CHAPTER 5: IMPLICATIONS

This chapter will provide a brief summary of the study, relate the findings to prior research, and suggest possible directions for future studies.

Summary of Study

The goal of this study was to use a small sample of university faculty to generate an initial explanatory model of faculty conceptions about the teaching and learning of problem solving in introductory calculus-based physics. The initial model developed in this study will be tested and refined in future studies. To develop the initial model, interviews were conducted with six University of Minnesota physics faculty. The interview was designed around three types of concrete instructional artifacts that were all based on a single introductory physics problem. It consisted of specific questions relating to a particular instructional artifact or teaching situation, as well as more general questions about the teaching and learning of problem solving in introductory calculus-based physics.

The interviews were transcribed and each transcript was broken into approximately 400 statements that captured the information relevant to this study. Based on these statements, concept maps were constructed for each instructor that showed how he conceived of the teaching and learning of problem solving. Once this task had been completed for each instructor, the individual concept maps were combined to form composite concept maps that described all six instructors. This set of composite maps forms an initial explanatory model of faculty conceptions of the teaching and learning of problem solving in introductory calculus-based physics. This explanatory model consists of 14 general features that are related to one-another on the Main Map (see Figure 4-2, p. 109) and described in more detail on the feature maps (see Chapter 4). Tables 4-1 to 4-5 (pp. 172 to 176) summarize the general features of the explanatory model. Once tested and refined in future studies, this explanatory model can be used to help researchers and curriculum developers understand how faculty think about the teaching and learning of problem solving in introductory calculus-based physics courses. It is my hope that this understanding will help to bridge the gap that currently exists between faculty conceptions of the teaching and learning of problem solving and the existing curricular materials that have been shown to develop students' problem-solving skills.

Theoretical Implications

One of the major implications of this study is that it does appear to be possible to generate a model of faculty conceptions about the teaching and learning of problem solving in introductory calculus-based physics. As discussed in Chapter 3 (p. 88), the model developed in this study meets all of the relevant criteria for viability (Clement, 2000). In addition, it appears to have the potential to be a productive framework with which to study faculty conceptions. As discussed in Chapter 1 (p. 2), the research team intends to use this model as a starting point for future studies of physics faculty conceptions of teaching and learning.

This study is the only study that I am aware of with a focus on faculty conceptions of teaching and learning of a specific content (problem solving) in a specific context (introductory calculus-based physics). For example, the Prosser and Trigwell (1999) study did not focus on a specific content (the range of their study was physics and chemistry) nor on a specific context (the context of their study was first-year physics and chemistry courses, however, the level of the courses was not examined). Although they did not have strong evidence, they indicated their belief that these context and content variables have an effect on faculty conceptions (Prosser et. al., 1994). These more general studies, although they may provide some information for researchers and curriculum developers, do not provide any information about how these conceptions manifest themselves in day-to-day teaching situations.

Because the focus of this study was limited to a specific content and context, it was possible to ask questions about specific teaching situations using concrete instructional artifacts. Thus, the model of faculty conceptions generated can provide information at several levels of detail. The Main Map provides information about the general features of the model (e.g. these instructors ideas about student learning activities can be placed into three distinct categories: working, using feedback, and looking/listening). These general features may be useful in generating models of faculty conceptions in other contexts. The feature maps provide more detailed information about each of these features (e.g. Map 9 provides some very specific information about what these instructors believe the role and content of appropriate example solutions should be). This more detailed information will be useful, in the short term, for developing instruments to test and refine the model generated in this study, and, in the long term, for using the revised model to influence instruction.

Methodological Implications

Although none of the research methods used in this study were new, this study combined them in ways that had not previously been done. In particular, as described in Chapter 3, the analysis method of breaking the interview transcript into statements of relevant meaning, forming individual concept maps, and then forming composite concept maps is a technique that future researchers may find useful. It proved to be a fruitful analysis method that can lead to the generation of an explanatory model to describe complicated data and make connections explicit so that these connections can be confirmed or refuted in future studies. In addition, the method provides transparent ways to ensure the viability of the explanatory model through the referencing of statement numbers on the individual maps and instructor numbers on the composite maps.

Although previous studies have had teachers critique instructional artifacts, I am not aware of other studies, like the current study, where instructors were asked to critique several different instructional artifacts that spanned the range of common practice. This technique has shown itself to be quite effective at uncovering some of the implicit conceptions that faculty have.

