and essentially I believe I may have been grouped as another teacher in their minds (at least initially). Thus, I could sense they were trying to determine if what they were telling me was eventually going to filter back to their teacher (for either good or bad reasons). Secondly, students can only evaluate what they have been exposed to. I found this to be a pivotal point in my study. I falsely assumed that students would be aware of their learning styles, needs and preferences with regards to learning physics and therefore would be the best qualified to discuss what should be done in the classroom that would help them develop conceptually. What I soon learned was that students were not discussing necessarily what was best for them – they were discussing what was best for them *based on what they had been exposed to up until that point.* Thus, the focus of their teacher and the logistics of the class and school had a large role to play in what the students related as important to them. In educational research this is often described as the learning environment and there is much literature, such as Wilkinson (1988) and Lawrenz (1976), describing the influence the learning environment has on physics students. I was unable to find any research, however, on how a student's perception and thus interpretation may be bounded by the priorities established in their classrooms by their teacher. At St. John's, the students and teacher openly admit that they almost never do labs in their high school physics classes. This is attributed to a lack of materials and time, and thus the class consists predominantly of lectures and seat work. A participant I will call Jane commented that she did not like labs because they used up valuable time that they did not seem to have enough of anyway, but said that she would like to do more hands-on stuff since she believes she is a physical learner. This obvious contradiction suggests that she has been influenced by her environment but is trying to resolve that influence with what she believes would help her learn better. It is worth noting that all of the participants at St. John's, when contrasted with those at Comp High, tended to choose strategies for learning conceptually that were driven by the lecture/seat work environment they were familiar (and comfortable) with. Most did not even consider hands-on strategies as options until asked specifically about why they chose not to mention them. The students at Comp High did not always value hands-on work either, but it was at least an option available for them to consider and either value or dismiss.

Despite having prefaced this section with the statement that the students may have been strongly influenced by what they had been previously exposed to, the comments they did make about what they valued within the scope of their experience were valuable. These comments, and ultimately the concepts they spawned, showed both overlap and grouping upon analysis. Ultimately I decided to categorize the derived concepts as:

- Non-context-specific factors affecting conceptual development;
- Physics specific factors affecting conceptual development;
- Factors driven by passive recipients;
- Hands-on practical activities and their affect on conceptual development.

One key concept kept surfacing and resurfacing throughout the study, namely students' willingness, personal motivation and drive. When the students' motivation is used as the mindset, the concept categories above begin to connect and make sense. The motivation or willingness mindset helped me understand what the passive recipients stated was the most important, why high achievers are just that, and why the various strategies that make Physics fun, interesting or relevant are the ones that students remember and inevitably are the most valued with regards to their conceptual development.

Non-context-specific factors affecting conceptual development

The factors I have categorized as non-context-specific (either personal or environmental) are what the students valued with regards to their conceptual development, but realistically could be applied to most classes they take and are not specific to science classes in general or physics in particular. Participants were given pseudonyms and any comments given by the student are attributed to the pseudonym.

Connect what I am learning to the 'Real World'

> "The only time that I value physics enough to go beyond the minimum I need to pass is when I am convinced that it affects my life in some way" (Cathy, First interview)

Of all the non-context-specific factors described by the students, this is the one thing that they valued most. Students like to know how what they are learning relates to them. At some point in the interview process, 8 of the 13 participants stated that this is important to them – and over half of these 8 reiterated how important this concept is to them in each of their interviews. Mary stated that she actually likes the math aspects of physics more than the conceptual ones, but if she is to learn conceptually, what she is learning needs to be connected to her own experience. Another student, Paul, tied his motivation level directly to whether he could see the connection between what he is learning and his own life. Emily stated that a real world context allowed her to see what the formulas are for and how they tie to the concepts. This idea is not new to education. As Wilkinson (1999) describes, there have been a number of initiatives developed around the world (such as the Dutch PLON project, the Canadian Large Context Problem (LCP), Event Centered Learning in Brazil and so on) in an attempt to make physics more interesting for students by using a contextual approach to include more science, technology and society issues. Learning needs to be connected to the students' experiences, and a constructivist like Tytler (2002) would even argue that it begins with their experiences:

> "If we believe that knowledge is highly contextual, and the fundamental difficulty in developing new understandings is extending them to new situations, then we need to plan for students to be exposed to a range of situations in which particular science insights can be used." (Tytler, 2002, p.30)

I am responsible for my own learning

As I have come to learn, this is the core concept at the heart of this study. A number of the participants (Jill, Paul, Lucy and Bill) actually related this directly, listing how their own attention, willingness and motivation were the key factor in whether they underwent some conceptual development. However, all of the participants at some point inadvertently used terms like “motivated to learn”, “liked…, but didn’t like that” or even “what’s the point?” In response to this motivation issue, the question then becomes – how do we motivate our students to learn what we teach them? Darling-Hammond & Snyder (1993) have suggested there needs to be a shift in the perspective of the schools and school divisions if the emphasis is to become focused as much as possible on a ‘learner-centered’ approach and away from the belief that schools are only obligated to provide the opportunity not the motivation. In this learner-centered approach, teachers are no longer simply driven by the curriculum, but are also now expected to develop connections with all students in a way that actively helps them construct and use their own knowledge. It may be a bit naïve and ambitious to believe that a teacher can connect on a more personal and motivational level with all of their students, but the shift toward recognizing the value of this is important.

Other non-context-specific factors

A number of other aspects of class were valued by various students as aiding them conceptually and in order to be thorough I will thus describe them here. However, because these were not a recurring theme with the students, with only one or two of them mentioning these as important to their conceptual growth, I will not go into a lot of detail about them within the scope of this paper.

Humour was described as important to a few of the students – it created moments that made the class interesting and motivated the student to want to attend class and listen to the teacher. It could be argued that this ties in to the creation of motivation within the students, but it was described by the participants separately and thus I mention it here as a distinct category.

Sensitivity to the various learning styles was described by a few of the participants as important. Specifically they described a need to "see" the concept in action, in order to understand it. Lucy agreed that being given a visualization of the concept was important, but stated a preference for being able to "manipulate the concept" - describing herself as a "tactile learner".

Opportunity for personal input in the class was seen by some participants as important. Questions asked of the group tended to pass these students by and those moments when they were asked specifically for input were the moments they learned the most conceptually. Both of the participants who mentioned this also mentioned that they understood this was not always possible in a large class but that perhaps they could do more 'small group work' where the chances to offer input individually would be increased.

A few of the students said that formats which minimized surprises were preferable. Particularly noted was homework with keyed answers, test insights, labs with given data and so on, which permit them to focus on the how and why and quit worrying about the marks or having to be right. The students suggested that this builds their own confidence over the semester so that their willingness to think for themselves and thus do better conceptually is increased.

Judy and Bill wanted to be told the origin of the concept they were being taught and why it was important so that they could see a broader applicability – specifically if it was tied to the real world. Seeing the context within which the concept originated gave them a better appreciation of how it might be used in the contexts in which they were being asked to apply the concept.

Time was an issue for two participants in particular. Jane stated that she learns best when she has time to think and reflect, and thus the home environment – with the resources she can access there – is, in her opinion, where most of her conceptual development occurs. Bill mentioned that he tends to default to memory and formulas when he is short on time. Further, he commented that time pressure limits the class discussion from which he personally develops a deeper level of comprehension.

Lastly, Jill wished for a welcoming environment in which she feels comfortable to learn and to risk being wrong. This environment motivates her to attend class and participate, a scenario she contrasts with classes where she does not feel that way.

Physics specific factors affecting conceptual development

The factors I have categorized as physics specific are experiences and strategies that are either commonly used in teaching physics or are somewhat unique to the physics class (as compared with the other subjects the participants were studying concurrently).

