CHAPTER 2: LITERATURE REVIEW

This chapter will explore the literature that is relevant to understanding the development of, and interpreting the results of this study. In the first part of this review of the literature, I will describe two distinct types of research on teaching: research on teachers' behaviors and research on teachers' cognitions. I will summarize the assumptions and major findings of each of these types of research. In conducting this review, I have primarily concentrated on research conducted on secondary and college teachers; however, I have also included some studies conducted on teachers of primary grades when they are particularly relevant.

The second part of this literature review is a brief summary of research on the effective teaching of physics problem solving. This is not meant to be an exhaustive review of the literature. It is intended to familiarize the reader with the basic assumptions about problem solving in physics that went into the design of this study and the interpretation of the results.

Research on Teaching

Typically, research on teaching is conducted in order to improve teaching. The results of the research are often used to make recommendations for improving teacher preparation programs and teacher enhancement programs for current teachers. Since this type of research is done with the goal of providing guidance to teachers and curriculum developers, it is not surprising that the research is usually consistent with the dominant instructional techniques of the time. The earlier research on teaching was clearly influenced by the behaviorist approach to teaching. The goal of this research was to break down the complex task of teaching into a set of discrete skills that could be taught to teachers. More recently, instructional techniques based on information processing and constructivism began to focus more on student thinking and the ways that students' prior experiences, ideas, and ways of thinking influence how they react to instruction. In a similar way, research on teachers began to focus on teachers' thought processes associated with teaching as well as the knowledge and beliefs that were necessary to support these thought processes. Currently, much of the research on teaching is designed to understand how teachers make sense of teaching and learning and how this relates to their actual classroom practices.

Research on teaching is most frequently done on pre-service and in-service K-12 teachers. There have been relatively few research studies done on college teachers. These studies, however, have tended to use research methods that are similar to those used with K-12 teachers and, for the most part, the findings have also been similar.

Research on Teachers' Behavior

Prior to the 1970's, most of the research on teaching was focused on teachers' behavior (e.g., Calderhead, 1996; Shulman, 1986). I will not review this research in detail since it is not directly related to the current study. I will, however, provide a short summary of this research in order to provide a context that will help in understanding the research on teachers' cognitions. Brophy and Good (1974, 1986) provide an excellent review of the literature in this area and discuss the major findings of this research program.

Research on teachers' behavior is often known as process-product research. The goal of process-product research was to describe teacher behavior that was associated with gains in student performance. Shulman (1986) provides a good description of this research program in his introduction to the Third Edition of the Handbook of Research on Teaching:

> "Overall, the findings take the form of propositions describing those forms of teaching behavior that are associated with gains in student performance, often conditioned on grade level and subject matter. That aspect of teacher behavior usually described is either classroom management behavior (responses to misbehavior, allocation of turns, establishment of rules) or generic instructional behavior (use of lower- or higher-order questions, frequency of praise or criticism, wait time), rather than behavior describing the *substantive* subject-specific content of instruction (e.g., choice of examples, sources of metaphors, type of subtraction algorithm employed, reading comprehension strategy demonstrated and explained, and the like)." (Shulman, 1986, p. 12 – italics are original)

In this research program, teaching effectiveness was viewed as attributable to combinations of discrete and observable teacher actions that were not dependent on time or place. Thus, meta-analysis techniques were used to combine the results of process-product studies to find the "true score" for the relationship between a given teacher behavior and a pupil outcome measure (Shulman, 1986). Brophy and Good (1986) note that although much of this research is correlational, many of the links were also validated experimentally. They describe the major findings of this research program in terms of five basic categories: quantity and pacing of instruction, structuring of information presented to students, questioning students, responding to student responses, and handling seatwork and homework assignments. For example, Brophy and Good (1986) suggest that one of the major findings of this research program is that the amount of time that students spend engaged in learning activities is highly correlated with student achievement. Most researchers relate time that students spend engaged in learning activities to the teacher's ability to manage the classroom efficiently and handle student inattention or resistance.

Although process-product research is not currently in fashion, many of the ideas introduced by this research program can still be found in the educational literature. For example, process-product research introduced ideas such as advance organizers and wait-time (Brophy & Good, 1986). This research also cataloged a large number of student attributes (e.g. social class, race, gender, physical attractiveness, seating location, writing neatness, etc.) that affect teachers' interactions with them in the classroom. These interactions in turn influenced subsequent student behavior and, in some cases, created a self-fulfilling prophecy where a teachers' communication of high expectations to a student can produce high student achievement and vice-versa (Brophy & Good, 1974).

Research on Teachers' Cognitions

In the late 1960's and early 1970's, the psychological theory of information processing began to influence research on teachers. Initial research into teachers' thinking was based on the premise that teachers' thought processes could be thought of as a series of decisions that teachers explicitly made (Calderhead, 1987). The aim of this type of research was to develop a system of rules that govern the decision-making process and describe the types of information that teachers use in making decisions. Many researchers, however, began to realize that much of teachers' thinking did not seem to involve the degree of deliberation and choice that is generally associated with decision-making (Calderhead, 1996; Mitchell & Marland, 1989). They also began to realize that much of the information that influenced teachers' thinking was implicit and could not be articulated by teachers. This led to a focus on teachers' conceptions as an area of research.

Teachers' Decision-Making

Although there was some research on teachers' decision-making prior to 1975, Clark and Peterson (1986) credit the June 1974 National Conference on Studies in Teaching as being a major factor in the change from process-product research to research focusing on teachers' thought processes. Panel 6 of this conference, "Teaching as Clinical Information Processing", was chaired by Lee Shulman and included a diverse group of experts. The report from this panel argued that teachers' actions are directed by their thought processes and that these thought processes should be the focus of research on teachers. In addition to calling on the research community to shift their attention, the Panel 6 report had the more concrete result of influencing the development of The Institute for Research on Teaching at Michigan State University in 1976. This organization then began the first large program of research on teachers' thought processes.

Research into teachers' decision-making often focuses on one of three basic times when teachers might engage in decision-making: decision-making that occurs prior to instruction (preactive decision-making), decision-making that occurs during classroom instruction (interactive decision-making), and decision-making that occurs after instruction (postactive decision-making). Relatively little research has been done on postactive decision-making. Some researchers (e.g. Clark & Peterson, 1986) argue that, due to the cyclical nature of teaching, postactive decision-making after a given day of teaching may be more appropriately thought of as preactive decision-making for the next days teaching. Thus, I will not discuss postactive decision-making separately from preactive decision-making. More recently, researchers have focused on postactive reflection on teaching as a way of developing teaching skills. This role of reflection in the development of teaching skills will be discussed in the section on Teachers' Conceptions.

Preactive thinking

Most of the research on teachers' decision-making has been on preactive teaching, or teachers' planning. Much of this research has been conducted with teachers at the elementary level. For example, of the 18 studies that Clark and Peterson (1986) use in their review of the teacher planning literature, 16 were conducted with elementary teachers. Of the remaining two studies, one was conducted with junior high school teachers and one was conducted with high school teachers. Nonetheless, these studies have influenced the thinking of researchers conducting studies on teachers at higher levels. In his review of the literature on teachers planning, Calderhead (1996) described six main features of the planning process:

1. **Planning occurs at different levels**. Planning differs in terms of the span of time for which the planning took place (i.e. weekly, daily, long range, short range, yearly , and term planning) (Clark & Yinger, 1987; Shavelson & Stern, 1981) as well as the unit of content for which the planning took place (i.e. unit and lesson planning) (Clark &d Peterson, 1986). Each level of planning has a different focus. For example, in yearly planning, teachers might be most concerned about the selection and sequencing of topics, while in weekly planning teachers might be more concerned with matters of timing and the organization of particular materials and activities (Calderhead, 1996).
2. **Planning is mostly informal**. Teachers do not usually write formal plans for their lessons. When they do, the plans are frequently written to satisfy administrative requirements (Calderhead, 1996) and seldom reflect the teachers' entire plan (Clark & Peterson, 1986; Clark & Yinger, 1987).

3. **Planning is creative**. Models of teacher planning as typically taught in teacher preparation courses usually involve a logical process of deciding on goals and objectives and then translating these into classroom practice. The research, however, indicates that teachers do not follow a linear process when planning (Calderhead, 1996; Clark & Yinger, 1987; Shavelson & Stern, 1981).
4. **Planning is knowledge based**. Teachers use their knowledge of subject matter, classroom activities, children, teaching, school conventions, etc. when planning instruction (Clark & Yinger, 1987; Shavelson & Stern, 1981). Calderhead (1996) suggests that this extensive use of knowledge in planning may be why planning is difficult for beginning teachers and may result in plans that are incomplete or unworkable in practice.
5. **Planning must allow flexibility**. Sometimes unexpected events cause a given plan to be inappropriate. Studies have found that experienced teachers are more successful in adapting their plans to a given context. Beginning teachers, however, appear to adhere more rigidly to their plans, even when it may be inappropriate to do so (Calderhead, 1996).
6. **Planning occurs within a practical and ideological context**. Planning can be influenced by the expectations that exist within the school or by the teachers' conceptualization of the subject matter itself. Teachers' planning decisions are influenced by the textbook, district objectives, and their own views of teaching (Calderhead, 1996).

Although much of the research results reported above were developed from studies with elementary teachers, the few studies that have been done on high school and college teachers suggest similar findings. Taylor (1970) conducted one of the earliest studies of teacher planning. He conducted focus groups with over 40 British high school teachers roughly evenly divided between English, science, and geography. In addition he administered a written questionnaire to a similar sample of 261 high school teachers. His general conclusions are that teachers, when planning, do not appear to follow a linear strategy from objectives to activities. Instead he found that teachers' first consideration when planning was the specific learning activities. Teachers then went on to consider the likely levels of interest and involvement from the students, and finally they attempted to relate the activities to the purposes of instruction.