Relation to Prior Research

Although this study was done in a specific context where no prior work has been done, it nonetheless can be related to the larger picture of research on teaching as described in Chapter 2. Overall, the model of physics faculty conceptions resulting from this study is completely consistent with the major findings from this body of research.

Some of the faculty conceptions identified for the particular context examined in this study are similar to conceptions found by previous studies that examined other contexts. Other faculty conceptions identified in this study have not been identified by previous studies. These conceptions, however, do not contradict the results of these previous studies.

Making connections to previous studies explicit will help to strengthen the major findings of this body of research as well as help to put the results from the current study into the proper context. Also, recall from Chapter 3 (p. 88) that being consistent with existing knowledge is one of the criteria that Clement (2000) used in describing the viability of a theoretical explanatory model. In this section, I will discuss each of the feature maps (or clusters of feature maps) in terms of their relation to prior research.

<u>Some College Students (Map 1)</u>

This map shows how the instructors in this study use student characteristics of natural ability and learning characteristics (e.g. motivation, study habits) to describe whether a student would learn how to solve physics problems (see Some College Students Map, p. 114). As discussed in Chapter 2, previous studies have identified teachers' conceptions of student characteristics in terms of ability, motivation, and homogeneity of students (see p. 39). Teachers' conceptions of student ability and motivation in these studies appear to be similar to the current study. Teachers use these characteristics to explain why some students might not do well in the course (e.g. Boice, 1994; VanDriel, 1997). The current study, however, differs from previous studies in that motivation is not the only learning characteristics that these instructors indicated were important in determining which students would learn. Other learning characteristics, such as study habits, were not identified in previous studies. Only one of the instructors, RU6, mentioned heterogeneity of students' math backgrounds as being a factor that made it difficult to reach all students.

Gallagher & Tobin (1987) found that the high school teachers they studied generally use the top 25% of students in making decisions about the pace of the course (see p. 34). If these students appear to understand, then the teachers are satisfied.

Similarly, the college instructors in this study seemed to use their beliefs about student ability and learning characteristics to justify their teaching decisions. In the current study, two instructors indicated that they specifically target certain groups of students – one targets students with high and middle ability and the other targets students with beneficial learning characteristics (see Some College Students Map, p. 114). They are satisfied if these students learn. Similarly, the other instructors also appear to have conceptions that students' failure to learn how to solve physics problems is a result of student characteristics rather than instruction.

Solve Physics Problems (Map 2)

This map deals with instructors' conceptions of the problem-solving process. As discussed in Chapter 2 (p. 36), there has been very little prior research in this area. This map can, however, be related to the research in expertise. The instructors in this study did not describe the problem-solving process in much detail (although they were provided with many opportunities to do so). Just as experts in other fields can solve problems and perform tasks with little conscious thought (see p. 45; or Dreyfus & Dreyfus, 1986a, 1986b), the instructors in this study can look at an introductory physics problem and immediately know what approach would be most fruitful. As a result of their expertise, these instructors appear to have only implicit knowledge of the process of problem solving. Only two of the instructors appear to realize that there is a difference between the way that experts (the instructors) and novices (the students) solve problems (see Solve Physics Problems Map, p. 117).

Students' Current State (Map 3)

This map contains instructor conceptions of the characteristics of students that are typically found in introductory calculus-based physics classes. The characteristics are divided into two basic groups; personal characteristics related to learning and knowledge/skill related to problem solving.

Personal Characteristics Related to Learning. Some of the instructors' beliefs about personal characteristics related to learning have been explored in previous studies.

As described above for Some College Students, previous studies have identified instructor beliefs about students' motivation and innate qualities. The concept of motivation in this study appears to be similar to the way instructors conceptualize motivation in other studies. Innate qualities, however, in this study refer not only to intelligence, but also to other types of innate qualities. For example, one instructor said that female students tend to be more collaborative than male students (see Some College Students Map, p. 114). In addition, this study identified personal characteristics that were not identified in previous studies. Instructors in this study expressed conceptions of students' personal characteristics such as time constraints, study habits/skills, beliefs about learning physics, and beliefs about self.