Repetition

Students want to practice using the concepts they are being taught in as many different contexts as can reasonably be provided. The overwhelming majority of the participants noted that doing a series of questions using each concept they were expected to learn helped them to make deeper conceptual connections. One student, Paul, stated that after doing many questions he almost passively began to see how the concept could be used in different contexts and how it might be applied in situations he had yet to be exposed to. He began to see the deeper commonalities that applied to all situations where the concept was being used. It was carefully pointed out by Jill and Emily, however, that they did not want the same question with just different numbers to crunch; they wanted a variety of related questions that used the core concept in new contexts and in different formats. Problem solving is a prominent strategy used in physics classes and ways to improve this process have been the focus of much research (see Sambs (1991) for some ways to combine mathematics and physics problems solving strategies, for example). Kim & Pak (2002) would seem to contradict the norm however, in that they found no correlation between the numbers of problems that students did in physics and increased conceptual understanding. The Korean students they studied showed no significant improvement in their conceptual understanding despite showing immense improvement in their algebraic abilities. They suggest that efforts need to be made to ensure the use of strategies other than problem solving if the goal is to have the students improve conceptually. The participants listed above did state they believed repetition of problems was helping them conceptually; perhaps it is not just the repetition that is important, but the use of the practiced concept in many different contexts that is helping them develop conceptually, as suggested by Jill and Emily.

Let me know I am right or why I am wrong

Judy, Paul, Lisa, Cathy and Jill all related that they wished for fairly immediate reinforcement about the work and questions they were doing. This could be provided by the teacher directly, but answers given out with the assignments were considered to be just as effective. They liked being able to determine if what they were doing and the way they were conceptualizing the questions was resulting in them getting the right answer. They did not want to spend large amounts of time learning a concept a particular way only to find out that what they had believed was accurate was in fact not, and thus what they had learned was flawed in some manner. Lisa and Jill reflected that in those moments when this occurred they could not be bothered to go back and 'fix' their mistakes and the way they thought about the concept, since it required too much effort and time – they had lost their motivation. As a physics teacher I understand the value of giving students the answer, but I have seen many students take the easy way out by either working backwards from the answer itself or by using trial and error in an attempt to stumble upon a method of producing the expected answer, with very little learning of the concept taking place. When the students listed above were asked whether this practice of giving them the answer made them lazy with regards to their willingness to struggle for their own comprehension, Jill summed it up nicely with the response that the chances of them learning conceptually were better if they worked with the knowledge that they were right, rather than finding out after the fact that they were wrong. She also went on to describe how knowing the work is done correctly builds confidence that carries over into situations like exams and quizzes in which the answer is not given. Immediate feedback is not a new idea in educational research. Both Barringer & Gholson (1979) and Fuller (1976) contend that immediate feedback, either in verbal or symbolic form, reinforces the concept the student is learning and thus increases the retention of that concept. As Fuller (1976) describes, it is based on a simple educational principle "If I receive something good soon after and as a result of a task I have performed, I will have a strong tendency to increase the number of times I perform the task." (p. 259)

There are two kinds of physics – Mathematical and Conceptual

Five of the thirteen participants saw physics as being composed of two distinct components: a mathematical component in which students use formulas and their calculators to derive correct numeric answers to the questions they are being asked, and a conceptual component in which they are asked to "think" and to relate their answers in words and descriptions. The math was described as having a "way" that could be learned and mastered that required little thought beyond memorizing which formula to use in which situation. In fact all of the participants who saw a dichotomy described the mathematical component by drawing analogies to what they do in math class. I would bet that their math teacher would be disturbed to learn that their students believe they need nothing deeper than knowledge of techniques and formulas to master math. By contrast, the students' descriptions of the conceptual component seemed to address the 'why' of situations and how they could be used in new contexts. I found it disturbing that these five participants did not see any connection between the two components, beyond needing to be able to do both well in order to get a good grade in the class. In the research done by Kim & Pak (2002), the Korean students they discussed were very clearly being taught the mathematical/analytical components of physics separate from the conceptual components (if there was any conceptual component at all). Hewitt (1994) suggests that most physics classes (either inadvertently or intentionally) do have a dichotomy between concepts and computation and that not only do these areas need to be bridged, but that by beginning with the concepts, a more context rich and thus conceptual environment is built around the calculations that inevitably follow in physics.

Other physics specific factors

The other factors that were listed by the students as important but were listed by only one, or at most two, of the participants were as follows.

Cathy listed evaluation in class as an important factor in what she learned conceptually. Essentially she stated that what is being marked narrows her focus toward what she believes the teacher is indirectly telling her is important (by choosing that particular concept to be evaluated), and thus she goes out of her way to make sure she learns the evaluated concepts well. Henry stated that he believed that evaluation in general makes students into more efficient learners by focusing them on what they need to learn to be successful in class, but limits their willingness to go any deeper.

Judy and Bill appreciated having the material they were learning re-explained to them by their fellow students or peers who understood them and their mindset better and were thus capable of explaining the concept at a level they could grasp and see the deeper meaning in.

Lastly, Jill believes that physics is a whole other way of looking at the world and is not as intuitive as perhaps other subjects that she inadvertently grew up being exposed to (for example nutrition, conservation, body awareness and so on all set a good context for the eventual study of biology). She needed to learn the way to think about physics before she could begin to learn the concepts she was being taught (even though she now realizes that physics was all around her through life as well – she just could not make that connection as quickly as she did for most of her other subjects). She stated that her conceptual development in the last year or two of taking physics has improved predominantly because she now knows how to think in a way that enables her to understand the explanations she is being given.

Passive nature factors

I was hesitant to use a heading that effectively attributes a number of factors that affect conceptual learning in physics to a particular personality type that we see in our physics classrooms. However, these were significant factors that influenced conceptual development and their origins lay not within the structure or the format of the classroom directly, but rather in the motivations and basic willingness of the participants themselves. It is possible to modify teaching to be more effective for these students, but I believe it is important to acknowledge the origins of these factors that affect the conceptual development of many students in the physics class. Physics seems to be a subject that naturally discriminates between those with willingness and those with none. The applicability of concepts to so many contexts favours students that are motivated to look beyond 'the way' to the deeper connections underneath. Student interest, drive and motivation are what allow for true conceptual change. Tasks dismissed as "have to" or as simply for marks seem rarely to be internalized at a conceptual level.

Physics is only a prerequisite

I was quite surprised to learn that the majority of the participants were taking physics simply because it was a requirement for entrance into the program they wanted to take at university. Jane admitted to using learning strategies that were dogmatic because (in her own words) "she is only doing this because she has to". She has no interest in physics and does not care for anything beyond being told the 'way to do it'. She knows this is not the best way to do well or to learn the material at some deeper, lasting level, but she does not care – she "just wants to get it over with". Emily also said she was looking for the easiest way through - "I just want to get my credits so I can get out of here".

Of the seven participants who admitted to wanting to simply pass physics, the most common strategy they used was repetition of the formulas they were given and told they would need for the exam. Their attitudes suggest that they do not care if they understand anything about the formulas beyond what kinds of questions require the use of them. It is no surprise that these students do not seem to make many deeper conceptual connections in physics. This suggests that the largest determiner of success, be it conceptual or otherwise, is not the strategy used or course structure; rather, it is the inherent willingness and motivation of the students themselves that is the largest determiner of whether students gain conceptual understanding. Barlia & Beeth (1999) focused very specifically on the role of motivation in conceptual change learning. They concluded that teachers need to convince students that learning for conceptual change is a valuable task, and that students need to find applications for their new conceptions within their everyday lives. Other factors such as the teacher's personality and the classroom environment were also noted as significant influencers of student motivation. It is hard to imagine why any student would bother to learn conceptually if they could find no relevance or connection to their everyday lives (beyond being made to) – but this would be particularly difficult for those students who are only taking physics because they are required to.

Other passive recipient factors

A number of students had insights that I have attributed to a rather passive approach to their own learning in physics, but these comments were not widely represented in what other students had to say about conceptual learning. Again, I list them here so that a better scope of the factors discussed by the students is realized, even though they are not the focus of this paper.

James has complete confidence that whatever his teacher chooses to emphasize and reinforce in class will prepare him to do well on the final exam in physics. His learning is driven entirely by what the teacher values and compels the class to learn. There is no willingness to learn beyond what he is told is important. He relies on his teacher not only for his insights, but also ultimately for the motivation to learn what he has been told is important. What is the influence on the conceptual development of a student who has no will beyond what the teacher prescribes? In a similar manner, Judy has attributed her love of physics to her teacher, and thus is motivated to do well because she likes the teacher (as compared to her poor performance in the previous year, because of her expressed 'hatred' of the teacher). In both these examples it would seem that the responsibility to learn conceptually and do well in physics has not been accepted by the student, but is driven by the teacher and the relationship he or she has with these students.