In a study of 13 high school science teachers, Duschl and Wright (1989) attempted to expand the understanding of teachers' planning characteristics from elementary teachers to high school teachers. Their focus was on the knowledge used by these teachers when planning instruction. Similar to the research on elementary teachers, their major findings were that these high school teachers' planning decisions were dominated by considerations for the level of the students in the particular class, the objectives as stated in the curriculum guide, and the pressures of accountability. The authors were attempting to understand what role the teachers' understanding of the nature of scientific theories had in their decision-making. They conclude that teachers "hold a view of science that does not recognize theories or theory development as centrally important in the scientific enterprise" (p. 493) and thus, their understanding of the nature of scientific theories is not an important part of their planning.

John (1991) also attempted to understand the planning process by non-elementary teachers. He studied the planning processes of five student teachers in mathematics and geography. Similar to the conclusions of Duschl and Wright (1989), John found that one of the main concerns of these student teachers were the abilities and needs of the pupils. John also found that a major concern while planning was developing activities that would maintain their classroom control. In contrast to the Duschl and Wright (1989) study, John (1991) concluded that the teachers' understandings of the nature of the subject had a significant impact on their planning. For example, he found that the mathematics teachers saw math as a predominantly hierarchical subject involving a logical, staged progression of understanding. Thus, these teachers planned in a sequential manner that was consistent with their view of the subject.

John (1991) also found that all of the student teachers appeared to approach the planning process in three stages. The first stage was informal and consisted of the interpretation of the lesson assignment and searching for appropriate resources and approaches. The second stage involved more formal planning in which the resources were ordered and structured and an actual plan was made. The final stage involved the production of a usable classroom version of the plan, which often served as a guide during interactive teaching. He noted that these stages tended to become condensed as the student teachers gained experience.

In one of the few studies conducted with college teachers, Andresen et. al. (Andresen, Barrett, Powell, & Wieneke, 1985) conducted weekly interviews with 7 college teachers from a variety of disciplines. They found that these teachers appeared to have a regular routine of ongoing planning. For example, one teacher describes attempting to get into a pattern of "trying to prepare next week's lecture and polish it up as much as I can this week and then have another look at it on Monday" (p. 314). Another major planning concern of the teachers in this study was assessment, which was a particularly important concern at certain stages of the course.

Interactive thinking

The research shows that while planning does have an influence on what happens during actual teaching, many of the details of classroom teaching are unpredictable and interactive decisions must be made (Clark & Yinger, 1987). Clark and Yinger (1987) see planning as shaping the broad outlines of what is possible or likely to occur while teaching and as useful for managing transitions from one activity to another. Once teaching begins, however, the plan moves to the background and a teacher's interactive thinking becomes more important.

Similar to research on preactive thinking, most of this research has been done with teachers at the elementary level. For example, of the 12 studies that Clark and Peterson (1986) use in their review of the literature on teachers' interactive thoughts, 11 were conducted with elementary teachers. One study was conducted with 7th and 8th grade teachers.

One of the goals of many researchers on interactive thinking was to create a flow chart model of a teacher's interactive thinking process. This required an understanding of the types of decisions that teachers made and data they used in making these decisions.

Figure 2-1: Model of teachers decision making during interactive teaching (Shavelson & Stern, 1981)

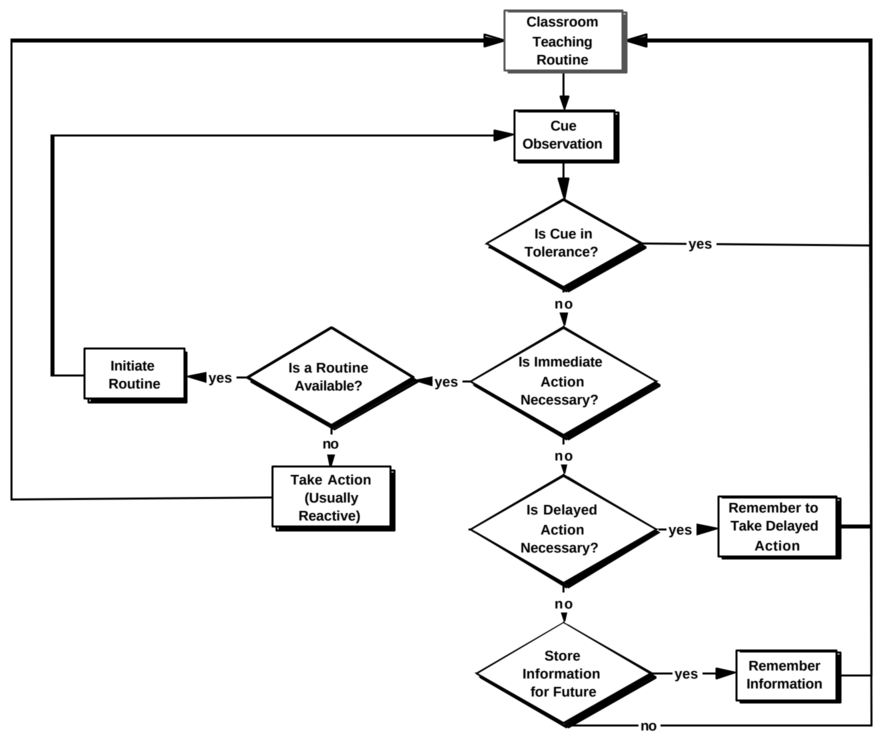


Figure 2-1 is a model of teachers' interactive decision-making created by Shavelson and Stern (1981) in their review of the literature. This model has several important features based on the research literature. There is substantial and consistent evidence that, on

average, teachers make one interactive decision during every two minutes of teaching (Clark & Peterson, 1986). A decision is based on information about how the planned lesson is proceeding (Calderhead, 1996; Clark & Peterson, 1986; Shavelson & Stern, 1981). The type of information most frequently considered has to do with student behavior problems (Clark & Peterson, 1986; Shavelson & Stern, 1981). At a decision point, a teacher has two basic alternatives; to continue the lesson, or to make a change in the lesson. If the student behavior appears appropriate, there is no reason to change the lesson. If, however, there appears to be a lack of student involvement, behavior problems, or a question from a student the lesson may need to be modified. Most often at these points teachers choose to continue the lesson (Clark & Peterson, 1986; Shavelson & Stern, 1981). In some cases the decision to continue is based on a teacher's choice to deal with the problem at a later time. In other cases the decision to continue is based on a lack of alternatives (Clark & Peterson, 1986; Shavelson & Stern, 1981).

One explanation for the resistance of teachers to change their lessons midstream is that such a change would cause a disruption in the flow of the lesson. Studies suggest that during planning, teachers develop a mental script, or image, of what the teaching will look like. One of the benefits of having such a mental script is that it reduces the information processing demands on the teacher and allows the teacher to maintain the flow of the lesson. To deviate from the mental script, however, requires a higher level of information processing which can interrupt the flow of the lesson and increase the likelihood of classroom management problems (Shavelson & Stern, 1981).

A study conducted with six Australian high school teachers (Mitchell & Marland, 1989) supports the idea that teachers use mental scripts to help reduce the information processing demands of teaching. In contrast to Shavelson & Stern (1981), however, Mitchell and Marland found the mental scripts used by teachers to be of a more general nature and not dependent on prior planning. Mitchell and Marland identified three "frames" through which a teacher interprets his classroom environment. These frames are supported by frequently used routines. For example, they show how a teacher's "ego enhancement frame" guided his interaction with a student during interactive teaching. The teacher noticed that one, fairly quiet, student had missed a previous answer on his worksheet. Thus, the teacher's "ego enhancement frame" identified this student as having a potential "ego problem". The teacher then used his questioning routine to ask the student a question about the next section that he believed the student was likely to answer correctly.

Although the Mitchell and Marland (1989) study comes from a decision-making perspective, they report some results that are inconsistent with the idea of decision-making. In their study, they videotaped three experienced teachers and three inexperienced teachers during interactive teaching. Afterwards, the teachers were interviewed and asked to describe their thinking. One of their findings was that much of the teachers' decision-making activities appeared to be done implicitly. For example, they found that a teacher rarely thinks to himself "in this situation I'll use questioning strategy X". However, the teacher's selection of strategy X would frequently be appropriate. Another related finding is that, although the content of a teacher's interactive thoughts are similar for both experienced and inexperienced teachers, the experienced teachers report making fewer interactive decisions. These differences between experienced and inexperienced teachers and the ability of experienced teachers to work effectively while reducing their decision-making load has been examined from other perspectives and will be discussed in more detail later (see p. 45).

Summary of Research on Teachers' Decision-Making

Research on teachers' decision-making marked a distinct shift from research solely on teaching behavior to a focus on both behavior and the mental processes behind that behavior. This research agenda brought an understanding of the different types of thinking that teachers engage in (i.e. preactive, interactive, postactive) and was successful in identifying the types of decisions that teachers needed to make in each situation. The research agenda was also successful in developing a new set of research methods that could be used in the study of teachers' thinking. Qualitative research methods such as think aloud procedures (e.g. a teacher is asked to think aloud while completing a planning task), stimulated recall (e.g. a teacher is videotaped while teaching and later asked to view the tape and report on thoughts and decisions), and policy capturing (e.g. a teacher is asked to make judgments or decisions about hypothetical teaching situations or materials) were all introduced to research on teaching during this period. They continue to be among the prominent research methods used in research on teachers.