Knowledge/Skills Related to Problem Solving. There have been no previous studies identifying instructor beliefs about students' knowledge/skill related to problem solving. The results of this study are, however, consistent with the research on students. That is, these instructors appear to make reasonably correct assessments of the current state of their students' knowledge/skill related to problem solving (see Students' Current State Map, p. 120). Consistent with previous research on student learning (see, for example Maloney, 1994; Van Heuvelen, 1991a), these instructors see their students as having limited knowledge of physics concepts, poor approaches to solving a problem (e.g., using formula-centered approaches), poor performance monitoring (e.g., not evaluating their answer), and poor beliefs about problem solving (e.g., believing that problem solving should be quick and easy).

<u>Learning Activities Cluster (Maps 4-6)</u>

The three maps in this cluster describe three distinct ways that these instructors think students can learn how to solve physics problems: by working on problems (Path A), by using feedback while/after working on problems (Path B), or by looking/listening to example problem solutions or lectures (Path C). Comparing these conceptions of learning with those identified by Prosser and Trigwell (see p. 30), it is clear that the two studies identified different aspects of conceptions of learning. The current study identified conceptions of student learning that are categorized in terms of the specific activities that students engage in to learn (e.g. working on problems). The conceptions of learning identified by Prosser and Trigwell are categorized in terms of the general processes involved in learning (e.g. conceptual development to satisfy internal demands). One reason for the differences in these outcomes may be due to the contexts of the study. As previously discussed, the current study is based in a particular context (the learning of problem solving in introductory college calculus-based physics) while the Prosser and Trigwell study was based in a more general context (student learning in introductory college chemistry and physics). The more general context of the Prosser and Trigwell study may have lead to the identification of more general conceptions of learning.

These differences in the types of conceptions of learning identified in these two studies also illustrates how the questions asked in the interview can influence the results. For example, in the current study instructors were asked (among other things) what students can do to learn how to solve physics problems and the resulting conceptions of learning are organized around activities that students can engage in (see Main Map, p. 106). On the other hand, Prosser and Trigwell (1999) asked (among other things) how students can know if they've learned something and the resulting conceptions of learning are organized, in part, around how students assess their learning.

Nonetheless, the instructors in the current study appear to have conceptions of learning that require the students to build and monitor their own problem solving skills through working on problems either with or without feedback. These beliefs are clearly not at the lowest level on the Prosser and Trigwell hierarchy (see p. 30), but it is not clear how these six instructors' conceptions of learning might align themselves with the other four levels.

Another similarity between these two studies is that the teachers in both studies lack an understanding of how students learn. Instructors in both studies had difficulty expressing their views about the process of learning. Prosser et. al. (1994) 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). In this study, the lack of detail on the concept maps in the learning activities cluster point to the same conclusion.

Management and Resources Clusters (Maps 7-9 and 11-13)[3]

The six maps in these two clusters describe these instructors' conceptions of their teaching activities in terms of providing resources, making suggestions, and setting constraints. Recall from Chapter 2 (p. 28) that Prosser and Trigwell (1999) attempted to separate conceptions of teaching and teaching practices. They noted a "reasonably close" relation between the conceptions of teaching and the approaches to teaching taken by 24 instructors of introductory college physics and chemistry (Prosser and Trigwell, 1999, p. 154). The current study was unable to make any distinctions between the conceptions of teaching and the teaching practices of these six instructors. It seems likely that this is because the six instructors do not make such distinctions, which would be consistent with the Prosser and Trigwell findings. It may, however, also be that the interview instrument was not carefully structured to capture such a distinction, should it exist.

As discussed in Chapter 2 (p. 28), several researchers have looked at conceptions of teaching held by college teachers (Biggs, 1989; Martin & Balla, 1991; Prosser & Trigwell, 1999; Prosser et. al., 1994; Samuelowicz & Bain, 1992). All of these studies produced hierarchical lists of the different ways that teachers understand teaching. Although the lists are somewhat different, they all range from conceptions of teaching as presenting information to conceptions of teaching as facilitating student learning. The studies that indicated where the teachers fell on the hierarchy found that most teachers had relatively low (near the presenting information side) conceptions of teaching. This finding is somewhat different from the current study. In the current study, the instructors viewed students' prior knowledge/beliefs (e.g. see Students' Current State Map, p. 120) as very important. The instructors in this study also did not typically think of their job as transmitting information to students, but rather as setting up situations in which students could build their own understanding. For example, the instructors in this study described assigning problems for students to work on and then providing appropriate example solutions for students to use to analyze their mistakes and develop their own understanding (see Management of Students' Engagement in Learning Activities of

[3] The management and resources maps have been grouped together in this section because they all relate to instructors' views of actual or possible teaching activities.