Cathy is a good example of a student who likes some aspects of class and believes that they are helping her conceptually; however, she admits she does not know what else might help her, even though she has heard about some 'cool' things that other students are apparently doing. She stated that she does not value hands-on activities because she has never done them (although she suspects they would help her).

Hands-on activities and their effect on Conceptual Development

The specific focus of my research has been to identify and evaluate the factors Physics 30 students believe to be important in their own conceptual development. Further, I wished to learn what role technology served in this process and more specifically, whether the Modular Approach to Physics (MAP) was valued by the students in the process of increasing their conceptual understanding in physics. This was a delicate line to walk, since the very nature of grounded theory is to let the students originate the data that becomes the backbone for the analysis that reveals the significant theories or generalities that can be generated from the students' responses. How do you get the participants to discuss whether computer technologies have a role in their conceptual development without inadvertently pushing the participants to discuss something that may not have occurred to them to include as important? In the end the students did discuss the impact computers as well as other lab-type activities had on their conceptual development in what they inadvertently grouped as hands-on activities. Perhaps even the observation that students did not consider the use of computers to be significantly different than doing a lab is in itself important.

Value of Practical activities

As mentioned earlier, there was some consistency in the responses of the participants when grouped together by school. The students at St. John's had never done any formal lab work in physics class, and over the duration of the study had yet to be exposed to the MAP simulation applets. As a result, most did not even consider mentioning any form of hands-on activity as important in their conceptual development. When told that other students had listed some forms of practical activity as important, the students at St. John's fairly consistently dismissed them as unimportant. Jane, for instance, outright dismissed all forms of practical work as not worth the time for what is gained. Lucy also dismissed practical work as unimportant, but more because it was just another "hoop to be jumped through" in physics. Not one student at St. John's stated that they thought practical work could help them conceptually, despite three of the participants at that school stating that they suspected they were either physical or visual learners.

The students at Comp High had done a number of labs as physics students and also had worked with the MAP simulation applets 4 times during the study. Without exception, all the participants at Comp High did mention practical work at some point in the interview process, although not all valued it with regards to their conceptual development. Bill described hands-on work as "doing [labs] because you have to" and because they are worth marks. "You look for the right answer and then move on. There is not enough time to consider anything you are doing at a deeper level" (Bill, second interview). In a similar tone, Judy described labs as “fun, but a waste of time. They are not about making deeper connections or experiencing the concept; they are about doing the procedure, getting an expected result and getting a mark” (Judy, second Interview). Nonetheless, some of the participants did state they valued labs because they provided another source of visual reinforcement of what they were learning. White (1979), in an evaluation of the merits of practical work with regards to cognitive development, acknowledges the benefits of labs for physics students’ motor skills, but reports that the traditional approach of following a set format to acquire a set result does little to aid the students cognitively. He suggests adding three forms of practical work that would increase the students’ comprehension of the physics concepts being studied. First, doing labs that engage the emotions by being odd, dramatic, beautiful or puzzling; these labs are both motivating and easily recalled later on. Second, doing labs derived from contexts that are directly related to the students’ everyday experiences. These provide meaning and context for the concepts being studied. Third, White suggests doing labs that are true attempts at solving problems with unknown experimental designs or outcomes. These types of labs ask the students to use the concepts they are developing in class in a practical manner to reach a solution – a highly effective tool for promoting permanent conceptual understanding.

Labs can be effective tools to promote the use and application of learned concepts in a practical environment, however using them purely as an alternative form of evaluation or simply as a way to show the concept in action would seem to have little long term influence on the students.

The Modular Approach to Physics (MAP)

The Modular Approach to Physics is a series of computer simulations that mimic situations in the world and allow the user to anticipate and analyze the simulated results of a number of real world systems that are commonly discussed and analyzed in physics class. The participants at Comp High worked with the applets during the study, and without exception when asked if computers in general had any influence on their conceptual development in physics, began an evaluation of the MAP applets. Apparently this was the only exposure that these students have had to computers in their physics class.

Bill related that he did not like the applets as much as labs since he felt that he was rushed and that it was being used with concepts he already understood. On the other hand he did like the way that the applets 'showed' him a theoretical concept.

Henry, by contrast, loved the applets and the way that they allowed him to play with a concept and see the result, without ever having to apply and calculate any specific values from it. He even specifically described it as a "stage setting conceptual tool" in our second interview.

James considers himself a bit of a computer expert, and said that since he already loves to work with the computer, it was inherently motivating for him to learn at a deeper level. Also because of his familiarity with the computer, he related that he did not think that he had as many problems 'playing' with the applets as some of his classmates did. James even went on to describe the MAP applets as his favourite conceptual tool.

Judy also loved the applets, because unlike labs, they allowed her to visualize the concept and keep flawless control in a risk free environment. She believes labs can go wrong in so many ways and seem to be more about getting the right answer than understanding the concept. The applets to her were all about illustrating concepts she had only thought of as mathematical before using the applets. She believed that her conceptual understanding of those concepts illustrated was much better after using MAP than before.

Lucy admitted she knew that the MAP applets she was being asked to use were for her to increase her conceptual understanding in physics, but had great difficulty getting them to work for her nonetheless. She said that unless what she was seeing was accompanied with an explanation of how what she learned in class (and had written in her notes) was related to what she was doing on the computer screen, the applets made no sense to her.

Summary of Participants' Positions on Conceptual Growth

Participant	Summarized Basic Position
Jill	- Takes responsibility for own learning - Humour helps motivate to learn - Is affected by learning environment - Likes to do many questions in different contexts - Prefers immediate feedback - Physics is different than anything else - Labs are not a good use of time, but are fun
Jane	- Needs more time - Views mathematical and conceptual physics as separate - Taking physics because she has to - Labs are not a good use of time
Mary	- Prefers 'Real World' context - Taking physics because she has to
Cathy	- Prefers 'Real World' context - Prefers immediate feedback - Views mathematical and conceptual physics as separate - Evaluation drives motivation - Taking physics because she has to - Values what she has been exposed to - Labs are not a good use of time
Lisa	- Appreciates opportunities for own input - Prefers immediate feedback - Physics is math with notes - Taking physics because she has to - Wants to be asked to participate but will not volunteer
Paul	- Takes responsibility for own learning - Prefers 'Real World' context - Needs to see it to understand it - Likes to do many questions in different contexts - Prefers immediate feedback - Views mathematical and conceptual physics as separate
Lucy	- Takes responsibility for own learning - Prefers 'Real World' context - Needs to see it to understand it - Appreciates opportunities for own input - Likes to do many questions in different contexts - Labs are not a good use of time - Recognizes MAP is a conceptual tool, but has difficulty with it anyway

Summary of Participants (Cont.)

Judy	- Prefers 'Real World' context - Humour helps motivate to learn - Prefers immediate feedback - What is the origin of what I am learning - Likes to do many questions in different contexts - Prefers explanations at own level - Believes teacher will get her through - Labs are a good use of time – good visual tool - Likes MAP because it allows her to visualize and play in a risk free environment
Bill	- Takes responsibility for own learning - Prefers 'Real World' context - Prefers immediate feedback - What is the origin of what I am learning - Needs more time - Likes to do many questions in different contexts - Prefers explanations at own level - Labs are not a good use of time - MAP shows concepts but is no better than labs
Emily	- Prefers 'Real World' context - Likes to do many questions in different contexts - Taking physics because she has to - Labs are not a good use of time - Likes how MAP allows her to see the concepts - Can't use technology at home
Brad	- Humour helps motivate to learn - Likes to do many questions in different contexts - Views mathematical and conceptual physics as separate - Taking physics because he has to
Henry	- Evaluation drives motivation - MAP encourages 'playing' with a concept - Physics is common sense – the physics he does at home is beyond what he is taking in school.
James	- Prefers 'Real World' context - Believes teacher will get him through - Likes MAP because it is on the computer

Discussion of Research Questions

This study was driven by a very basic question: *What is the students' perception of their conceptual development in physics?* The conclusion (assumption?) that students with greater conceptual understanding will achieve better grades, retain more of what they are taught later on in life and will be able to apply what they are learning in more situations seems reasonable and has been the focus of other research (Beeth & Hennessey, 1996; diSessa & Sherin,1998; Driver & Easley,1978). Some researchers / teachers have suggested that we need to pay more attention to the human aspects of science, realizing that scientific theories are human constructions, and the students' experiences in science are valuable tools in obtaining conceptual understanding (Brouwer, 1995). It seems odd then that little research has been done on what the students themselves believe significantly increases their conceptual understanding. Are they even aware of a progression or what is helping / hindering them?