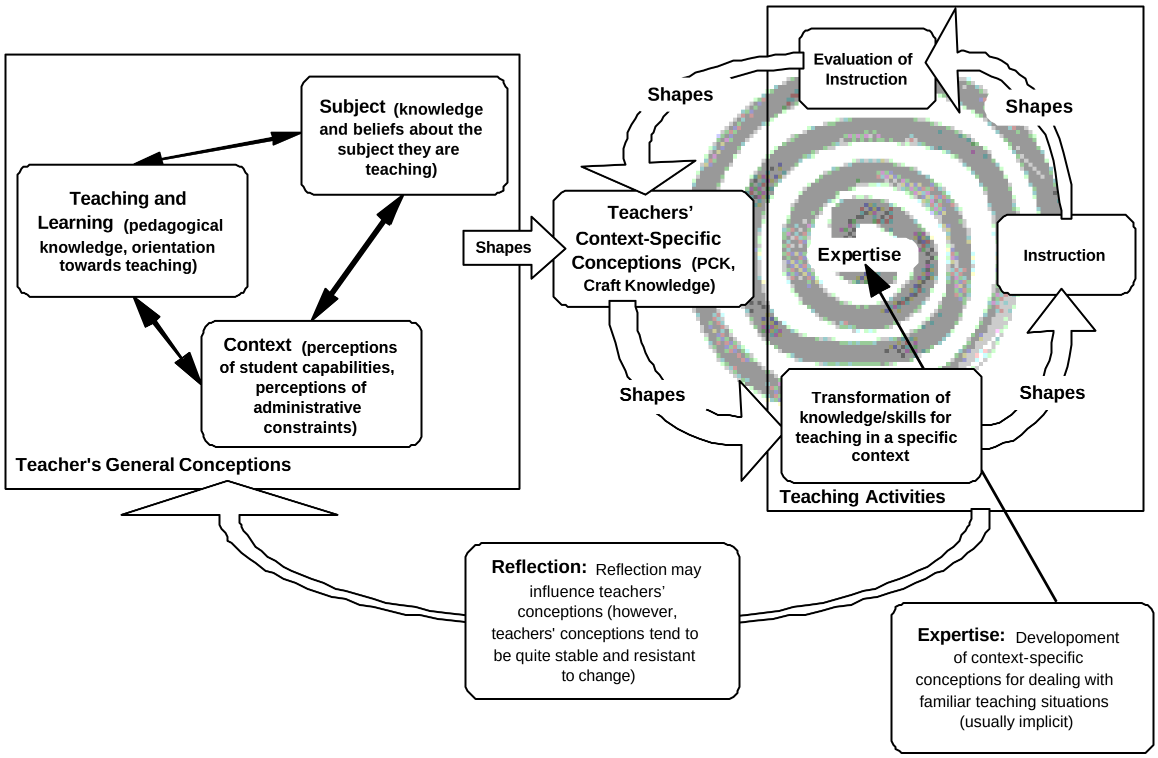
The most important result of the research on teachers' decision-making is the realization that teachers work in a rich and complex environment and make a large number of decisions. Teachers, however, do not deliberately make many of these decisions. Despite many efforts, this research agenda failed to develop any workable models of a teacher's decision-making process. Thus, researchers began to expand their research to include not only explicit teacher thinking, but also implicit teacher thinking and the mental constructs that guide such implicit thinking.

Although the current study was conducted from a teachers' conceptions perspective, it was influenced by the research on teachers' decision-making. This study made use of many research methods initially developed for decision-making research. Much of the interview was based on policy capturing techniques that seek to learn about teacher thinking by asking them to engage in hypothetical teaching activities. The instructors in the study completed three activities in which they examined and evaluated different types of instructional artifacts. For example, in a planning activity, instructors were shown three different instructor solutions and asked to describe how they are similar or different to the solutions that the instructor typically uses. The instructors were also asked to explain their reasons for using a particular type of solution. The interview questions were designed to help the instructors verbalize as much of their decision-making process as possible.

Teachers' Conceptions

The shift away from research on teachers' decision-making and towards research on teachers' conceptions occurred gradually, and there was no important event that signaled the end of one and the beginning of the other. Freeman (1994) sees the work on teacher decision-making as being a logical starting point for research on teachers' cognition. He argues that early researchers imposed the decision-making framework because they had no better model to work with and a decision-making framework had been used successfully in studies of other types of professional thinking (e.g. medical diagnosis). As researchers gained more experience working with teachers' cognitions, however, they began to see teaching from the teachers' perspective and to understand what Freeman calls the "teacher's story". The teacher's story is the framework within which the work of teaching makes sense. This shift occurred around 1985 (Freeman, 1994), and began by looking at the knowledge and knowledge structures used in teaching. The research quickly expanded to examine various types of conceptions that teachers have, how these conceptions are related to teaching, and how these conceptions develop and change. The research also expanded to include research on college teaching, which, until this period had been very minimal.

Figure 2-2: Framework for Understanding Research on Teaching



In reviewing the research literature on teachers' conceptions, there appear to be three general bodies of literature. One body describes teachers' general conceptions that are related to teaching. This type of research is called by such names as teachers' conceptions, teachers' perceptions, teachers' mental images, or teachers' orientations. The second general body of research deals with conceptions of teaching in a specific context. This type of research is called by such names as pedagogical content knowledge or craft knowledge. The third general body of research deals with expertise and how expertise develops.

Based on these three general bodies of research and my personal understanding of teaching, I have developed the framework shown in Figure 2-2 to help in the organization of this literature review. I will first present an overview of the framework and then look at the literature relevant to each of the parts in more detail.

Teachers General Conceptions. Many researchers have investigated teachers' general mental states. The types of general conceptions examined can be classified in three basic areas: conceptions of teaching and learning, conceptions of the subject, and conceptions of the teaching context. Most of these conceptions are implicit. Although it has been shown that these conceptions affect teaching activities, they do not always do so in a logical manner. It has been shown that teachers can have conflicting conceptions and it is often difficult to predict how these conflicts will be resolved. For example, a teacher may believe that having students actively involved in group work is a productive teaching strategy (a conception of teaching) while at the same time believing that the class is too large for group work (a conception of the teaching context). Whether the teacher would engage in teaching involving group work is dependent on the relative strengths of these two conceptions and, possibly, on other factors. These general conceptions have also been shown to influence how teachers interpret events and, thus, can limit their perceived options.

Most of the research on teachers' general conceptions has been confined to looking at a particular type of conception (e.g. conceptions of teaching). At least one study has attempted to consider all types of conceptions and has been successful in using this information to account for differences in the way different teachers interpret curricular materials (Lantz & Kass, 1987).

Teachers' Context-Specific Conceptions. Initially, a teacher has few context-specific conceptions. A beginning teacher must make decisions based on his/her general conceptions. Going through this process, however, leads to the development of context-specific conceptions. These conceptions are experience-based and help teachers relate their past experience to current problems, define problems, and test out possible solutions to them (Calderhead, 1996). It is these conceptions, which are well-suited for the task of teaching particular material to particular students, that guide much of a teacher's activities and reduce the mental load of teaching.

Expertise in Teaching. As a teacher gets experience and develops more context-specific conceptions, his/her teaching decisions become more and more automated until the teacher reaches the point where he/she implicitly knows what to do without having to engage in conscious thought. This is what Berliner (1987) defines as expertise. It does not mean that the teacher always does things in the best possible way, only that the teacher's thought processes are highly automated.

Reflection. There have been suggestions that the best way to get a teacher to change his/her teaching practice is to change his/her general conceptions. It has been proposed that this occurs through a process of conceptual change (Posner et. al., 1982), which can only be accomplished through reflection. It is noted that, similar to students, teachers do not frequently engage in this type of reflection, so teachers' general conceptions tend to be stable and resistant to change.

Teachers' General Conceptions

Conceptions are instrumental in defining tasks and selecting cognitive tools with which to interpret, plan, and make decisions regarding such tasks; hence they play a critical role in defining behavior and organizing knowledge and information (Knowles & Holt-Reynolds, 1991; Pajares, 1992, p. 325; Nespor, 1987). Carter and Doyle (1995) suggest that these systems of conceptions function as paradigms in that they: "(1) define what is recognized as notable in the stream of experience; (2) specify how issues and problems can be thought about; and (3) persist even in the face of discrepant information" (p. 188).

Conceptions of Teaching and Learning

A number of researchers have looked at conceptions of teaching held by college teachers[1] (Biggs, 1989; Martin & Balla, 1991; Prosser & Trigwell, 1999; Prosser, Trigwell, & Taylor, 1994; Samuelowicz & Bain, 1992). All of these studies have produced a hierarchical list of different ways that teachers understand teaching. The lists differ in the number of discrete ways of thinking identified, but they all range from teaching as presenting information to teaching as facilitating student learning. Further, they are all hierarchically arranged from less complete conceptions (presentation of information) to more complete conceptions (facilitating student learning). In these hierarchies, the higher conceptions include aspects of the lower conceptions, but not vice versa. For example, in an interview study with 24 college physics and chemistry teachers, Prosser and Trigwell (1999) and Prosser et. al. (1994) identify six conceptions of teaching first year university physical science:

1. **Teaching as transmitting concepts of the syllabus**. Teachers see their role as transmitting information based on the concepts in the textbook or syllabus, but do not focus on how the concepts are related to each other, or on students' prior knowledge.
2. **Teaching as transmitting the teachers' knowledge**. Teachers see themselves as the source of knowledge rather than having knowledge come from some external source such as a textbook (as in conception 1). Similar to conception 1, teachers see their role as transmitting information to students and do not focus on how the concepts are related to each other, or on students' prior knowledge.
3. **Teaching as helping students acquire concepts of the syllabus**. Similar to conception 1, teachers focus on the concepts as detailed in the textbook or syllabus. Rather than being transmitters, however, they see themselves as helping the students acquire those concepts and the relations between them. Unlike conceptions 1 and 2, students' prior knowledge is seen as important.
4. **Teaching as helping students acquire teachers' knowledge**. Similar to conception 2, teachers focus on their own understanding of concepts. Like conception 3 and unlike conception 2, they see themselves as helping their students acquire those concepts and relations between them. Unlike conceptions 1 and 2, students' prior knowledge is seen as being important.
5. **Teaching as helping students develop conceptions**. Teachers focus on their students' worldviews or conceptions of the subject matter rather than their own conceptions or the concepts in the text. They see their role as helping their students develop their conceptions in terms of further elaboration and extension within the students' current worldview.