Using Feedback Map – Path B, p. 158). The conceptions of teaching found in this study would put these instructors at least at level 3 in Prosser and Trigwell's hierarchy (see p. 28). One reason for the relatively high level of conceptions of teaching found in this study (as compared to other studies) may be that the context of this study is the teaching and learning of *problem solving*. Although the other studies do not specify the type of subject matter they are concerned with, it is likely that they are concerned with the teaching and learning of *concepts.* There is some evidence from this study that instructors may have different teaching/learning theories for physics concepts than for physics problem solving (see p. 198).

The approaches to teaching in the Prosser and Trigwell study (1999) attempt to identify the roles that the teachers think students and teachers should take in the teaching/learning process (see p. 33). It seems that the instructors in this study would be at levels 3 or 4 in Prosser and Trigwell's approaches to teaching. Consistent with level 4, the instructors in this study appear to structure teaching and learning situations in which the students are encouraged to take responsibility for their learning. This is seen in the preference of instructors to manage students' engagement in learning activities by making suggestions or providing resources rather than setting constraints (see the maps in the Management Cluster, p. 151). This is also similar to conceptions of teaching found by Gallagher and Tobin (1987) where high school teachers expected students to take responsibility for their own learning. Gallagher and Tobin (1987) also found that teachers typically interact with only the top 25% of the students during whole-class interactions. If these "target students" appear to understand the material, the teachers would typically move on. This is similar to the results of the current study that teachers do not expect all of the students in their class to learn.

A major result from prior research is that teachers' conceptions of teaching develop, to a large extent, through their experiences as students (see. p. 35). The results from the current study are consistent with this conclusion. Although the interview provided very little information about how these instructors were taught, it is very likely that they received traditional instruction when they were students. The manner in which they currently teach involves fairly traditional thinking about the teacher's role and possible teaching activities. Their thinking about the teacher's role is traditional in the sense that they see their job as providing opportunities for students to learn while the students' job is to take advantage of these opportunities. Similarly, teaching activities for a college physics course traditionally involve the same activities that these instructors engage in: solving example problems for students, assigning or suggesting problems for students to solve, and providing lectures about problem-solving techniques and physics concepts.

One of the major findings of this study is that these instructors made decisions about what resources to provide based on three perspectives (see p. 131): the perspective of the effect on student learning, the perspective of required instructor time, and the perspective of the match with student preferences. Although the perspective of the effect on student learning has not been explicitly identified in previous studies, many studies appear to make the assumption that this is the main consideration of teachers. The perspective of required instructor time and the perspective of the match with student preferences have been identified in previous studies (see p. 39).

Two studies (Prosser & Trigwell, 1997; Boice, 1994) have identified the contextual variable of required instructor time as affecting teaching decisions. For example Prosser and Trigwell found that one of the variables associated with higher approaches to teaching was that the workload was not too high. This is consistent with instructors in the current study dismissing some instructional options as requiring too much instructor time.

Perception of student preferences is an important contextual variable that has been identified in several previous studies (Brickhouse & Bodner, 1992; Carter & Doyle, 1995; van Driel, 1997). As Carter and Doyle (1995) suggest, when considering a new instructional approach, most instructors consider likely student reactions. Consistent with the results from this study, Carter and Doyle found that teachers tend to think about likely student reactions in terms of how they reacted, or would have reacted to similar practices as students. For example, RU3 explains that he doesn't focus on dimensional analysis because "when I was in high school, I remember the expression for kinetic energy was derived for me strictly by dimensional analysis and I was very unsatisfied with it" (RU3, statement #131).

Appropriate Knowledge (Map 10)

This map contains instructor conceptions about what types of knowledge or skills good problem solvers use to solve physics problems. Although no prior research has been done on instructors' conceptions of knowledge and skills related to problem solving, the types of knowledge and skills identified in this map are quite similar to those identified by research on expert problem solvers. As described in Chapter 2 (see p. 51), there are three main characteristics of expert problem solvers in physics: they have a knowledge base hierarchically organized around physics principles, they typically approach a problem by first carrying out a qualitative analysis of the problem and then develop a plan for solving the problem, and they continually evaluate their progress.