As discussed earlier in this document, one initiative being developed specifically to increase student conceptual understanding is the use of computer generated applets in which students interact with a modelled everyday system on the computer. An example of these applets is the Modular Approach to Physics (MAP) project, and research such as that done by Zhou (2002) showed that these applets can be effective at increasing the conceptual understanding of physics students. Once again however, I found myself asking if the students think so as well.

Since there seemed to be a number of issues that went deeper than the overall question listed above, I decided to create three sub-questions that I would address within my research as well. They are:

1) To what extent are physics students aware of progression or improvement in their conceptual understanding?
2) What classroom activities and environments do physics students value with regards to their conceptual development?
3) Do physics students perceive that MAP has an impact on their conceptual development?

In this section I hope to address each of these sub-questions in turn, using the observations and categories derived from the data to support any conclusions made, then by addressing the overall research question distil the overall theme or conclusion to which my research has led me.

To what extent are physics students aware of progression or improvement in their conceptual understanding?

To the average person, the idea of conceptual understanding and whether it changes with exposure to physics and time is not something that is considered, and these student participants are no exception. At the beginning of each of the three interviews with the students, it was necessary to explain conceptual understanding, although each was given the opportunity to explain it to me first, and thus I could build upon their own ideas and what they remembered from the previous interviews. Theoretical definitions were not very effective at helping them to understand what conceptual understanding was, but analogies and examples drawn from some of their own experiences were. However, once it became clear to them what conceptual understanding was, all of the participants except one stated they were aware of their own progression and could explain why they believed so.

Cathy, Judy, Emily, Brad and Henry all referenced their awareness of the world around them as proof of their progression. They could now see how systems in the world could be explained with physics, whereas when they started taking physics they could not.

Jill could not delineate as clearly the difference between achievement and any growth in her conceptual understanding when she noted how she now found physics easier and new topics no longer produced as much stress. She did offer an interesting insight in that she described how she could see the connections between the concepts and units taken and they did not seem as distinct as they did when she began taking physics.

Bill, Jane and Mary saw their improvement conceptually as a move away from being so formula dependent (as they were in Grade 10) towards a feeling of knowing what to do because “it just makes sense”. Bill described this as feeling like he has a bigger toolbox than just his formula sheet and calculator to help him find the solutions. Mary went on to share that she was much better at the ‘why’s’ and the application of the concept to new circumstances than she was at the beginning.

Although students do not think in terms of formal labels like conceptual understanding, based on the responses noted above, they seem to be aware of a progression toward a more holistic, deeper comprehension of why situations require a particular way of looking at them, and away from a concern with how to do the calculations. Further, they also begin to see the connections between concepts and how they might be applied to new contexts or other everyday phenomena. It seems reasonable to conclude that students are qualified to offer an evaluation of what strategies and techniques are best at helping them gain a greater conceptual understanding of the material they are being taught in physics.

What classroom activities and environments do physics students value with regards to their conceptual development?

As detailed in the data section above, the participants gave quite varied opinions about which activities were the best to use in the class if the teacher wants them to gain a better conceptual understanding of the material they are being taught. These opinions were strongly influenced by the physics teachers since it was the choices of their teachers that essentially created the alternatives that the students considered when relating what they valued. Students who were not exposed to particular activities in physics, did not list them as important for their conceptual development even if they had been exposed to them in other subjects they were taking. This devaluing seemed to be based either on the students just not having any awareness of the alternatives, or them assuming that if it was not being used it must not be as good as what they are doing now. The activities or strategies they did identify were not new to me as a physics teacher, but the emphasis and reasoning they used for their opinions were valuable to learn.

"Connect what I am learning to the real world" as stated in the first interview by Paul, voiced a common perspective of the participants. Some wanted to see the context for the concept they were using, so that it would make more sense to them and so that they would know when to use it. Other participants wanted to derive a personal connection from what they were learning; they wanted to be convinced it was important or interesting for them to learn the concept (as a source of motivation). Whatever the reasoning, activities that related the concepts they were using to their lives (either immediately or even more globally), were valued above the more theoretical types of learning activities like discussion of the formulas or writing of the theory behind the concept.

Repetition of the concepts in different contexts was also a valued strategy. The participants who listed this as important stated that if they were to understand a concept at a deeper more applicable level, they needed opportunities to see and use the concept in as many different contexts as was reasonable given time constraints. Unfortunately for some of the participants, I believe this repetition was valued since it gave them more contextual cues to memorize in the hopes that the exams would use the same contexts and would not require them to analyze new situations. However, for many of the students, like Paul, repetition of problems allowed them to begin to see patterns of how the concept is used and allowed them to apply the concept to new problems and contexts that were given.

Another insight offered by the participants was that it is not as much the selection of a specific activity, but rather the way the activities and teaching strategies are being used in their physics class that is relevant to conceptual development. Many of the participants desired to know whether the way they were learning the concept and applying it in their problems was correct and if it was not, the reasons they were wrong. This was more an issue relevant to designing activities or homework in a manner that gives the students immediate feedback on their work. Admittedly, some of the students simply wanted an easy way out, but most recognized that they needed to be able to use this concept later on (if even just for the final exam), and so used this feedback as a way of redirecting themselves toward the accepted way of using the concept. As a teacher I have too often seen students do problems later in a course with only the recognition that they have done the problem that way before, and with no cognizance of whether that way was correct or flawed. It would seem to be wise to ensure that students use the concepts properly and repeatedly as much as possible – without spending their time practicing a flawed conceptualization of the problem.

A typical physics class in the schools I observed follows a fairly consistent format. Teachers call students to order, go over the homework and ask for problem areas, present, discuss and provide notes on the new concept of the day, do a few examples using the concept in problems and then allow the students to practice on their own with more problems; repeat the next day. This is a fairly efficient way to present the concepts the students are expected to learn, but may be one of the factors contributing to an issue raised by the participants in this study. Approximately half of participants stated that physics is dichotomous in that it has a conceptual aspect and a mathematical / analytic aspect – "we do the theory and then we do the math", as so eloquently described by Jane in her second interview. The students who described an awareness of this separation discussed how they had difficulty determining how these two aspects originated from the same concept, and described using different strategies to learn each aspect. For the theory section they described looking for understanding of the concept and the context it came from, for the math they looked for how the problems fit formulae from the formula sheet best. Initially this issue arose because the participants assumed that when I wanted them to discuss their conceptual understanding it was the "theory" aspect of physics I wanted them to focus on and not the math aspect. For most it was quite strange to think that there is any conceptual component in the problems they were doing with their formula sheets and calculators. When the participants were asked how they might merge these apparently separate worlds, they suggested creating activities and problems that require a combination of theory comprehension with the more mathematical analysis that is such a large part of physics. Unfortunately for many physics students, this combined exposure does not happen until they write their final exam. In an attempt to address this issue, the students at St. John's were given a "unit assignment" which was very carefully created to compel the students to combine an explanation of the theory behind the formula with a mathematical analysis and then further discussion of possible alternative applications.

It should be noted that many of the participants do not blame the teachers or even hold them responsible for their conceptual growth. It is believed that the teachers should only be required to present the material and it is subsequently the students' responsibility to learn it well enough to be able to explain it conceptually or otherwise. For Bill it was simply logistics; he required more time to learn things at a deeper, more conceptual level, time of which there was not enough in class. He therefore stated that most of his learning takes place at home when he has a chance to stop and think about what he is being asked to learn and what its connection is to his previous learning and to his own life. Thus, the resources he has available to him at home (like his text, siblings and parents) are important contributors to his personal conceptual growth.