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[1] In a review of the literature on conceptions of mathematics teaching, Thompson (1992) reported similar

6. **Teaching as helping students change conceptions**. Similar to conception 5, teachers focus on their students' worldviews or conceptions of the subject matter. In contrast to conception 5, however, teachers see their role as helping students change their worldviews.

Prosser et. al. (1994) argue that these results may be dependent on the specific context variables of course level and discipline. The similarity of these results to the results of the other three studies suggests that this range of conceptions is rather stable across disciplines. For example, Samuelowicz and Bain (1992) conducted their study with both science and social science teachers and did not report any differences between the groups. Both Samuelowicz and Bain (1992) and Prosser et. al. (1994), however, do indicate that these conceptions appear to be dependent on course level. Samuelowicz and Bain (1992) report that several teachers in their study expressed different conceptions of teaching between the undergraduate level and the graduate level. Conceptions of teaching at the undergraduate level seemed to be lower in the hierarchy (teaching as transmission of information) and conceptions of teaching at the graduate level seemed to be higher in the hierarchy (teaching as facilitating conceptual change). Similarly, Prosser et. al. (1994) report that teachers of science service courses were more likely to report lower conceptions of teaching than teachers of introductory courses for science majors.

In the same study mentioned above, Prosser and Trigwell (1999) and Prosser et. al. (1994) identify five conceptions of learning first year university physical science held by college teachers:

1. **Learning as accumulating more information to satisfy external demands**. Learning is seen as the accumulation of facts, principles, etc which are added to or replace existing knowledge through processes such as rote learning. The outcome of learning is determined extrinsically.
2. **Learning as acquiring concepts to satisfy external demands**. The difference between this and conception 1 is the way teachers see the acquisition of knowledge. Learning is seen to involve a process of developing

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results for studies conducted with preservice mathematics teachers.

meaning by acquiring the concepts of the discipline and knowledge of how those concepts are related.

3. **Learning as acquiring concepts to satisfy internal demands**. Here, the process of learning is similar to conception 2. The outcome, however, is not only to satisfy external demands. The students will know when they have learned something because it will have personal meaning for them.

4. **Learning as conceptual development to satisfy internal demands**. Learners come to see things in their own way through development of their own meaning rather than according to the discipline knowledge. The students' structure of knowledge may not be the same as that held by the teacher as it would be in conception 2 and 3. Similar to conception 3, however, learning is seen as a personal process and students use their own criteria to determine whether they have learned something.

5. **Learning as conceptual change to satisfy internal demands**. Learning is the development of personal meaning through a paradigm shift in the students' worldview. Students change the way they think about the discipline by restructuring their current worldview to produce a new worldview. This is different from conception 4 in that the students adopt a new worldview (conceptual change) rather than developing new meaning within their current worldview (conceptual development).

Prosser et. al. (1994) note that the high degree of similarity between the teachers conceptions of teaching and their conceptions of learning is due to the teachers' lack of differentiation between teaching and learning. Only teachers with the higher conceptions were able to differentiate between teaching and learning. Another interesting finding from the Prosser et. al. (1994) study was that these conceptions of teaching and learning are largely implicitly held by teachers. They report that "it was clear from the interviews that these teachers did not spend a lot of time thinking about the way their students learn" (p. 227). They suggest that this might explain the difficulty that many teachers, especially those with the lower conceptions, had in expressing their views about the process of learning.

An alternative way that some researchers have considered teachers' conceptions of teaching and learning is in the form of metaphors (Briscoe, 1991; Carter & Doyle, 1987) or cultural myths (Tobin & McRobbie, 1996). For example, Carter and Doyle (1987) identified metaphors for teachers' roles. In their study, one teacher thought of her role as a driver navigating a complex and often treacherous route, while another teacher thought of her role as a defender of a territory or a commodity. These types of metaphors shape their interpretation of classroom events (Carter & Doyle, 1987), and can shape the interpretation and enactment of curricular changes (Briscoe, 1991).

Tobin and McRobbie (1996) identified 4 cultural myths based on a qualitative analysis of 4 weeks of class observations in an 11th grade Australian chemistry class and four 1.5 hour interviews with the teacher:

- *The Transmission Myth*: The teacher is the principal source of knowledge and the students are the receivers of knowledge.
- *The Myth of Efficiency:* Has four components: the teacher having control of students, time being a commodity in short supply, content coverage being more important than learning with understanding, and the work program being in the control of others.
- *The Myth of Rigor:* The teacher has the responsibility to ensure that students learn at a level that is consistent from one set of students to another and from one year to the next (i.e. covering the prescribed content, maintaining high standards, preparing students for the next educational level, and recognizing the specification of the curriculum was the prerogative of external agencies).
- *The Myth of Preparing Students for Examinations*: Tests and examinations focused the enacted curriculum and resulted in an emphasis on low cognitive level types of engagement by students.

Tobin and McRobbie (1996) suggest that these myths are based on two basic sets of beliefs: beliefs about the nature of knowledge, and beliefs pertaining to the distribution of power. The authors also point out that these cultural myths support the status quo and constitute a conservative force to many proposed student-focused curricular changes.

Relationship between conceptions of teaching and learning and teaching practice. In the same set of studies discussed earlier (p. 28), Prosser and Trigwell (1999 and Trigwell, Prosser, & Taylor, 1994) identify 5 approaches to teaching adopted by the 24 college science teachers they interviewed:

1. **A teacher-focused strategy with the intention of transmitting information to students** (13 teachers). The focus is on transmitting facts and demonstrated skills with the hope that students will automatically receive this information. The teacher engages in little or no interactions with the students and the students have little or no responsibility for the teaching-learning situation. If the students ask questions, the teacher may answer the specific questions but make little or no adjustment to his/her pre-planned strategy.
2. **A teacher-focused strategy with the intention that students acquire the concepts of the discipline** (6 teachers). The focus is on helping students acquire the concepts of the discipline and their underlying relationships. This approach differs from approach 1 in that the students are expected to be able to relate concepts and solve transfer problems. It is similar to approach 1 in the focus on the teacher.
3. **A teacher/student interaction strategy with the intention that students acquire the concepts of the discipline** (3 teachers). The goal is similar to approach 2, however, students are seen to gain this disciplinary knowledge through active engagement in the teaching-learning process. The teacher, however, maintains responsibility for the teaching-learning situation. For example, the teacher asks, and encourages students to ask, questions which are mainly answered by the teacher. In answering the question, however, the teacher may depart from his/her pre-planned structure.
4. **A student-focused strategy aimed at students developing their conceptions** (1 teacher). The teacher aims to help the students develop their knowledge within a worldview, assuming that the students' worldview is consistent with that of the discipline. The teacher structures teaching and learning situations in which the students are encouraged to accept

responsibility for their own learning. For example, small groups may be used to encourage students to interact with one another.

5. **A student-focused strategy aimed at students changing their conceptions** (1 teacher). The teacher aims to confront and qualitatively change the students' worldview. The student-focused nature of this approach is similar to approach 4.

Prosser and Trigwell (1999) report a "reasonably close" relation between the approaches to teaching taken by the 24 teachers and their conceptions of teaching and learning. They found that teachers who adopted a student-focused approach to teaching had conceptions of teaching and learning that were relatively high in the hierarchy. Similarly, they found that teachers who adopted teacher-focused approaches to teaching had conceptions of teaching and learning that were lower in the hierarchy. They also noted that there are some contextual variables that affect the approaches to teaching -- these will be discussed later (p. 39).

Another interesting finding of this set of studies (Prosser and Trigwell, 1999; Trigwell et. al., 1994; Trigwell & Prosser, 1996) is that a teacher's intention in teaching is strongly related to the strategy used. That is, an information transmission intention is always associated with a teacher-focused strategy and a conceptual change intention is always associated with a student-focused strategy. They did not find, for example, a teacher who had an information transmission intention and a student-focused strategy. They confirmed this strong relationship between intention and strategy in a quantitative study of 58 Australian college chemistry and physics teachers (Trigwell & Prosser, 1996). They argue that this finding has important implications for professional development efforts in that "just helping academic staff become aware of, or even practicing, particular strategies will not necessarily lead to substantial changes in teaching practice. The associated intentions or motives also need to be addressed" (p. 85).

This strong link between teachers' conceptions of teaching and learning and their teaching practices was also found by Gallagher & Tobin (1987) in a study of 16 Australian high school science teachers. These teachers had conceptions of teaching and learning that would be relatively low on the Trigwell & Prosser hierarchy. The teachers tended to equate task completion with learning. The teachers believed that it was their job to cover the material in the text and whether or not learning occurred was the student's responsibility. Thus, these teachers tended to work in such a way that would ensure that content was being covered. For example, Gallagher & Tobin (1987) noted that a majority of class time was spent in whole-class interactions, during which the teacher had control over the pacing of the lesson. They also found that the teachers would generally interact with only the top 25% of the students during these whole-class interactions. If these "target students" appeared to understand the material, the teachers would typically move on to new material.

It becomes more difficult to determine the relationship between a teacher's conceptions of teaching and learning and his/her teaching practices when the teacher has conflicting conceptions. For example, in a study of 107 K-12 science teachers, Lumpe, Czerniak, and Haney (1998) found that these teachers "believed that including cooperative learning in the classroom could help increase student learning, make science more interesting, increase problem solving ability and help student learn cooperative skills" (p. 128). However, they also believed that the use of cooperative learning would increase student off-task behavior and take up too much class time. It was found that the concern for off-task behavior was a bigger predictor of a teacher's intention to use cooperative learning. Although the authors did not draw this conclusion, it seems that this conception of teachers as needing control over student behavior is a conservative force that makes many curricular innovations difficult.

How do conceptions of teaching and learning develop? In a review of the research literature, Pajares (1992) suggests that conceptions of teaching are well established by the time students get to college. He suggests that these conceptions are formed during a teacher's experience as a student. Knowles and Holt-Reynolds (1991) agree and go on to argue that one of the main differences between teaching and other professional jobs (such as medicine or law) is this apprenticeship of observation that all teachers have had.

