CHAPTER 1: INTRODUCTION

The two most common goals for introductory physics courses are to improve students' understanding of physics principles and to improve students' problem solving skills. Problem solving, in fact, is one of the most prominent features of a college or university introductory calculus-based physics course. Instructors typically spend much of the class time solving problems while students watch, and students spend a significant fraction of their study time struggling with homework problems. Student success in the class is almost always evaluated by having students solve problems on tests.

There is, however, a growing body of evidence that suggests that these problem-solving activities in introductory physics courses are not producing the desired student outcomes. Several studies in the past decade have shown that many students leave their introductory college or university physics course without the desired understanding of physics concepts *and* without the desired problem solving skills (see Van Heuvelen, 1991). Research indicates that many introductory physics students are solving problems based on rote memorization or blind use of formulas, rather than the sorts of thoughtful approaches that most physics faculty would like to see employed (e.g., Chi, Feltovich, & Glaser, 1981; Maloney, 1994; Mazur, 1997; McDermott, 1993). For example, in their studies of students' knowledge organization, Chi et. al. (1981) conclude that students usually only notice the surface features of problem situations. This reliance on surface features leads students to choose inappropriate equations. Another piece of evidence pointing to student use of inappropriate problem solving skills is that several studies have found that students in introductory physics courses who get the correct answers to traditional physics problems often do not understand the physics concepts on which the problems are based (e.g., Maloney, 1994; Mazur, 1997).

In an attempt to improve this situation, physics education researchers have developed a number of strategies that have been shown to be effective in improving student problem solving performance: (a) students are taught a problem solving framework that helps to externalize the implicit problem solving strategies used by experts (Cummings, Marx, Thornton, & Kuhl, 1999; Heller & Hollabaugh, 1992; Heller, Keith, & Anderson, 1992; Mestre, Dufrense, Gerace, Hardiman, & Touger, 1993; Reif & Scott, 1999; Van Heuvelen, 1991b), (b) "real" problems are used that require a higher level of analysis from the students and discourage poor problem solving practices (Cummings et. al., 1999; Heller & Hollabaugh, 1992; Heller et. al., 1992; Van Heuvelen, 1991b), (c) students work with other students, or with a computer, where they must externalize and explain their thinking while they solve a problem (Cummings et. al., 1999; Heller & Hollabaugh, 1992; Heller et. al., 1992; Reif & Scott, 1999; Van Heuvelen, 1991a), and (d) concept maps are used in instruction to help students understand the relationships between important concepts and to develop a hierarchically organized knowledge structure that is more similar to that of experts (Bango & Eylon, 1997; Bango, Eylon, & Ganiel, 2000; Van Heuvelen, 1991b). Curricular materials using these instructional strategies have been shown to improve students' problem solving skills as well as their understanding of physics concepts (Bango et. al., 1997; Cummings et. al., 1999; Foster, 2000; Heller & Hollabaugh, 1992; Heller et. al., 1992; Mestre et. al., 1993; Reif & Scott, 1999; Van Heuvelen, 1991b).

In spite of the variety of curricular materials that are readily available and have been shown to be effective at improving students' problem solving skills, relatively few physics instructors have chosen to use these curricula. In addition, there is some evidence to suggests that some instructors who do attempt to use these materials may not understand the learning theories upon which the materials are based and may use them in ways that limit their effectiveness (Yerushalmi & Eylon, 2001). One likely cause of this problem is that these curricular materials do not align with, and perhaps are in conflict with, the ways that physics instructors think about the teaching and learning of problem solving. This has led the Physics Education Research and Development Group at the University of Minnesota to undertake a long-term research program to first understand physics faculty conceptions about the teaching and learning of problem solving, and then to use this understanding to develop and/or refine curricular materials.

The current study is the first phase of a three-phase research program. The goal of this study is to use a small sample of research university faculty to generate a viable explanatory model of faculty conceptions of the teaching and learning of problem solving. The tentative model developed in this study will then be tested and refined using a sample of faculty from more diverse institutions (i.e. community colleges, private colleges, and state universities). Finally, a closed-format survey will be developed to determine the distribution of faculty conceptions within the model. In addition to determining the distribution of faculty conceptions within the model, a larger sample will permit researchers to determine what context variables (e.g. years of teaching experience, type of institution, etc.) are correlated with particular conceptions. The model of faculty conceptions generated and tested through this research program will help researchers and curriculum developers understand how faculty think about the teaching and learning of problem solving in introductory calculus-based physics courses.