As may be apparent, it is difficult to specify activities or strategies that are the most effective at enabling all physics students to gain a better conceptual understanding of the material. Each student as an individual learns in his / her own way and each values activities based on their own priorities and tastes. The similarity of the participant-derived insights above suggests that there are some common issues that we as physics teachers need to address when designing our lessons if we are to help our students increase their conceptual understanding of the material we are presenting.

Do physics students perceive that MAP has an impact on their conceptual development?

Long term conceptual development in physics students is a goal of virtually every one of these students' teachers (whether they choose to categorize it that way or not). Posner et al (1982), Macbeth (2000), diSessa & Sherin (1998), Eryilmaz (2002) and so on have all suggested initiatives designed to improve the conceptual understanding of students. The Modular Approach to Physics (MAP) is one such initiative and at its heart it was designed to foster improved conceptual ability in the physics students by immersing them in a simulated system taken from their everyday world. An evaluation of MAP and its effectiveness at increasing conceptual understanding in physics students was done by Zhou in 2002. He tested students before and after using MAP and concluded that it was effective for increasing their conceptual understanding of the material they were being taught in physics if used as a tool in conjunction with, and not as a replacement for, the lessons that are already being used for that particular concept. In none of the studies in which MAP has been used, has there been any reference to the value placed on MAP by the students using it, and whether they believed it was significant in their own conceptual development.

By using a grounded theory methodology I chose not to confront the participants with a description of the value they placed on MAP conceptually. The participants were asked to discuss their conceptual development as a whole; it would be a significant finding if the students chose to specify that MAP was valuable in that process, without being prompted to evaluate it. As a result, the participants were selected with approximately half of them using MAP concurrent to the study, and the other half not using it at all. During the interviews no reference was made to MAP unless initiated by the participant, and even then (with one exception), it was upon reflecting on whether they valued computers in general with regards to developing their conceptual understanding that the participants reflected upon the value of MAP in that process.

The vast majority of the participants did not differentiate clearly between labs and using MAP. Both labs and MAP use visual tools in the analysis of systems or processes and physical manipulation to collect data that the students evaluate in the context of the concept they are learning. A further similarity came from the logistics of how the MAP applets were used with the class. As with labs, the students left their regular classroom, went to a different room for the whole class (computer room vs. lab room), and were asked to explore a concept and derive findings as specified by the teacher. The MAP applets were not used as an addition within the class, but rather as an alternative to the class (as physics labs tend to be). This was not a matter of choice, however, as the school layout and resources did not permit an alternative means of using MAP (or doing labs for that matter). As a result, there was substantial overlap in the reflections of the students regarding MAP and practical work in general. Nonetheless, the students who did have an opportunity to use the MAP applets did reflect upon them when asked if computers had an influence on their conceptual understanding.

There was not a lot of consistency in opinion between the participants about the value of MAP in developing their conceptual understanding. Students who use computers frequently in their everyday lives tended toward valuing MAP for its ability to illustrate the concept and play with the concept in a manner that allowed them to see a visual representation of their preconception and then to assess whether it was supported or refuted by the accepted way of understanding the concept. Their familiarity with computers seemed to alleviate much of the learning curve and interface issues that other students commented on.

The students with less computer expertise commented that the MAP applets were like doing a lab with a prescribed goal and outcome desired, but believe the applets were helpful when the teacher or peers were there to help them understand why what they were seeing was a representation of the concept they were being asked to learn. In one instance the participant dismissed MAP outright as just another hoop to jump through and as a result did not value it as a conceptual tool at all – it was merely another assignment to be completed for marks.

Overall, the students who had an opportunity to use MAP seemed to understand that it was a conceptual tool and whether it was valued or not had less to do with the applets themselves and more to do with the inherent computer ability and tastes of the user. Perhaps if the applets were used as an illustrative tool within a lesson or as a means to demonstrate what happens when the conception of the student coming into class is reflected against the accepted way of conceptualizing that topic, the applets would have been more widely accepted as a valued conceptual tool, as suggested by Zhou (2002). As it was, MAP was a work intensive strategy for both the teacher and students, and due to the logistics of the school, was used as an alternative to the class and not as a part of it. It is not surprising, given Zhou's (2002) conclusion, that MAP needs to be immersed within the existing lesson structure of the physics class to be effective, and that MAP was not perceived by the participants as being overwhelmingly effective for improving their conceptual understanding.

What is the students' perception of their conceptual development in physics?

So when you step back, what is the overall perception by the students of their conceptual development? As was seen, even though they do not quantify it as such, students are aware that there is a progression in their conceptual understanding. Also, the students are able to list a number of strategies they believe are addressing their conceptual understanding and are acting to improve it. One of these strategies mentioned was the use of the MAP applets, and although not consistently perceived as the best tool that they are exposed to, the students did see that it was a tool specifically designed to aid their conceptual understanding and as such, counted it as valuable. What seemed to be at the heart of the relative value that the various participants placed on their experiences in physics went beyond identifying specific strategies, to the personal willingness and motivation of each individual. At one extreme, the students who admitted they were taking physics because they had to (the majority of the participants interviewed fit this categorization), did not care if they gained any conceptual understanding. They simply wanted to be told what they needed to learn and what the best way to do so was. They were able to list a number of strategies that did help them conceptually, but that was not their intent – conceptual learning was described to happen incidentally and not deliberately. Their motivation was to finish the course with as good a mark as they could achieve without having to worry about the deeper connections that go beyond "how do I do this" to "why is this concept relevant and applicable". These students deliberately chose to focus on using their formula sheets and calculators to succeed and did not want to expend the mental energy to go beyond that.

At the other extreme were the participants who openly loved physics and went beyond the cursory discussions of how to use the formulae to look for the deeper connections and the "why's" behind the material. It should be noted these students did not always begin with this perspective and in fact a number of the participants described how it was their teacher and his (both participating teachers were male) enthusiasm and willingness that motivated them to dig deeper than the minimum. These participants were quite explicit about which strategies were most valuable conceptually and why. Without exception, it was this motivated group that praised the MAP applets and described how it was valuable to them. What this suggests is that initiatives like MAP are most successful when the students themselves have already bought into the relevance and importance of physics as a whole. They are willing to look beyond the learning curve and hiccups of initiating any strategy to the value of what the new strategy brings. Perhaps if the MAP applets or any other conceptual strategy were integrated into the normal lesson seamlessly, the students who are more passive about their learning would inadvertently gain benefits similar to the more motivated students. But when these strategies are used as alternatives to the 'normal' lesson, the natural resistance to change of the less motivated tends to overwhelm any benefits that might otherwise be gained. They do the activity because, effectively, they are ‘forced’ to, but will as a matter of course dismiss its value – conceptually or otherwise.

Conclusions

Research on conceptual change in students is quite uniform in finding that changing students' alternative conceptions to more scientifically acceptable conceptions is a difficult process, and making that change permanent is even more so. It is affected by context, ability, motivation, teacher ability and belief, among many other factors. Yet none of the studies reviewed suggest stopping research into how to best facilitate conceptual change. The literature not only stipulates the difficulties associated with creating permanent conceptual change but also some solutions that the researchers believe may be appropriate to address the issues they raise. Often that is the focus of the studies – these problems introduce the rationale for why teachers should consider using the proposed solutions. It is appropriate at this point to discuss some of the solutions that researchers have suggested to try to promote conceptual change in students.

Solutions from Literature

In any discussion of ways that can be used to increase students' conceptual ability in science, it must be noted that none of the suggestions from the various researchers can be shown in all circumstances to work for all students. Teachers (who are themselves a diverse group) work with amazingly diverse groups of students, and often instinctively use different techniques with different people – based on their perceptions of how receptive a particular student is to what is being attempted and also based on experience with that student. However, being aware of different initiatives that have been shown to have some reported success increases the number of tools that a teacher has to attempt to increase the conceptual understanding of their students.