Researchers on college teaching come to the same conclusion (Counts, 1999; Grossman, 1988). For example, in a case study of one college physics teacher, Dr. Bond, Counts (1999) noted that Dr. Bond based his ideas of good and bad teaching on his experiences as a physics student. As Counts described, Dr. Bond recounted his experiences in a particular class with a professor who "held a positive regard for the students and was very challenging but reasonable" as being the model of an excellent professor (Counts, 1999, p. 129).

Influence of prior research on conceptions of teaching and learning on the current study. Several studies done with college teachers suggest that the college physics teachers interviewed for this study will have conceptions of teaching and learning that range from teaching as transmission of information to teaching as facilitating conceptual change. They also suggest that most of the faculty interviewed will likely be closer to the transmission of information side. These studies also suggest that, for many teachers, it may be impossible to distinguish between their conceptions of teaching, their conceptions of learning, and their teaching intentions. Thus, the interview was designed to probe teachers to make distinctions between these three different types of conceptions when they were able, but not forcing distinctions where none existed.

Another major influence on the current study was the idea of teacher versus student roles and the use of "target students" (Gallagher & Tobin, 1987). Based on the research team's experience with introductory physics instruction, it seemed that these were important themes and the interview was designed to probe teachers' conceptions of the role of the teacher and student. The interview was also designed to determine if there was a particular type of student that teachers aimed their instruction towards.

Conceptions of Subject Matter

In science, much of the research on teachers' conceptions of subject matter has been focused specifically on teachers' conceptions of the nature of science (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Brickhouse, 1990; Brickhouse & Bodner, 1992; Hodson, 1993; Lederman & Zeidler, 1987).

The subject matter of primary interest in this study, however, is problem solving in physics. The only study that I am aware of to investigate high school or college teachers' conceptions of problem solving in physics was conducted by Yerushalmi and

Eylon (2001). Based on a questionnaire given to 8 Israeli high school teachers, they found that these teachers were aware of the "necessary problem solving processes[2]" and wanted to develop these processes in their students. These teachers, however, were not necessarily representative of the population of high school teachers. They were all teachers who chose to participate in a professional development program that focused on instruction aimed at promoting students' self-monitoring in the process of solving physics problems.

In mathematics, Cooney (1985) conducted a case study of one high school mathematics teacher's conceptions of mathematics problem solving. He found that this teacher believed that the "central point of teaching problem solving is teaching heuristics". There was no clear explanation of how the word "heuristics" was used.

Relationship between conceptions of subject matter and teaching practice. In the case study of one mathematics teacher mentioned above, Cooney (1985) conducted regular classroom observations. He observed that the teacher occasionally used "recreational math problems" to help students understand and become interested in mathematics problem solving. Cooney, however, concluded that this teacher placed little emphasis on problem solving heuristics and that his lessons were "clearly textbook oriented and handled in a rather cookbook fashion" (Cooney, 1985, p. 332). Thus, for this one mathematics teacher, there appears to be little relationship between his conceptions of mathematics problem solving and his teaching practices.

Several studies have found that there does not appear to be a link between a teachers' conception of the nature of science and their teaching behavior (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Brickhouse & Bodner, 1992; Hodson, 1993; Lederman & Zeidler, 1987). For example, in a study of 13 preservice high school teachers' conceptions of the nature of science, Bell et. al. (2000) found that although the teachers had views of the nature of science that were consistent with contemporary conceptions and indicated that the nature of science was an important instructional goal, none of them thought that they had adequately addressed the nature of science during their teaching. They mentioned a number of constraints to

[2] The article does not describe what the authors consider to be the necessary problem solving processes.

explain this apparent discrepancy. Most frequently they mentioned a perceived conflict between teaching the nature of science versus teaching the science content and process skills. They also mentioned the substantial time that was required to teach the nature of science and that this would prevent them from keeping up with other teachers. A final factor was the preservice teachers' lack of confidence in their own understandings of the nature of science.

Similar findings were reported by Hodson (1993) who conducted a study with 12 secondary science teachers in New Zealand. He found that even those teachers who hold clear and consistent views about the nature of science do not plan laboratory-based activities consistently in relation to those views. Instead, the teachers were more concerned with issues of classroom management and course content coverage.

In a case study of one middle school science teacher, Brickhouse and Bodner (1992) found that teachers can have conflicts between their beliefs about what science is and what it means to teach science. The beginning teacher in the study thought of science as an open-ended inquiry, but seemed to think that his role as a teacher was to transmit knowledge to his students in a way they can make sense of it. He also had a conflict between his view that a scientist should be motivated by the pursuit of knowledge, but that his students were motivated by grades.

There is some evidence, however, that teachers' beliefs about the nature of science may influence their classroom practice. Brickhouse (1990) conducted a study with three science teachers. She found that the teachers' views of the nature of scientific theories, scientific processes, and scientific progress all were correlated with their views of teaching and with their teaching actions. For example, in terms of scientific progress, two of the teachers "considered science to progress by the accumulation of facts rather than by changes in theory. Similarly, they expected their students to learn by accumulating bits of information. [The third teacher, however,] believed that science has progressed through new interpretations of old observations and that students learn science not only by assimilating new information, but also by thinking about old information" (p.57). Brickhouse concludes that these three teachers' teaching strategies appeared to be well aligned with their views about the nature of science.

Influence of prior research on conceptions of subject matter on the current study. The studies of teachers' conceptions of the nature of science and of the nature of mathematics problem solving suggest that instructors' conceptions of problem solving in physics may not play a major role in shaping their teaching practices. Since this is a largely unexplored area and a major focus of this study, in order to determine this relationship between conceptions of problem solving in physics and teaching practice, the interview was designed to elicit teachers' views of problem solving separately from their views of the teaching and learning of problem solving.

<u>Conceptions of the Teaching Context</u>

Many studies have focused on teachers' conceptions of various aspects of their teaching context. Aspects of the teaching context investigated include:

- Class size (Prosser & Trigwell, 1997, 1999)
- Perception of control over course content (Prosser & Trigwell, 1997, 1999)
    - Perceived need to cover certain prescribed material (Bell et. al., 2000; Hodson, 1993; Lantz & Kass, 1987)
    - No choice of textbook (Brickhouse & Bodner, 1992)
- Perception of control over teaching methods (Prosser & Trigwell, 1997, 1999)
- Perception of departmental support for teaching
    - Versus research (Prosser & Trigwell, 1997)
    - No support for innovation (Brickhouse & Bodner, 1992)
- Perception of teaching ability/self-efficacy (Abd-El-Khalick et. al., 1998; Bell et. al., 2000)
- Perception of teaching workload (Prosser & Trigwell, 1997; Boice, 1994)
- Perception of requirements for earning tenure (Boice, 1994)
- Perception of students
    - Motivation (Brickhouse & Bodner, 1992; Carter & Doyle, 1995; van Driel, 1997)

- Ability (Boice, 1994; VanDriel, 1997)
- Homogeneity of students (Prosser & Trigwell, 1997)

- Perception of school facilities (e.g. lack of lab equipment and facilities) (Lantz & Kass, 1987)

Relationship between conceptions of the teaching context and teaching practice. In their study of approaches to teaching, Prosser and Trigwell (1999) identified several context variables that were related to approaches to teaching (refer to description of approaches to teaching, p. 33). In a questionnaire administered to 58 Australian college chemistry and physics teachers they found that “a conceptual change/student-focused approach to teaching is associated with perceptions that the workload is not too high, the class sizes are not too large, that the teacher has some control over what and how he/she teaches and that the variation in student characteristics is not too large” (p.156). They also indicate that “an information transmission/teacher-focused approach to teaching is associated with perceptions that the teacher has little control over how and what he/she teaches and that there is lttle commitment to student learning in the department” (p. 156). Making an analogy to research on students’ approaches to learning, Trigwell and Prosser (1997) suggest that a teacher’s choice of a teaching approach is dependent on both his/her prior experience with such an approach and his/her perceptions of the teaching situation (i.e. perceived teacher control of content and teaching methods, class size, etc.) as being compatible with such an approach. For example, they argue that a teacher will adopt a conceptual change/student-focused approach only if the teacher has sufficient prior experience with such an approach and perceives the teaching situation as being compatible with such an approach.

In another large study with college teachers, Boice (1994) interviewed 197 new and experienced faculty in a variety of disciplines. He concluded that both new and experienced faculty describe their teaching practices as dominated by facts-and-principles lecturing. He identified these teachers’ conceptions of the requirements for earning tenure as contributing to this stability in their teaching practices. Boice (1994) noted that new faculty were concerned about criticism of their teaching that might affect their tenure review and taught in ways that they believed would minimize this criticism. This meant that they taught defensively and made sure that they had the facts straight. In addition, instead of reflecting on their teaching styles upon receiving low teaching ratings, they tended to blame teaching failures on contextual factors such as poor students, heavy teaching loads, and invalid rating systems.

In a study of 60 first-year college teachers in The Netherlands in a college that was trying to move to a more student-centered teaching approach, many of the teachers appeared to value such an approach, but did not focus on developing process skills and thinking strategies in their students in order to promote self-regulated study activities. Many teachers attributed this choice of teaching practices to their perception that students did not have the necessary ability or motivation to develop these thinking strategies (VanDriel, 1997).

Although a teacher's perception of students is an important contextual variable, Carter & Doyle (1995) suggest that teachers are often not good at perceiving student abilities or interests. They noted that teachers often judge instructional practices based on how they reacted, or would have reacted to similar practices as students. They suggest that, since most teachers were successful as students, they base their teaching practices on incomplete assumptions about "the range and diversity of students' capabilities and interests and on unrealistic beliefs in the attractiveness of their own preferences" (Carter & Doyle, 1995, p. 189). They also see this tendency of teachers to think about teaching from their perspective as students as a conservative force in the curriculum. They note that studies of students suggest that when the work is familiar and predictable, the classes tend to run smoothly. On the other hand, when teachers try new practices, students typically experience high levels of risk. Thus, from their perspective as students, teachers are reluctant to change their practices.