Background

Research into teachers' thinking about teaching and learning has been growing in popularity in the last 20 years. Traditionally researchers have attempted to distinguish between different aspects of teachers' thinking. For instance, many studies attempt to distinguish between teachers' knowledge and teachers' beliefs (Calderhead, 1996). More recently, however, some researchers (e.g., Thompson, 1992) have decided that making the distinction between different aspects of thinking is neither useful nor possible, and have instead turned to investigations of teachers' conceptions, where conceptions is a broad term used to describe a more general mental structure that involves beliefs, knowledge, mental images, preferences, and similar aspects of cognition (Thompson, 1992).

As described in more detail in Chapter 2, researchers typically focus on one of two basic types of teacher conceptions: teachers' general conceptions or teachers' context-specific conceptions. Teachers' general conceptions refer to basic values and beliefs that can impact their instruction. These can include such things as teachers' general beliefs about teaching and learning, their knowledge and beliefs about the subject they are teaching, and their beliefs about the context in which they teach. Context-specific conceptions refer to knowledge or beliefs about how to teach specific topics to particular students. Context-specific conceptions go by such names as pedagogical content knowledge and craft knowledge.

This study will focus on instructors' context-specific conceptions about the teaching and learning of problem solving in introductory calculus-based physics. Although the focus of this study is on context-specific conceptions, this study is informed by and has the potential to inform research on teachers' general conceptions. There has been very little prior research that has examined teachers' context-specific conceptions about the teaching and learning of problem solving in introductory calculus-based physics.

Ways of learning about teachers' conceptions

There are many different ways that researchers have attempted to learn about teachers' conceptions. Interviewing teachers is the most common method used, although many studies also make use of classroom observations or written questionnaires. Studies that simply ask teachers about their conceptions, either in an interview or written questionnaire, have been criticized because it is thought that conceptions are not always evident to the person who holds them (Bowden, 1995; Calderhead, 1996; Francis, 1993; Pajares, 1992). Thus, much research has combined interviews along with classroom observations (e.g., Nespor, 1987) or descriptions of concrete hypothetical teaching situations (e.g., Shavelson & Stern, 1981; Kennedy, Ball, & McDiarmid, 1993). This study will use the later technique to understand physics instructors' conceptions as they relate to different instructional situations through the use of concrete instructional artifacts.

Prior research into Teachers' Conceptions

There are two areas of previous research on teachers' conceptions that have strongly influenced this study. These areas will be briefly introduced here and described in more detail in Chapter 2.

The Relationship Between Teachers' Conceptions and Their Instructional Choices.

This study is interested in determining teachers' conceptions of teaching and learning in the expectation that this knowledge will allow us to better understand teachers' instructional choices. Prior studies investigating teachers' conceptions commonly agree that these conceptions play a major role in their teaching practices (Nespor, 1987; Pajares, 1992; Thompson, 1992). These conceptions strongly influence a teacher's perception of what is happening in the classroom and constrain a teacher's ability to generate solutions to perceived problems. Conceptions about the subject they teach, how students learn, appropriate teaching practices, and about their own ability can all have an influence on instructional choices. Thus, it is reasonable to expect that a model of faculty conceptions of teaching and learning will be useful in understanding both their current instructional choices as well as the likelihood that they will adopt particular types of curricular materials.