> The educational problem brought to the fore by the alternative conceptions literature is not, I argue, that students have alternative conceptions or strong, highly resistant to change preconceptions; the problem is that many students do not develop new meaningful relationships with the new contexts that they are introduced to within the educational environment. (Linder, 1993, p. 295)

Using the observation that students use different conceptions for different contexts as their basis, Martinez (2001) and Linder (1993) both suggest that teachers should explain the appropriate context of the new concept to students explicitly. Further this context must be related to other contexts to which the scientific conception can be applied to as well. "Students achieved context-independent and stable conceptual change by perceiving the commonalities and accepting the generality of scientific conceptions across context" (Tao & Gunstone, 1999, p. 872). If students can only associate a specific scientific conception with the examples used to explain it to them, they may not be able to make the connections to the other novel contexts they will be tested on, or even more importantly, the everyday contexts from which the conceptions originate. A technique that constructivist theory suggests is to begin with a personal context the students bring with them into class, and then find the science that allows them to explain it to themselves. This allows students to construct their scientific conceptions within a context that is meaningful and real to them, and can be related to more than just the classroom. The participants who evaluated their conceptual understanding for the research done in this thesis would seem to agree with a more constructivist approach, as they were continually referencing the need for the concepts to be immersed within contexts that had meaning to them. By gaining a personal connection to the material they were able to make many more lasting connections and related that they were able to derive more inherent interest in physics as a result.

Eryilmaz (2002) suggests that a way to promote cross-contextual relationships is to engage the students in “conceptual discussions” with their peers and with the teacher. By asking the students to explain their reasoning to other students (who have their own schema into which to fit the conception into), they were forced to expand the contexts in which their concepts could be applied. This resulted in a decrease in the alternative conceptions the students maintained over the course of the study. This conclusion also received some support from the participants of this study, as a few of the students related that they gained much more from the sounding board and feedback their peers provided than from the teacher who many times was unable to communicate the concept at a level that made sense to the participant.

Macbeth (2000) suggests that many of the alternative conceptions students possess can be attributed to explanations obtained inductively from their own experiences. In an ironic twist he suggests that inductive reasoning can then also be set up to show the student how their alternative conceptions cannot hold in more scientific contexts. By contriving situations in which students are asked to interpret their observations hypothetical-inductively, conflict is created by having the students themselves create scientific conceptions that refute their own alternative conceptions. This is really just a description of a specific technique for creating conceptual conflict, but it is intriguing to see how the same mechanisms that students have used all of their lives to create alternative conceptions can then be used by teachers to replace those conceptions with more scientific variations. Effectively Macbeth (2000) is attempting to get the students to construct a new scientific paradigm using a technique students are already familiar with. Was there evidence of this process occurring within the body of research done for this thesis? No. The participants rarely, if ever, had any awareness of attempts to create a dissonance between what they brought into class as an alternate conception and what they were expected to learn as the accepted view. Even an initiative like the MAP applets, which are at their root an attempt to contrast visually what the student holds as true with what they learn is the accepted way for phenomenon to occur, were not perceived as creating conceptual conflict. It is almost as though the students default into a position of assuming they are wrong and will be told what the right way is. Whether that results in any permanent conceptual change or growth is debateable but certainly the students are unaware of this conceptual conflict that we as the teachers so often try to create for them.

There are many other solutions that have been proposed by researchers and have been shown in certain circumstances to have some effect on student conceptual ability. Winer & Vazquez-Abad (1995) borrow a technique from personal construct psychology and advocate the use of more visually based techniques like “repertory grid technique” to identify problems and then suggest interventions that purportedly aid student conceptual change. diSessa & Sherin (1998) suggest that the answer lies in being more precise in defining what a conception really is and propose a “coordination model” to facilitate the process of conceptual change. In my opinion, evaluating these kinds of techniques from the students’ perception of their success is likely not the best course of action. The time to explain what the various labels and origins are would be time better served in actual instruction, and the students assume the instruction they receive will meet their needs. In a study, such as the one I conducted, that bases its conclusions on what the participants originate and value, evaluation of the more theoretical models that Winer, Vazquez-Abad, diSessa and Sherin suggest is not possible.

Metacognition has received some attention as well, as it is believed that if students were more aware of their own conceptual growth, they would take steps to make the changes more personal and permanent (Zhou, 2002).

> "Helping children focus on the importance of their own ideas and thoughts about science concepts could contribute to better conceptual understanding of science. Students will be more aware of their own conceptions and how those conceptions may change with observation and explorations in which they engage in the classroom" (Dickinson & Flick, 1997, p. 26).

The research conducted with the participants in this study, although borrowing some techniques from metacognitive studies (like reflective practice), did not in fact focus on their physics ideas and the ways that more scientifically acceptable concepts could be merged with their own conceptions. The participants were asked to evaluate what they valued with regards to increasing their conceptual understanding, but were not actually asked to undergo any conceptual change themselves as a product of this study. Nonetheless, the participants displayed an increasing facility with the jargon and the belief that conceptual understanding was important, and I believe will continue to carry with them a greater potential to develop conceptually, simply because they have now been asked to focus on and evaluate how conceptual understanding develops for them.

In short, there are many ideas that have been offered to address the problem of facilitating students' permanent change from alternative conceptions to scientific conceptions. Which is best or most applicable seems largely determined by personal bias, experience and the actual dynamic of the students making up the class. However, Dykstra, Boyle & Monarch (1992) provide a concise summary of the general approach to promoting conceptual change most commonly held by researchers. "The general treatment strategy for reconceptualization seems to be:

1. Find some phenomenon which is easy to produce, not part of normal everyday experience, but close enough that students feel confident predicting its outcome, *and* whose outcome differs in some significant way with their predictions;
2. Have the students predict the outcome and discuss their justifications for those predictions;
3. Have them test their predictions against the actual outcome;
4. Establish a *town meeting,* a facilitating environment which supports the student community in a discussion to develop and test new ideas in order to resolve perceived discrepancies between their predictions and their justifications and the actual outcome of the experiment." (p. 642, emphasis in original)

Core Concept or Thesis

This research has, at its heart, been driven by students' perception of how their conceptual understanding changes. The students valued techniques such as:

- Making what they were learning real to themselves by connecting their everyday worlds to what they were learning in class;
- Being given responsibility for their own learning;
- Being exposed to repetition of the core concepts in different contexts;
- Being given timely feedback from the teacher on whether their answers are right or wrong and why; and
- Being given opportunities to try the newer conceptual initiatives like the MAP applets and other practical work.

Throughout every interview though, there was a recurring undercurrent in the statements of the participants. Essentially, if the teacher wants the students in physics to learn conceptually he / she must address what motivates students to learn at this stage in their lives.

One of the difficulties in deciding whether motivation is at the source of students' lack of conceptual understanding is that you cannot see or touch motivation, and to evaluate its role you must infer motivation from a students' persistence and completion – engagement in learning is one of the few visible outcomes of motivation (Wlodkowski, 1999). Yet Paulsen and Feldman (1999) suggest that motivation has a direct effect on performance and also an indirect effect on the students' use of learning and self-regulatory activities. In a study done by Barlia and Beeth (1999), in which they analysed the impact that motivation has on conceptual change in science, they concluded that conceptual change teaching strategies combined with student motivational factors such as goals, interests, values, and self-efficacy had a crucial effect on the quality of student engagement in learning. Pintrich, Marx and Boyle (1993) help define what goals, interests, values and self-efficacy mean as student motivational factors.

First, goals (or goal orientation / student purpose) are what guide students' behaviours, cognition and affect, and these are typically categorized as either intrinsically (mastery) oriented or extrinsically (performance) oriented. The factors that determine whether a student adopts an intrinsic or extrinsic motivational orientation include:

1) The nature of the tasks; challenging, meaningful or authentic / real world tasks tend to promote intrinsic orientations.
2) Authority structure; allowing students' choices and control over their activities favour intrinsic orientations.

3) Evaluation procedure; evaluation that focuses on competition, social comparison and external reward favour extrinsic orientations.