Influence of prior research on conceptions of teaching context on the current study. The research reviewed here suggests that teachers have many different contextual variables that they refer to when talking about their teaching. Further, these perceptions of contextual variables often serve as conservative forces that lead to the continuation of current teaching methods. Thus, knowing about teachers' conceptions of these variables is very important to the goals of this study. The interview was designed to give teachers opportunities to discuss these variables when talking about their instructional decisions.

Teachers' Context-Specific Conceptions

Context-specific conceptions go by the names of pedagogical content knowledge (Fernandez-Balboa & Stiehl, 1995; Grossman, 1988; Shulman, 1986); van Driel, Verloop, & de Vos, 1998; Wilson, Shulman, & Richert, 1987), craft knowledge (van Driel, Verloop, Werven, & Dekkers, 1997), and practical knowledge (Beijaard and Verloop, 1996; Berliner, 1986; Elbaz, 1981; van Driel, Beijaard, & Verloop, 2001). Although there are some subtle differences between these different ways of thinking about context-specific conceptions, the essence of all of these ideas is that, as part of their classroom experience, teachers acquire conceptions that they use in their day-to-day teaching (Calderhead, 1996). These conceptions are seen as the interface between a teacher's conceptions of the subject matter and the transformation of this subject matter for the purpose of teaching (Geddis, 1993). Just as with general conceptions, these context-specific conceptions are usually implicitly held. Having a large network of context-specific conceptions is one of the signs of expert practice.

Currently the most common way that these context-specific conceptions are discussed is as Pedagogical Content Knowledge (PCK). Shulman (1986) introduced the idea of PCK as one type of knowledge used in teaching. A later article (Wilson, Shulman, & Richert, 1987), described PCK as not only a type of knowledge, but also a "way of thinking" that facilitates the generation of alternative transformations of the subject matter for the purpose of teaching (p. 115).

In their review of the literature on PCK, van Driel et. al. (1998) conclude that there are two elements that all researchers include as part of PCK: knowledge of comprehensible representations of subject matter, and understanding of content-related learning difficulties. In a study of the pedagogical content knowledge of four relatively new humanities and social science college teachers, Lenze (1995) noted three characteristics of pedagogical content knowledge: it is often tacit, it is individualized with respect to each teacher's purpose, and it is discipline-specific.

Relationship between context-specific conceptions and teaching practice. The exact relationship between context-specific conceptions and classroom practice is not yet clear. They are, however, seen as the link between the mental processes involved in teaching and the teaching itself (Cochran, 1997).

How do context-specific conceptions develop? As shown in Figure 2-2 (p. 26), teaching experience is an important factor in the development of context-specific conceptions. As Wilson et. al. (1987) suggest, pedagogical reasoning begins with the teacher's comprehension of the subject matter to be taught. The teacher must then transform this subject matter into a plan or set of strategies for teaching the subject matter to a particular group of students based on their context-specific conceptions. The instruction is then the outcome of the plan. Evaluation and reflection occur both during and after instruction. This process of learning from experience may lead the teacher to develop new context-specific conceptions. These new conceptions then inform the teacher during the next transformation phase, and the cycle continues.

In their review of the literature on PCK, van Driel et. al. (1998) suggest that there is agreement among researchers that PCK is developed primarily during the experience of teaching in a classroom (Cochran, 1997; Counts, 1999; Grossman, 1988; Lenze, 1995; van Driel et. al., 1997). Thus, beginning teachers should be expected to have little PCK. For example, in a case study of one college physics professor, Dr Bond, Counts (1999) found that the professor pointed to past teaching experiences as an important contributor to his conceptions of teaching. During interviews, Dr. Bond made comments like "I am doing things that I have found to work" and "[you] hope that you [can] learn from your mistakes" (Counts, 1999, p. 161).

The type of PCK that is developed through practice, however, is expected to be influenced and shaped by the general conceptions held by teachers (van Driel et. al., 2001). For example, in a study of 10 university teachers from a variety of disciplines, Fernandez-Balboa (1995) concluded that the general conceptions held by the teachers strongly influenced their context-specific conceptions. For example, he found that the teachers identified that their main purpose for teaching was to help students be able to solve problems and think critically so that they could enjoy life more and be independent, life-long learners. This meant that the context-specific conceptions developed by these teachers were geared for these purposes rather than for the mere transmission of subject matter knowledge. Beijaard (1996) suggests that these context-specific conceptions develop based on experience during a teacher's first several years of teaching. After several years of experience, however, these conceptions become stabilized, so that the teacher is less open-minded towards innovation or change (Beijaard, 1996, p. 276). Cochran (1997), however, suggests that teachers can improve their context-specific conceptions by continually reflecting on why they are teaching the specific content the way that they do and by talking with other teachers about the ways they teach the specific content.

Because context-specific conceptions are developed primarily through experience, it may be reasonable to expect differences to exist between the conceptions of college teachers and K-12 teachers. The experience of college teachers is considerably different from that of a high school teacher (Baldwin, 1995; Fernandez-Balboa et. al, 1995). College teachers typically, although not always, have larger classes. This may lead college teachers to have fewer opportunities to interact with individual students. College students are also assumed to be more mature than K-12 students. This means that college teachers typically do not have to consider the management of classroom discipline to the same extent as do K-12 teachers.

Another difference between K-12 teachers and college teachers is their level of knowledge about the subject matter and about pedagogy. One of the prerequisites to the development of context-specific conceptions is a thorough understanding of the subject matter (Grossman, 1988; van Driel et. al., 1998). While lack of subject matter knowledge may be a difficulty for some K-12 teachers, it seems reasonable to assume that college teachers possess sufficient subject matter knowledge. On the other hand, unlike K-12 teachers, college teachers frequently receive no formal educational training. It may be that the educational training K-12 teachers receive leads them to interpret classroom situations differently from college teachers and, thus, form different context-specific conceptions.

Influence of prior research on context-specific conceptions on the current study. The research on context-specific conceptions points to the key role that these conceptions play in shaping teaching practice. Thus, one of the primary goals of this study was to understand the context-specific conceptions that these instructors have related to the teaching and learning of problem solving in introductory calculus-based physics. Because these conceptions are largely implicitly held, it would not be fruitful to simply ask the instructors to describe their conceptions. This led to the design of an interview around concrete instructional artifacts that would allow context-specific conceptions to be inferred from what the instructors said during the interview.

Expertise In Teaching

Many of the studies mentioned above noted that teachers' context-specific conceptions develop through experience. Some researchers have focused on the way that teachers develop their teaching skills (Berliner, 1987; Berliner 1988; Carter & Doyle, 1987; Dunkin & Precians, 1992; Kwo, 1994). These researchers have compared the development of the skill of teaching to the development of other types of skills based on the model of skill development introduced by Dreyfus and Dreyfus (1986a, 1986b). For example, based on Berliner's (1988) work, Kwo (1994) described five stages of skill development in teaching as follows:

1. **Stage 1: Novice**. At this stage, a teacher is labeling and learning each element of a classroom task in the process of acquiring a set of context-free rules. Classroom-teaching performance is rational and relatively inflexible, and requires purposeful concentration.
2. **Stage 2: Advanced Beginner**. Many second- and third-year teachers reach this stage, where episodic knowledge is acquired and similarities across contexts are recognized. The teacher develops strategic knowledge and an understanding of when to ignore or break rules. Prior classroom experiences and the contexts of problems begin to guide the teacher's behavior.
3. **Stage 3**: **Competent**. The teacher is now able to make conscious choices about actions, set priorities, and make plans. From prior experience, the

teacher knows what is and is not important. In addition, the teacher knows the nature of timing and targeting errors. However, performance is not yet fluid or flexible.

4. **Stage 4: Proficient**. Fifth-year teachers may reach this stage, when intuition and know-how begin to guide performance and a holistic recognition of similarities among contexts is acquired. The teacher can now pick up information from the classroom without conscious effort, and can predict events with some precision.

5. **Stage 5: Expert**. Not all teachers reach this stage, which is characterized by an intuitive grasp of situations and a non-analytic, non-deliberate sense of appropriate behavior. Teaching performance is now fluid and seemingly effortless, as the teacher no longer consciously chooses the focus of attention. At this stage, standardized, automated routines are operated to handle instruction and management.

This view of skill development helps to explain why the research aimed at modeling teachers' decision-making ultimately failed. As Dreyfus and Dreyfus (1986b) explain, "when things are proceeding normally, experts don't solve problems and don't make decisions; they do what normally works" (p. 30). This view of skill development also helps to explain how general conceptions can influence teaching behavior. Dreyfus and Dreyfus (1986a) note that one of the key components of competence is that the performer, to avoid being overwhelmed with information, must choose a plan, goal, or perspective which organizes the situation. The performer can then examine only the small set of features and aspects that are most important to that plan. They note that the choice of a plan or perspective to organize information "crucially affects behavior in a way that one particular aspect rarely does" (Dreyfus & Dreyfus, 1986a, p. 322). Further, this choice of perspective is what guides the development of expert behavior, with different perspectives resulting in different types of behavior. When thinking about expert behavior, it is important to note that, according to Dreyfus and Dreyfus (1986b), the stages refer only to the type of thought processes. They warn that, although all experts perform routine tasks without conscious effort, not all experts perform these tasks equally well.