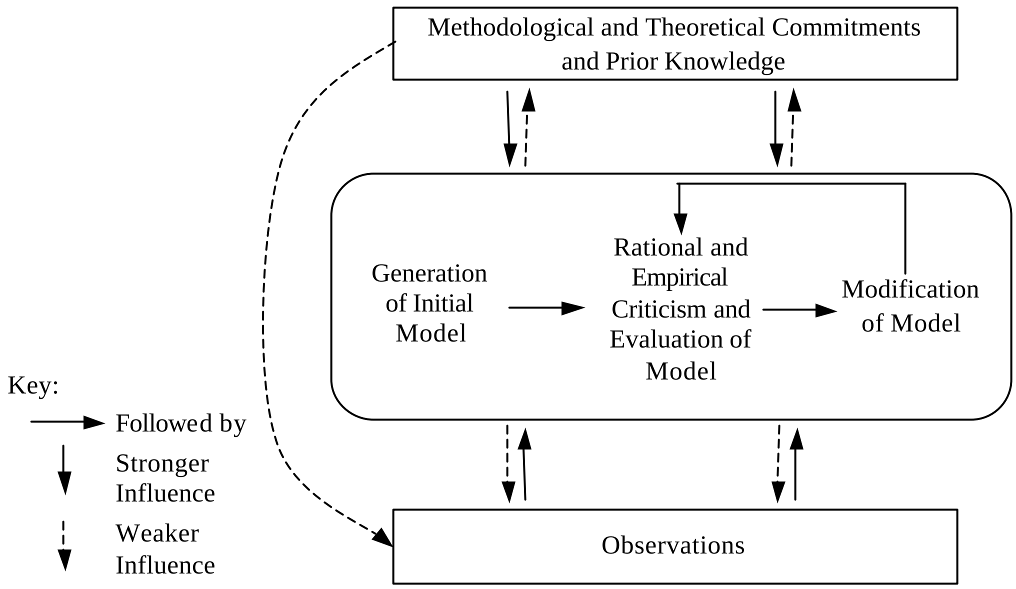
The Nature of Teachers' Conceptions

One of the difficulties in conducting research into peoples' conceptions of any type is that conceptions do not appear to be completely stable entities. In previous studies teachers' conceptions about teaching and learning have appeared to be context dependent and even, at times, conflicting. Calderhead (1996) and Schoenfeld (1998) have indicated that teachers often have contradictory conceptions. The specific context of a given situation can result in the activation or choice of one conception over another (Calderhead, 1996). This nature of conceptions has impacted both the design of the interview tool as well as the interpretation of the results. For example, as mentioned earlier, this study used interviews based on specific teaching situations to understand instructors' conceptions as they relate to several different concrete instructional situations.

Model Generation and Testing

The goal of this study is to use a small sample of university faculty to generate a viable explanatory model of faculty conceptions of the teaching and learning of problem

Figure 1-1: Cyclical process of generation and modification in the development of explanatory models. (Clement, 2000, p. 554)



solving. The tentative model developed in this study will then be tested and refined in future studies. As Clement (2000) argues, this is the same way that explanatory models are developed in the physical sciences.

Clement describes two basic types of studies that play essential roles in the development of new scientific theories. *Generative* studies focus on formulating new constructs and new elements of a theoretical model. *Convergent* studies "attempt to provide reliable, comparable, empirical findings that can be used" in testing a theoretical model (Clement, 2000, p. 558). He describes this "cyclical process of hypothesis generation, rational and empirical testing, and modification or rejection" of a scientific model in Figure 1-1 (Clement, 2000, p. 553).

As Clement describes,

> "The scientist aims to construct or piece together a theoretical model in the form of a conjectured story or picture of a hidden structure or process that explains why the phenomenon occurred….The initial hypothesis for a hidden mechanism … can be a creative invention as long as it accounts for the observations collected so far….However, it should also be a very educated invention, reflecting constraints in the scientist's prior knowledge about what might be the most plausible mechanisms involved….Then, the initial model is evaluated and revised in response to

> criticisms. This can involve evaluations by comparisons with new data, or it can involve evaluations via rational criteria such as simplicity and consistency. By such a process of successive refinements, we cannot arrive at absolute certainties, but a viable and successful explanatory model may be formed." (Clement, 2000, p. 554)

The theoretical explanatory models that result from this process are "more than just summaries of empirical observations, but rather, are inventions that contribute new mechanisms and concepts that are part of the scientist's view of the world and that are not 'given' in the data" (Clement, 2000, p. 549). A useful explanatory model allows scientists to be able to make predictions in other contexts and can lead to the creation of new lines of research (Clement, 2000). As Clement (2000) discusses, scientists frequently think in terms of theoretical explanatory models such as molecules, waves, fields, and black holes. These models have played important roles in helping scientists to think about and describe the natural world.