The instructors in this study have a category of PHYSICS CONCEPTS that relates to a solver's knowledge base of physics principles and concepts (see Appropriate Knowledge Map, p. 167). In the research literature, it is important for solvers to have an understanding of the physics concepts, but it is also important that these concepts are hierarchically arranged, a constraint that none of the instructors in this study identified. The instructors in this study had two categories that appear to overlap with the research literature idea that an expert problem solver typically approaches a problem by first carrying out a qualitative analysis and then developing a plan for solving the problem. APPROACH TO SOLVING A PROBLEM and "professional physicist beliefs about problem solving" express this same idea that a solver should have a strategy and not expect to solve a problem using a single formula. Finally, the research literature points to the importance of a solver continually evaluating their progress. This idea is found in the category of PERFORMANCE MONITORING that includes both "evaluating if heading in the right direction" and "evaluating the final answer".

Reflection on Teaching (Map 14)

This map describes the things that instructors said during the interview that indicate how they reflect on their teaching performance. Although understanding how these instructors reflect on their teaching was not an explicit goal of the study, the relatively small amount of reflection found is consistent with prior research (see p. 48) that teachers' decisions are largely implicit and little reflection takes place. Another indicator of a lack of reflection is fairly traditional teaching practices. As suggested by several researchers (Boice, 1994; Briscoe, 1991; Dreyfus & Dreyfus, 1986b; Pajares, 1992; Thompson, 1992), once a perspective of teaching is formed by an instructor, the instructor can maintain that perspective even in light of contradictory information. The fairly traditional practices of the instructors in this study may be an indication that they have adopted a teaching perspective and do not see the need to reflect on it.

Another indication of a lack of reflection on teaching practices was identified by Boice (1994) who suggested that, when faced with poor ratings and dissatisfaction with their teaching, teachers tend to stick with their approach to teaching and blame other factors such as poor delivery of lectures or under-prepared students. This is similar to the current study where some college students fail to learn how to solve physics problems, but none of the instructors consider their approach to teaching as a possible cause of this situation. There are basically three reasons that these instructors gave to describe why some students do not learn how to solve physics problems in their course; (a) some students do not have enough natural ability (see Some College Students Map, p. 114), (b) some students have enough natural ability, but have characteristics detrimental to learning (see Some College Students Map, p. 114), and (c) learning how to solve physics problems is difficult and takes a long time – it should not be expected from students after a single year-long introductory physics course (see Appropriate Knowledge Map, p. 167).

In addition to not providing any reasons why they did not consider improving their own performance, the instructors did not give any evidence to support their ideas of why some students did not learn how to solve physics problems. For example, although most of the instructors mentioned some ways that they learn about their students (see Reflection on Teaching Map, p. 170), the things that they hope to learn about tended to be vaguely described (e.g. becoming familiar with students). None of the instructors mentioned trying to find out more about the students who they believe do not have enough natural ability and trying to see if there are ways to help these students learn how to solve physics problems. Also, for those students with detrimental learning characteristics, the instructors gave no indication as to why they believe that students had these detrimental learning characteristics. There seemed to be an assumption by most instructors in this study that one of the biggest reasons students did not learn how to solve physics problems was because they did not work hard enough. None of the instructors suggested that they had any evidence to support this claim. This lack of the use of evidence to reflect on their performance is entirely consistent with the research literature (see p. 48).

The Instructional Paradox

In this section, I will make more speculative (i.e. less well supported by the interview data) interpretations of these instructors' conceptions of the teaching and learning of problem solving in introductory calculus-based physics. As Clement (2000) suggests, making these sorts of speculative hypotheses can be valuable to the field by "provoking new studies".

I will explore the hypothesis that these instructors have difficulty thinking about how to teach problem solving. In fact they appear to be caught in a paradox[4] where they believe that students learn how to solve problems by solving problems, but that students can't solve problems without knowing how to solve problems. Similar to other aspects of instructor conceptions that are identified in this study, the instructors do not appear to be explicitly aware of this paradox. Nonetheless, this paradox appears to play a prominent role in their thinking about teaching and learning. I will use this idea of an instructional paradox to compare and contrast the conceptions that these instructors use to think about the inherent difficulty in teaching the complex skill of problem solving to the conceptions that have been developed by educational researchers to deal with this difficulty.