Several empirical studies have produced evidence supporting this view of skill development in teaching (Berliner, 1987; Berliner 1988; Carter et. al., 1987; Dunkin et. al., 1992; Kwo, 1994). For example, Berliner and colleagues (Berliner, 1987; Berliner 1988; Carter et. al., 1987) describe a series of studies in which they investigated the differences between expert, novice, and "postulant" high school science and math teachers. They studied 18 expert teachers who were nominated as excellent by their principals and whose classroom teaching was judged by two or three independent observers to be excellent, 15 novice teachers who were highly rated student teachers and first-year teachers, and 21 postulants who were mathematicians and scientists from local industry and research organizations who expressed interest in obtaining certification for teaching. The research participants were presented with the simulated task of taking over a class five weeks into the school year after a previous teacher had abruptly left. The participants were given a short note left by the previous teacher, a grade book with grades and attendance recorded, student information cards containing demographic information on one side and teacher comments about the student on the other, corrected tests and homework assignments, and the textbook. The participants were then given 40 minutes to prepare for the first two classes. After their preparation, they were asked questions about their planning process and the lessons that they planned. The researchers concluded that "our experts see classrooms differently than do novices or postulants because they no longer see classrooms literally. They appear to us to weigh information differently according to its utility for making instructional decisions. Almost without conscious thinking they make inferences about what they see" (Berliner, 1987, p. 69). For example, they noted that the experts recalled fewer details about individual students and the class as a whole than did subjects from the other two groups. The novices believed that they should have remembered all of the information presented to them about each student, while experts only used the student information briefly to convince themselves that this was a normal class. The experts saw no use in remembering information about individual students.

In a study done with college teachers, Dunkin and Precians (1992) interviewed 12 award-winning teachers from The University of Sydney and compared these results with interviews of 55 novice teachers. They asked each of the teachers about possible ways to enhance student learning in their classes and found that the award-winning teachers were able to combine several dimensions (e.g. teaching as structuring learning and teaching as motivating learning) while novice teachers tended to only answer with a single dimension. They conclude that this indicates the group of award winning teachers had a more well-developed conceptual structure than did the novices. Having a well-developed conceptual structure requires the adoption of an organizational perspective and is indicative of the competent and higher stages of skill development.

Influence of prior research on expertise on the current study. One of the major findings from this research on expertise is that experts and novices can have different ways of looking at the same information. This required that the interview questions be designed so that either an expert or novice could understand and answer appropriately.

Reflection

In his review of several studies investigating changes in teachers' conceptions, Thompson (1992) noted that teachers' conceptions of mathematics and mathematics teaching are quite robust. He noted that being confronted with contradictory information was a necessary, but not sufficient, condition for conceptual change. This is because teachers, when faced with new information, first attempt to assimilate that new information. In many cases this assimilation is done by modifying the new ideas to fit into existing conceptions (Briscoe, 1991; Thompson, 1992). Less frequently, this new information causes teachers to change their existing conceptions.

Conceptions tend to be self-perpetuating (Dreyfus & Dreyfus, 1986b; Pajares, 1992). One reason is that individuals tend to turn conflicting evidence into support for an already held belief, even if this means completely distorting the conflicting evidence. Another reason is that conceptions influence behaviors and these behaviors tend to reinforce their original beliefs. For example, a teacher who thinks of teaching as a teacher-centered activity where the teacher presents information to students will likely behave accordingly and attribute all evidence of student learning to this approach and all difficulties to other factors. Pajares (1992) also suggests that conceptions are "unlikely to be replaced unless they prove unsatisfactory, and they are unlikely to prove unsatisfactory unless they are challenged and one is unable to assimilate them into existing conceptions" (p. 321).

Thus, changes in conceptions are seen as only possible if implicit conceptions are made explicit and reflected on (Dunn & Shriner, 1999; Ericksson et. al, 1993; Menges & Rando, 1989). In fact, in their review of the development of expertise in a variety of domains, Ericksson et. al. (1993) point to continual deliberate practice as the most important factor in predicting the development of exceptional performance. They suggest that this highly reflective activity is much more important than other factors, such as innate ability.

Boice (1994) provides an example of the self-perpetuating nature of teachers' conceptions. In his interview study with 197 college teachers from a variety of disciplines, he concluded that college teachers' teaching practices and their conceptions of teaching were very stable, even in their first few years of teaching. Boice reported that when faced with poor ratings and personal dissatisfaction with their teaching, most teachers did not consider changing their approach to teaching. They tended to view college teaching as delivering facts and principles to the students via lecturing. Thus, to improve their courses, these teachers tended to focus on the improvement of lecture content. They also mentioned their intention of making assignments and tests easier for students. This, presumably, would help to reduce some of the student criticism.

In a study indicating the powerful effect of a teacher's role metaphors and the self-perpetuating nature of such metaphors, Briscoe (1991) conducted a case study of one high school chemistry teacher, Brad, who said he was dissatisfied with his current practice and was ready to make some changes, but did not know where to turn to find solutions. Briscoe noted the high level of reflection and effort that was required for Brad to change his belief system. For example, Brad's image of himself as a teacher was as a "giver of information". This was inconsistent with the constructivist teaching model that he was trying to adopt and he frequently found himself in conflicts between these two ideas. Through his weekly conversations with the researchers, Brad was eventually able to change his images of teaching and his teaching practice, but he describes the importance of having someone to help with the process of reflection. Towards the end of the project, Brad tells the researchers "I'm sure by now I would have been back to more worksheets and stuff if I were doing it by myself" (p. 197). Thus, changing conceptions is difficult, but can occur with deliberate reflection.

Influence of prior research on reflection on the current study. The research on the role of reflection in the development of expertise suggests that conceptions tend to be self-perpetuating because teachers tend to take on an organizing perspective that focuses their perception. They typically maintain this organizing perspective even in the face of contradictory evidence. Understanding this organizing perspective is one of the goals of this study. Thus, the interview probes the way teachers think about a variety of different situations in an attempt to uncover this organizing perspective.

Summary of Research on Teachers' Conceptions

Taken as a whole, this body of research suggests that teachers' conceptions, to a large extent, shape their instructional behavior. As shown in Figure 2-2 (p. 26), teachers' general conceptions directly shape the development of context-specific conceptions, which directly lead to the choice of specific teaching activities. These general and context-specific conceptions are largely implicit and arise primarily from a teacher's experience as both a student and a teacher. Teachers also often have conflicting conceptions. It is not currently clear how these conflicting conceptions interact to influence instructional decisions. Beginning teachers frequently have a poorly integrated set of conceptions and make instructional decisions based on these conceptions. Most studies suggest that teachers with considerable experience teaching in a particular context (a particular class at a particular institution) have developed routines for many common aspects of instruction and no longer give instructional decisions much conscious thought. This body of research also suggests that it is very difficult to influence conceptions or the practices of either experienced or beginning teachers.

There has been very limited research done with high school or college teachers that investigates their general or context-specific conceptions about problem solving. Based on the framework presented at the beginning of this section and the supporting research literature, a teacher's general conceptions about problem solving, the role that problem solving should have in physics instruction, ways that problem solving could be taught, and students' ability to learn problem solving would all be expected to influence an instructor's conceptions of teaching problem solving in a particular context. These context-specific conceptions would then have a direct impact on their instructional practices. All of these conceptions can be expected to be quite robust and strongly influence a teacher's evaluation of new instructional techniques.

Research on Effective Teaching of Problem Solving

Researchers in physics and in other fields have built up a large body of literature related to the effective teaching of problem solving. In order to be a good problem solver, a student must have the necessary domain knowledge, as well as an understanding of general problem solving processes (Maloney, 1994). As previously mentioned, the common instructional practice of having students solve standard physics problems appears to be counter-productive for reaching these goals. This practice tends to reinforce poor problem solving procedures and ineffective knowledge structures (see review by Maloney, 1994).

Differences Between Expert and Novice Problem Solvers

Most instructional strategies designed to improve student problem solving are based on an understanding of the differences between expert and novice problem solvers. There are two basic types of differences between expert and novice problem solvers that can be identified in the literature on physics problem solving: differences in their knowledge, and differences in their approaches to problem solving.

Differences in Knowledge

One of the primary differences between experts and novices is that experts have more physics knowledge than novices (de Jong & Ferguson-Hessler, 1986; Maloney, 1994). More importantly, however, is that the knowledge of experts is appropriately structured for efficient use in problem solving by being hierarchically organized around physics principles. On the other hand, novices have a less efficient knowledge structure, typically organized around surface features of problem situations (Chi, Feltovich, & Glaser, 1981; de Jong et. al., 1986; Larkin, 1979; Larkin, McDermott, Simon, & Simon, 1980; Maloney, 1994; Reif, 1981; Van Heuvelen, 1991a; Zajchowski & Martin, 1993). Related to the organization of knowledge is the integration of knowledge. Novices often have two banks of knowledge – one that guides their thinking in "classroom" situations and another that guides their thinking in "real world" situations. For experts, however, knowledge is well integrated (Maloney, 1994).

Differences in Approaches to Problem Solving

Researchers have found that experts and novices differ considerably in their approaches to problem solving in all stages of the problem solving process. At the beginning of the problem solving process experts frequently approach a problem by first carrying out a qualitative analysis of the situation and developing a good physical representation. Based on this evaluation, experts develop a plan to solve the problem. Novices, on the other hand, frequently begin the problem solving process by searching for equations and typically do not develop a plan (Finegold & Mass, 1985; Larkin, 1979; Larkin & Reif, 1979; Larkin, 1980; Larkin, 1983; Maloney, 1994; Schultz & Lockhead, 1991; Van Heuvelen, 1991; Woods, 1987). One tool that experts typically use to develop a plan is their knowledge of problem solving heuristics (Martinez, 1998; Schoenfield, 1992). Novices typically lack knowledge of problem solving heuristics. As Martinez (1998) describes, "a heuristic is a rule of thumb. It is a strategy that is powerful and general, but not absolutely guaranteed to work" (p. 606). He describes several general heuristics, such as means-ends analysis, working backward, successive approximation, and using external representations. For example, working backward is a common heuristic used in solving physics problems. In working backward, you "first consider your ultimate goal. From there, decide what would constitute a reasonable step just prior to reaching that goal. Then ask yourself, what would be the step just prior to that?

Beginning with the end, you build a strategic bridge backward and eventually reach the initial conditions of the problem" (p. 607).