Phenomenographic Investigations of Thinking

Within the social sciences and education, researchers have identified a number of research traditions that operate within the framework described above. Each of these traditions consists of a set of compatible goals, assumptions, and methods that can help guide a researcher in designing and conducting a particular study. One research tradition that has grown out of science education is phenomenography. This research tradition is often used in studies designed to develop models of how students conceptualize physical phenomena. Frequently this phenomenographic research into *student conceptions* makes use of clinical interviews in which students are asked to explain how they interpret a particular situation (e.g., Driver & Easley, 1978; Wandersee,1994). More recently, some researchers have used phenomenographic methods in studies of teacher conceptions (e.g. Prosser & Trigwell, 1999; Samuelowicz & Bain, 1992).

The goal of a phenomenographic study is to define the range and nature of the conceptions that a group of people have about a phenomena and how these conceptions are related – that is, to define the "outcome space". The goals of a phenomenographic study are not to determine the distribution of a group of people within this outcome space. This type of goal makes sense for a generative study like the current study where little prior knowledge exists about the types of conceptions that physics instructors have about the teaching and learning of problem solving in introductory calculus-based physics. Once an initial model of the outcome space has been identified, future studies can be designed to refine the initial model to determine how the various conceptions are distributed throughout the population of interest. Because the goals of this study are consistent with the goals of phenomenography, the current study was guided by the research team's knowledge of previous phenomenographic studies. In the case of the current study, the goal is to develop an explanatory model that can describe the way(s) that a group of people (physics faculty) conceptualizes a phenomenon (the teaching and learning of problem solving in introductory calculus-based physics).

Research Questions

The goal of this study is to generate an initial explanatory model of the conceptions that physics faculty have about the teaching and learning of problem solving in introductory calculus-based physics. Future studies will use the results of this study as a starting point in an effort to refine the model developed in this study to more fully understand the range and nature of faculty conceptions about the teaching and learning of problem solving in introductory calculus-based physics. Put in terms compatible with phenomenographic research, the research questions addressed in this study are:

Goal of Study: Generate, if possible, a viable explanatory model of the conceptions that a small sample of research university faculty has about the phenomena of the teaching and learning of problem solving in introductory calculus-based physics.

Research Questions

1. What are the general features of this explanatory model and how are these general features related?
2. For each of the general features of the explanatory model:

a. What are the conceptions (the ideas and the relationships between ideas) that are used by these faculty to understand this general feature?

b. What are the qualitatively different ways that these faculty conceptualize this general feature?

Research Design and Analysis

As is common with phenomenographic studies, data was gathered using semi-structured interviews. Six participants were randomly selected for interviews from the pool of 20 physics faculty from the University of Minnesota, Twin Cities Campus who had recently taught an introductory calculus-based physics course.

The interviews were videotaped and the audio portion transcribed. Approximately 400 statements of relevant meaning were constructed from each interview transcript to capture the important ideas that were expressed during the interview. These statements then became the raw data used in the construction of a concept map that visually represented a model of the way that each interviewee conceptualizes the phenomena of the teaching and learning of problem solving. Finally, the individual concept maps were compared and a composite concept map was constructed to model the range and nature of the conceptions expressed in the interviews.

Significance of the Study

This study is a generative study that seeks to develop an initial explanatory model of the conceptions that physics faculty have about the teaching and learning of problem solving in introductory calculus-based physics. This study is significant as the first study to seek to form such a model. The results of this study are an important part of the research program undertaken by the University of Minnesota Physics Education Research and Development Group to understand physics faculty conceptions of the teaching and learning of problem solving in introductory calculus-based physics.

The current research will also provide a baseline that can allow other researchers to continue investigations of physics instructor beliefs and values about the teaching and learning of problem solving at both the college and high school level. The results of this type of research into faculty conceptions can lead to improvements in the teaching and learning of problem solving by: (1) enabling physics faculty to communicate more effectively, both with one another and with the physics education research community; (2) providing curriculum developers with the information about faculty that they need to better match curricular designs to the concerns and commitments of faculty; and (3) allowing curriculum developers to determine what type of professional development, if any, should be offered to physics faculty.