As can be seen from the description of the factors, students' use of an intrinsic goal orientation is preferable to an extrinsic one. This is confirmed by Donald (1999) who describes how students who placed a heavy emphasis on conceptual learning were motivated almost exclusively by intrinsic factors, but as the focus shifted to problem solving and achieving good grades, the students became motivated by extrinsic factors (interestingly, this was often the same student shifting their focus over the length of the course – what changed these students so that they gave up on conceptual understanding and shifted their focus to problem solving is beyond the scope of this paper but is an interesting question). When contrasting the preferred strategies of the participants in my study with the intrinsic/extrinsic factors above, it can be seen that inadvertently the participants were describing intrinsically motivating strategies. A preference for real world relevance, immediate feedback, and being given personal responsibility (control) are all factors that fit Pintrich, Marx and Boyles' (1993) description of factors that promote intrinsic motivation.

Pintrich, Marx and Boyle's (1993) second student motivational factor, interests, are the general attitude and preferences for content that the student has. Quoting Hidi (1990), they state that interests influence students' selective attention, effort and willingness to persist at the task, and their activation and acquisition of knowledge. These perceptions of the value of a task do not have a direct influence on academic performance but they relate to the students' choice of becoming cognitively engaged.

Third, values are the judgement by the students of the potential usefulness of content or a task toward achieving their goals. Any dismissal as unimportant or irrelevant would diminish the work ethic and the chances that the content would be retained for future use.

Finally, Pintrich et al (1993) identify self-efficacy, which is an individual's belief about their performance capabilities in a particular domain. This reflects upon conceptual change either by giving the student the confidence that they are right, thus making them resistant to conceptual change, or by giving the student the confidence in their ability to learn and in their thinking strategies, thus facilitating conceptual change. Pintrich, Marx and Boyle (1993) suggest that any teaching strategies that consider self-efficacy along with conceptual change need to give the students confidence that they can learn the concept, that they know how to use it, and that they will be helped in moments of cognitive conflict (which lies at the heart of Posner's conceptual change model).

Barlia and Beeth (1999), while working with high school science students found three levels of student engagement, namely, students who are:

- Intrinsically motivated to learn.
- Intrinsically motivated to learn but not engaged each day.
- Extrinsically motivated to learn to fulfill an academic requirement.

This pattern of engagement was reflected in the participants of my study as well. Participant James is a good example of a student who loves physics and without being asked to, is pushing the limits of his conceptual understanding (i.e. he is intrinsically motivated). Judy, Bill and Paul are examples of students who typically enjoy physics and do not have a lot of difficulty conceptually, but reflect that they periodically have "bad days" (i.e. they are intrinsically motivated but not every day). Lucy, Mary and Lisa are examples of students who admitted they are taking physics purely because they have to and want nothing more than a grade and to be finished physics (i.e. they are extrinsically motivated). When the participants are viewed from the framework of Barlia & Beeth (1999) and Pintrich, Marx and Boyle (1993), and the baggage that accompanies either being intrinsically or extrinsically motivated is included when evaluating the participants' conceptual understanding, it is not surprising that tools such as MAP (which are developed predominantly as cognitive devices to address the idea of conceptual understanding) can be a hit or miss proposition with the students who use them. Focusing on student cognition without considering students' motivations does not offer a complete picture of conceptual change. "Considering student motivational beliefs in the process of student learning is essential to engaging students in conceptual change learning" (Barlia & Beeth,1999, p.5). Motivation was originally not considered to be relevant when analyzing learning process, it was seen as at most supplying the energy for cognitive development without influencing cognitive structure at all (Fischer & Horstendahl, 1997).

It was perhaps within this conceptual framework that Posner, Strike, Hewson, & Gertzog (1982) conceived their original conceptual change model which has been the origin and focus of much conceptual change research. Boyle et al (1993) note that Posner has since re-evaluated his own model and has conceded that perhaps its biggest weakness is the absence of any motivational influence on the process he describes. Boyle et al go on to describe ways in which the existing conceptual change model could be supplemented with motivational factors. Perhaps Pintrich, Marx & Boyle (1993) are correct when they contend that Posner's conceptual change model is too 'cold' and may be flawed in assuming a rational progression from making sense of information to then coordinating it with prior considerations. However, without a willingness to address the conceptual understanding of the students, the motivation of the participants in my study and the role it plays in their conceptual understanding, would not have been identified.

Applications and Further Research

This study aims to understand the students' perceptions of how to increase their conceptual understanding in physics. It is valuable to physics teachers, curriculum developers and educational researchers for designing programs that contain approaches the students themselves have indicated are important in their conceptual growth. At all levels, it is easy to forget that the focus needs to be on the students first, and then on the material that they are expected to learn at some prescribed level. It is a difficult task to develop materials and teaching strategies for the physics class when every class is as individual as the students making it up. When individual student motivation is one of the key factors in the conceptual development of the student, it must be recognized that initiatives founded on sound research, like Dykstra, Boyle & Monarch's (1992) conceptual conflict model, are valuable, but cannot reach all students all of the time. This should not prevent researchers and other educators from attempting to find better ways to aid students conceptually, but it seems fruitless to remain frustrated that, despite our best efforts some students still seem to be slipping through with little to no conceptual change from their alternate conceptions. Continuing to strive for better conceptual understanding in the students, while not being convinced of our failure when we do not enable them all to attain this goal, is a worthwhile endeavour.

What do the students themselves value regarding the integration of computer technology into their physics class? This research suggests that it has potential, particularly when the facilities of the school match the intentions of the developers of the various initiatives. The relative value, and thus to some extent the good that comes from the integration, seems largely determined by the attitude, willingness and presentation of the physics teacher. Teachers who believe they are already pushed for time or resources will intentionally or inadvertently sell the students on the belief that the use of computers is not as good as the more traditional methods being used. I was surprised to learn how trusting students are in the lesson strategy choices the teacher makes. There seems to be a default assumption that the teachers know what is best and therefore a decision of whether to use a computer or not, is assumed to be made in the best interests of the students. However, in the two schools in which the study occurred, the teachers' choices were heavily influenced by the logistics of the school and the extra effort it required to even sit the students down in front of a computer. It would seem that for computers to truly to be effective they need to be integrated wholly or the expectations of their effectiveness must be adjusted. Until the students can use them as easily as they use their calculators or textbooks, they will continue to be hit and miss in their effectiveness.

Did this study provide an alternative to conclusions about student conceptual growth derived exclusively from test scores? Test scores are too often the only benchmark used to evaluate growth, success or understanding. For something as subjective as conceptual understanding, this research, which focuses on student perspectives and categorizes these according to their peers and environment, does raise issues that would not have been brought forth in a statistical analysis of relative test scores. For the students to initiate reflections upon the value of context, repetition, feedback, personal responsibility and motivation would seem to indicate these are factors that must be considered when making decisions about why students' conceptual understanding develops the way that it does. We assume that students often do not know what is best for them, and thus we mandate what concepts are covered within each respective curriculum and what sorts of subjects are required for them to graduate. However, students do know what works for them and are very capable of evaluating the relative merits of the techniques that teachers use with them in class. When designing initiatives like MAP or even just making the decisions about the day to day lessons within a physics class, as long as we remain open to the feedback of the students, most of what is attempted will succeed to some extent. After all, it is not possible to have everyone in class achieve above average.

Over the course of this study a number of issues arose that fell outside of the bounds of this research.

- How do you get at the best way for students to learn, when they themselves only know what they have been exposed to?
- Everything in the study seemed to have a time pressure undercurrent (both for students and apparently for teachers). What is the origin for this and is it good or bad?
- There is a lot of indirect pressure for teachers to integrate computers into their classroom. What is a realistic and pragmatic expectation for them, with regards to computer technology integration?
- Similarly, what is a reasonable expectation for the various conceptual change initiatives when they are initiated within the classroom? The reality and pragmatics of integrating any conceptual initiative tends to fall short of the hope or intention of the developers.

Perhaps by listing some of these questions here they will be given some consideration in future research.