Another difference between experts and novices is that experts continually evaluate their progress (Larkin, 1980; Maloney, 1994; Schoenfeld, 1985; Schoenfield, 1992; Woods, 1987). Experts commonly use monitoring and control strategies when solving problems by either explicitly or implicitly asking themselves questions such as: "What am I doing?", "Why am I doing it?", and "How does this help me?" (Schoenfield, 1992). The answers to these questions help them to evaluate their progress and decide what to do next. Novices, on the other hand, do not tend to ask these questions during the problem solving process. Schoenfield (1992) found that novices often start solving a problem by quickly choosing an approach and then sticking with that approach even if it turns out not to be fruitful. Novices are also not likely to evaluate their final answer (Larkin, 1980; Maloney, 1994; Reif, 1995; Schoenfield, 1992; Woods, 1987).

Strategies Designed to Improve Student Problem Solving

Many researchers have been working on the development of successful instructional approaches for teaching complex skills like problem solving. Beriter and Scardamalia (1992) suggest that cognitive apprenticeship is the unifying concept behind these approaches. Cognitive apprenticeship is an adaptation of traditional apprenticeship methods that have been used for centuries in teaching people to become experts in carrying out complex *physical* tasks. Cognitive apprenticeship has been used to teach complex *cognitive* tasks such as reading comprehension, writing, and problem solving (Beriter et. al., 1992; Collins et. al., 1991; Schoenfeld, 1985). In cognitive apprenticeship, as in traditional apprenticeship, teaching consists of three basic activities: modeling, coaching, and fading. Teaching begins by having the student observe the teacher executing the target process (modeling), which usually involves many different but related subskills. This observation allows the student to build a conceptual model of the thought processes required to accomplish the task. Because these thought processes are usually carried out internally, the instructor must externalize these hidden processes so that students can observe them. The student then attempts to execute these processes with guidance and help from the teacher (coaching). A key aspect of coaching is the provision of support (scaffolding) in the form of reminders or help that the student requires to approximate the execution of the entire complex sequence of skills. Once the student has a grasp of the entire process, the teacher reduces his participation (fading), providing only limited hints, refinements, and feedback to the student, who practices by successively approximating smooth execution of the entire process.

Researchers in physics education have developed a number of instructional models that are designed to help students become more expert-like problem solvers (Bango & Eylon, 1997; Heller & Hollabaugh, 1992; Heller et. al., 1992; Mestre et. al., 1993; Reif & Scott, 1999; Van Heuvelen, 1991b). Most of these instructional models can be thought of in terms of the cognitive apprenticeship instructional framework of modeling, coaching, and fading. There are four basic strategies that are used in these instructional models:

- Students are taught a problem solving framework that helps to externalize the implicit problem solving strategies used by experts (Cummings et. al., 1999; Heller & Hollabaugh, 1992; Heller et. al., 1992; Mestre et. al., 1993; Reif & Scott, 1999; Van Heuvelen, 1991b).
- "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).
- 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).
- Concept maps are used in instruction to help students understand the relationships between important concepts and to develop a hierarchically arranged knowledge structure that is more similar to that of experts (Bango & Eylon, 1997; Bango et. al., 2000; Van Heuvelen, 1991).

Instructional models using these strategies have been shown to improve students' problem solving skill as well as their understanding of physics concepts (Bango & Eylon, 1997; Cummings et. al., 1999; Foster, 2000; Heller & Hollabaugh, 1992; Heller et. al., 1992; Mestre et. al., 1993; Reif & Scott, 1999; Van Heuvelen, 1991b). It is important to note that none of these instructional models have the goal of making students expert physics problem solvers after a year of introductory physics. The goal of these models is to help students move in the direction of expert-like performance. It is expected that students will begin to develop a knowledge structure organized around physics principles (rather than surface features of problem situations) and a problem solving approach that includes planning and evaluating (rather than searching for the appropriate equation and never evaluating).

It is important to note here that what constitutes a problem is different for different people. Martinez (1998) defines problem solving as "the process of moving toward a goal when the path to that goal is uncertain" (p. 605). Maloney (1994) uses this same idea when he makes the distinction between a *problem* and an *exercise*. Typically in introductory physics courses, what the instructor assigns as problems for the students are exercises for the instructor. They are problems for the students because the students do not know how to proceed when they first look at the problem. On the other hand, because of his large amount of prior experience, the instructor can immediately look at an introductory physics "problem" and know exactly what to do in order to solve it. As described earlier (p. 45), similar to experts in any subject, these instructors do not need to consciously think about what they need to do to perform routine tasks (i.e. solving physics exercises) – they just know how to do it. Thus, in all phases of instruction designed to promote problem solving, the expert thought processes being explicitly taught are those of an expert solving a real problem where they don't already know how to proceed. The processes being modeled are not the (nonexistent) thought processes of a physics instructor solving an introductory physics "problem" that he already knows how to solve.

Problem Solving Framework

One of the most prominent features of instructional models designed to help novices approach physics problems in more expert-like ways is the use of a problem-solving framework (Heller & Hollabaugh, 1992; Mestre et. al., 1993; Reif & Scott, 1999; Reif et. al., 1976; VanHeuvlen, 1991b). These frameworks provide a general heuristic that can guide students in the problem solving process. The purpose of the framework is to break down and make explicit the things that an expert does or thinks about when solving problems. The framework provides scaffolding that enables students to envision the entire problem solving process while, at the same time, selecting and focusing on the specific decisions that need to be made at a particular point in the process. Although each instructional model uses a slightly different problem-solving framework, the same basic pieces of expert performance can be found in each of them. For example, Heller et. al. (1992) describe a 5-step framework (p. 630).

1. **Visualize the problem:** Translate the words of the problem into a visual representation: draw a sketch; identify the known and unknown quantities and constraints; restate the question; and identify a general approach to the problem.
2. **Describe the problem in physics terms**: Translate the sketch into a physical representation of the problem.
3. **Plan a solution:** Translate the physics description into a mathematical representation of the problem. Starting from the target variable, use the identified physics concepts and principles, to specify the mathematical steps necessary to solve the problem.
4. **Execute the plan:** Translate the plan into a series of appropriate mathematical actions.
5. **Check and evaluate:** Determine if the answer makes sense. Check that the solution is complete and that the sign and units of the answer are correct. Evaluate the magnitude of the answer.

In addition to introducing a problem-solving framework, each of these instructional strategies also specifies that this framework should be explicitly taught to students and the instructor should model its use. Students are then typically provided with opportunities to practice and receive help in using the framework (coaching). Problem solutions that students hand in are often required to be solved using the framework. Over time, however, students have hopefully internalized the framework and the requirement that they explicitly use the framework is faded.

"Real" Problems

Heller and Hollabaugh (1992) suggest that typical textbook problems reinforce novice problem solving strategies. Textbook problems typically refer to idealized objects that have no relation to the students' reality. Students are often capable of solving these problems using the novice approach of finding an appropriate equation. In order to encourage students to use the problem-solving framework and develop their problem solving skills, both Van Heuvelen (1991b) and Heller and Hollabaugh (1992) make use of more realistic problems. Although they go by different names ("context-rich problems" for Heller and Hollabaugh, and "case study problems" by Van Heuvelen), the features of these problems are similar. These problems typically require more than one step to solve, requiring the student to break the problem into parts and then combine the parts. In addition, these problems may not contain all of the necessary information (or more information than needed), requiring students to recognize that information is missing and make reasonable estimates.

Scaffolded Practice

In order to learn how to effectively use and internalize a problem solving framework, students must practice using it and receive feedback about their progress. In addition to just practicing, however, scaffolding and coaching are typically provided to help the students achieve success in solving problems using the problem solving framework. These instructional models also allow students to take on the role of a coach, thus requiring them to be able to externalize and explain their thinking. Reif and Scott (1999) do this by using a computer-based tutor in which the student and the computer take turns giving directions. The student thinking is scaffolded because the student is either thinking about the details (when the computer is giving directions) or thinking about the entire process (when the student is giving directions), but not both at the same time. Heller et. al. (1992) and Van Heuvelen (1991a) provide scaffolding and coaching, in part, by having the students work together on problems. For Heller et. al. (1992), students, working in groups, are assigned roles (manager, skeptic, checker/recorder) that reflect the mental planning and monitoring strategies that individuals must perform when solving problems alone. Because collaboration distributes the thinking load among the members in a group, the entire problem solving framework can be applied successfully early in the course to problems on which most beginning students would initially fail if working individually (Heller et. al., 1992). During this scaffolded practice, experts (i.e. teaching assistants) are also available to provide another layer of coaching and scaffolding when necessary.

Concept Maps

Some instructional models focus on developing student knowledge that is hierarchically organized around physics principles. Van Heuvelen (1991b) does this in addition to focusing on developing students' approaches to problem-solving. After students have had some experience with a group of related concepts, the instructor presents a hierarchical chart that shows how these concepts relate to one-another and to the concepts learned previously in the course. Bango and Eylon (Bango & Eylon, 1997; Bango et. al., 2000) focus on the development of hierarchically organized knowledge without focusing explicitly on approaches to problem solving. In their instructional model, students develop their own explicit representation of the relationships between physics concepts based on their experience solving problems. As they solve new problems (often carefully designed to highlight possible difficulties), the students refine and expand this explicit hierarchical model of physics concepts.

Summary of Effective Teaching of Problem Solving

There is a large body of evidence that experts and novices differ widely in their problem-solving performances. Experts are different from novices in two key ways.

Experts approach problems differently than novices and experts have a more efficiently organized knowledge structure than novices. Although traditional physics instruction does little to change students' novice problem-solving approaches or help them construct knowledge that is organized for effective problem solving, several instructional strategies have been shown to be effective in making such changes.

In order to teach problem solving well, a teacher should have an understanding of the differences between the ways that experts and novices solve problems and an understanding of how to effectively teach problem solving. Thus, the interview was designed to determine what type of knowledge the instructors have about these areas. For example, some of the student solutions had expert features (e.g. checking the final answer) and others had novice features (e.g. not starting from basic principles).