Limitations of the Study

This study is an in-depth examination of the conceptions that six physics faculty have about the phenomena of teaching and learning of problem solving in introductory calculus-based physics. The goal of this study is to develop an initial explanatory model that can be used to understand the range and nature of conceptions that six university instructors have about the teaching and learning of problem solving in introductory calculus-based physics. Because of the small number of faculty used in this study the results of this study are not generalizable to a larger population of physics faculty. As described earlier, the purpose of this study is to provide a starting point so that future studies can expand and refine the current model and develop a viable and successful explanatory model that can be generalized to a larger population of physics faculty.

Identifying conceptions from interviews is an interpretive task that requires the researchers to make inferences about conceptions based on what was said during the interview and the researchers past experiences. This interpretation can lead to the creation of conceptions that do not actually exist in the instructors' minds and the missing of conceptions that do exist. The effect of this interpretation, however, was minimized by the diverse set of backgrounds and viewpoints that the members of the research team brought to the study and the thorough analysis methods employed.

The Research Team

At the time this study was conducted, the author was a graduate student in Physics Education at the University of Minnesota. In addition to his formal academic work in physics and curriculum and instruction, the author has had experience teaching physics and working with physics faculty at three different colleges/universities.

In addition to the author, three other researchers were involved in various aspects of this study. Throughout this dissertation, the contributions of the other members of the research team will be noted where appropriate. One of the strengths of the research results reported in this dissertation is that they were informed by the diverse backgrounds and viewpoints of the members of the research team.

<u>Patricia Heller</u>: Patricia Heller is a professor of Science Education at the University of Minnesota. She has developed curricula for introductory calculus-based physics courses and has led many workshops for physics faculty on the use of these curricula. Dr. Heller is also regarded as an expert on problem solving in physics.

<u>Vince Kuo</u>: Vince Kuo is a graduate student in Physics Education at the University of Minnesota. He has had experience with course development and has also served as a mentor TA for the University of Minnesota Physics Department.

<u>Edit Yerushalmi</u>: Edit Yerushalmi is currently an assistant professor of Science Education at the Weizmann Institute for Science in Israel. She was a post doctoral research associate with the University of Minnesota Physics Education Research and Development Group during the first two years of this study. Dr. Yerushalmi has had considerable experience working with physics teachers in Israel.

Important Terminology

One of the difficulties in studying teacher thinking, or thinking in general, is that there is not a consistent vocabulary used by researchers in the field. Thus, it is important to clearly define the terms that are used in this study.

Concept Map: A schematic device for representing the relationships between concepts and ideas. The boxes represent ideas or relevant features of the phenomenon (i.e. concepts) and the lines represent connections between these ideas or relevant features. The lines are labeled to indicate the type of connection.

Conception: A general term used to describe beliefs, knowledge, preferences, mental images, and other similar aspects of a teacher's mental structure.

Feature Map: A feature map is a magnification of one of the general features on the main concept map. It allows the viewer to understand more about the feature of interest.

General Features of the Phenomena: A general feature is a group or category of ideas that can be helpful in describing the way that a person thinks about the phenomena.

Main Map: The main map is the highest order concept map that describes the general features and the relationships between these general features. Each of the general features can be "zoomed in on" by looking at the appropriate feature map.

Phenomena: The object of interest in a phenomenographic study. In this case it is the teaching and learning of problem solving in introductory calculus-based physics.

Statement of Relevant Meaning: A statement of relevant meaning, or statement, is a single idea as expressed by the interviewee. Statements were used as the raw data for the construction of concept maps.

Overview of This Dissertation

The following provides a brief guide to the remaining chapters in this dissertation:

Chapter 2: Review of the Literature

This chapter provides a review of research relevant to this study.

Chapter 3: Methods

This chapter presents a detailed description of the methods designed to collect and analyze data for this study.

Chapter 4: Results and Conclusions

This chapter presents and describes the model of faculty conceptions of the teaching and learning of problem solving that was generated in this study.

Chapter 5: Implications

This chapter provides a brief summary of the study, relates the findings to prior research, and suggests possible directions for future studies.

Bibliography

Appendices