Final Word

Adams & Chiapetta (1998) were quite explicit in their findings regarding how students who exhibited high degrees of conceptual change differed from those who exhibited little change in the way they approached science classes. They point out that the techniques that were most effective with one group were not well received by the other. However, they found that the students who ultimately displayed the largest amount of conceptual change were the students who responded well to a logical-sequential model of instruction. Pintrich, Marx and Boyle (1993) have also shown that the individual motivation of the students is a factor in conceptual understanding. This suggests that there is some fundamental difference between students in how they learn and subsequently how much conceptual change they undergo. It is not reasonable to expect a single technique or even a series of techniques to meet the needs of all of our students in science classes. Perhaps the historical belief in science that there is a grand unifying theory underlying any question motivates our efforts to seek out that "best practice" for promoting conceptual change. Is it reasonable for teachers to expect all students to undergo significant, permanent conceptual change in science? The answer to this question would seem to be "no". The sheer diversity in learning style, the motivation of the students, the inherent difficulty of the process of conceptual change and the varying teacher-student relationships would all seem to act to have individuals slip through the class without having their alternative conceptions significantly changed. Additionally, how do we as teachers merge more cognitively driven tools (like MAP) with the emotional and motivational states of our students? Should research into finding ways to improve the conceptual change we want students to undergo stop? Again, no. With every student who is reached who would not have been reached before, conceptual change research and work is a success.

What is the future for conceptual change research? Research into how computers may aid our efforts to increase students' ability to learn new concepts is beginning to emerge. Initiatives, such as the MAP applets, are being developed very specifically to capitalize on the strength of the computer while focusing on increasing the conceptual understanding of physics students. Dykstra, Boyle & Monarch (1992), Tao & Gunstone (1999) and Zhou (2002) all suggest that computers are excellent tools, that expose students to a variety of different contexts and conceptual conflicts, and after a specific conceptual change has been suggested, can then immediately offer practice and remediation with the new concept. Whatever the future for conceptual change research, this area will continue to both create frustrations for successive generations of teachers and students, as well as receive ongoing attention.

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Appendices

Appendix A

Dear Participant

My name is Mark Hirschkorn and I am a graduate student here at the University of Alberta doing research to complete my Master Thesis as partial requirement for my Masters Degree in Education. I would like to invite you to participate in my research which is directed toward evaluating students' perception of their own conceptual development in physics. This research will be used as the foundation of my thesis and may also serve as the basis for articles presented in education journals or at educator conferences.

There have been many studies done in physics that have attempted to measure students' conceptual growth in physics. Conceptual growth is difficult to quantify but includes intangibles like the students ability to visualize concepts, make connections with other ideas or even something as simple as remembering the "why's" and not just the "how's". These studies have chosen pre-test vs. post-test experimental methodologies to evaluate the effectiveness of various initiatives on students' conceptual growth. Interestingly, in none of the literature that I reviewed have I seen an attempt to establish what is occurring to the student (from their own perspective) when it comes to attempts to increase their conceptual ability in physics. Too often, I believe, students are seen as the passive recipients of various new initiatives and environments – with the relative success being gauged by their score on a test. The essence of constructivism is the willingness to allow students to bring their own experience and personal hypotheses with them into the classroom and find ways to create an environment that motivates them to construct / reconstruct the knowledge and perspective deemed desirable. Is it not important to use the students' own perception of the process to evaluate its success? A description by the students detailing how they feel / know their own conceptual growth has occurred should be an integral part of any evaluation of initiatives designed to improve their conceptual growth.

My intent is to use a series of tape recorded interviews done in the school (approximately 30-45 minutes long) to gauge what students believe to be significant with regards to their own conceptual development in physics. From these initial interviews patterns should begin to emerge that will allow me to open up new avenues for discussion in subsequent interviews. I anticipate no more than 3 – 4 interviews per person will be required but this number may vary slightly with the revelation of what the students believe. This approach is named "grounded theory" and it is driven by student perspective. The researcher does not have any preconceptions of what should be – it is entirely driven by the participants. I hope to have these interviews done in the first few months of the school year, with the majority of them done individually, but a few done as groups so that feedback from other participants may spark ideas within each individual.

If you have any questions regarding what is involved please do not hesitate to contact me. Thank you for your help with this, it is appreciated greatly.

Sincerely

Mark Hirschkorn

Appendix B

University of Alberta
Research Consent Form for Parents/Guardians

Title of Research Study: Students' Perception of their Own Conceptual Development in Physics: The Role of Computer Simulations

I, ______________________________, hereby [consent / do not consent]
(name of parent / legal guardian)

for ______________________________ to be interviewed by Mark
(print name of student)

Hirschkorn.

I understand that:

- My child may withdraw from the research at any time without penalty.
- All information gathered will be treated confidentially and discussed only with your supervisor.
- Any information that identifies my child will be destroyed upon completion of this research.
- My child will not be identifiable in any documents resulting from this research.

I also understand that the results of this research will be used only in the following:

- Research thesis
- Presentations and written articles for other educators.

____
(signature of parent / legal guardian)

Date Signed: ____________________

For further information concerning the completion of the form, please contact:

Mark Hirschkorn (780) 953 – 4924 (Researcher)	David Geelan / Norma Nocente (780) 492 - 3674 (Supervisors)	George Buck (780) 492 – 3674 (Graduate Coordinator)

Please return this form, whether consent is given or not with your child or to:
Mark Hirschkorn
Office: Education South – Rm. 368
University of Alberta
Edmonton, Alberta

"This study has been reviewed and approved by the Research Ethics Board of the Faculties of Education and Extension at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Chair of the Research Ethics Board at (780) 492-3751."

Appendix C

Interview 3 Questions

Name:_______________

1. Rank order the following factors that you as the participants have identified as having an effect on your conceptual development, from biggest effect (give it #1) to least important (give it #9). Please explain why you chose the order you have.

____ - Being told the why and where a concept comes from.

____ - Being given the answers to homework, the data for labs, etc., so you can focus on the how and why.

____ - Personal attention, willingness and motivation.

____ - Having your own input into class or groups.

____ - Being able to see the concept in action (like a demo, lab or computer simulations).

____ - Class and teacher being fun and humorous.

____ - Class is a welcoming and a comfortable environment.

____ - Having concepts related to students' lives (or other real world applications).

____ - Having as much time as you need to complete work and carry on discussions.

Explanation:____

2. State whether you agree or disagree with the following statements and why.

a) I am more motivated by work that is marked in physics.

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b) Doing many questions on a particular concept seems to give me a deeper more permanent understanding of that concept.

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c) I need to know if I am right or wrong about a question very soon after doing it.

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d) Physics is math with notes.

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e) There is a difference between conceptual learning and “normal” learning.

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f) I needed to learn the way to do and think about physics when I first started taking it; other subjects came to me much more easily.

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g) I usually need further explanation (beyond class) from another source (notes, text, classmates, etc.) to really understand a concept in physics.

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h) I do physics because I have to – it is a requirement for something that I want to do later in life.

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3. There is a belief that students can only judge if something is effective or not if they have been exposed to it. Of all of the things that you have heard of or done in classes other than physics, what would you like to see included in physics that you think would really help you develop conceptually. Explain why it would help you.

4. Many people believe that computer technology is the future of education. As a physics student do you agree or disagree with this belief? Why?

5. Describe the "perfect physics student".

Glossary

Applets: A computer application that has limited features, requires limited memory resources, and is usually portable between operating systems.

Concept: A concept is a class of objects, symbols, and events that are grouped together in some fashion by shared characteristics and find their meaning within a theoretical context.

Conceptual Change: A change by students from their conception of a concept or topic to a more scientifically acceptable representation of that concept.

Conceptual Growth: Similar to conceptual change, but more suggestive of the process of change and not the outcome of the change having occurred.

Conceptual Understanding: "When we say we conceptually understand something, we mean that we know what is going on, that we have ides about why it goes 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" (Zhou, 2002, p.2).

Constructivism: Can be defined differently by different authors, however, the essence of constructivism is the willingness to allow students to bring their own experience with them into the classroom and find ways to create an environment that motivates them to construct the knowledge and perspective deemed desirable.

Grounded Theory: Research Methodology that uses the idea that to develop a theory rooted (grounded) in the data it is necessary to allow the participants themselves and the data they provide to be the source of it.

Java: A trademark used for a programming language designed to develop computer applications, especially ones for the Internet, which can operate on different platforms.

MAP: The Modular Approach to Physics is a series of Java-based computer simulations that mimic situations in the world and allow the user to anticipate and analyze the simulated results of a number of real world systems that are commonly discussed and analyzed in physics classes.

Simulations: Computer imitations or representations of real world systems.