Evidence for the Instructional Paradox

The model of faculty conceptions of the teaching and learning of problem solving generated in this study indicates that these instructors have a strong conception that students will learn how to solve physics problem by solving physics problems (see discussion of Learning Activities Cluster Maps, p. 122). The instructors realize that students are novice problem solvers when they enter the introductory calculus-based physics course (see Students' Current State Map, p. 120). The instructors, however, do not appear to understand how novices can solve problems or how problem solving skills develop. In particular, the instructors appear to have conflicting conceptions about the role of prior experience and PERFORMANCE MONITORING skills in the problem solving process. On one hand, they see these things as being important aspects of the problem solving process (see Solve Physics Problems Map, p. 117). On the other hand they realize that novices do not possess prior experience or PERFORMANCE MONITORING skills (see Students' Current State Map, p. 120). The instructors do not offer any explanation as to how students solve problems without prior experience or PERFORMANCE MONITORING skills in order to attain them.

The Role of Prior Experience in Problem Solving

As previously discussed (p. 181), the instructors in this study appear to lack an explicit understanding of the problem solving process. This is especially true in relation to understanding how novices solve problems. In particular, many of these instructors seem to lack an explicit understanding of the role of prior experience with similar problems in helping students solve problems. On some occasions they talk about the problem solving process as one of using prior experience to decide what to do and on other occasions they talk about a problem-solving process that is based more on logical reasoning. These two conceptions of the problem-solving process come up in different situations and are seldom combined.

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[4] The instructional paradox is similar to the learning paradox that recognizes the inherent difficulty in developing a complete learning theory – that is, how is it that more complex knowledge is built from less complex knowledge? (see, for example, Bereiter, 1985; Carey, 1986; Prawat, 1999)

For example, in several places throughout the interview RU3 describes the problem-solving process as a series of linear steps that include "making a drawing, identifying the fundamental concepts of the problem, determine the chain of reasoning that leads you from what is being asked back to the steps that you are about to use, work through symbolically the solution, and put in the numbers as the very last step" (RU3, statement #15). In statements like this he makes no mention of prior knowledge. At one point in the interview, however, he implied that solving a problem could be facilitated by knowledge of previously solved problems, "Some students will look at this problem and say 'Hey, that's like these loop the loop problems.' These problems are nice because it's always a normal force and the normal force is always perpendicular to the direction, so you don't have to worry about doing work on it" (RU3, statement #119).

<u>The Role of PERFORMANCE MONITORING in Problem Solving</u>

As shown in Map 10 (Appropriate Knowledge, p. 167), most of the instructors mentioned PERFORMANCE MONITORING as being an important part of the problem solving process. None, however, expected students to be able to do this after a single year of introductory physics. These instructors typically thought of PERFORMANCE MONITORING skills, and some other aspects of problem solving, as "things that are not in the syllabus and that you hope over 4 years of a university education, that they cultivate" (RU3,statement #273). Thus, in terms of setting goals for the course, these instructors said that, although it would be nice if the students would acquire some PERFORMANCE MONITORING skills in the class, these skills really take a long time to develop and cannot be expected from students after only one year of studying physics. They do, nonetheless, see their course as leading to this long-term development of PERFORMANCE MONITORING skills. None of the instructors make it clear how a student can solve problems before they acquire PERFORMANCE MONITORING skills.

<u>Possible Reasons for the Instructional Paradox</u>

The instructors in this study appear to lack the knowledge about teaching and learning necessary to resolve the instructional paradox. This should not be surprising since educational researchers are only beginning to develop this knowledge. In fact, as

Bereiter et. al. (1992) suggest, "most cognitive scientists are skeptical about the teachability of problem solving" (p. 528). In addition, most physics professors have never received any formal instruction in theories of learning and instruction. This severely limits the resources that they have available to think about the teaching of problem solving.

As Reif (1995a) describes, there are three basic types of knowledge that an instructor needs in order to plan effective instruction: knowledge about the desired student outcomes, knowledge about the initial state of the student, and knowledge about how a student can move from their initial state to reach the desired outcome. The instructors in this study appear to have good knowledge about the initial state of the student, some knowledge about the desired student outcomes, and poor knowledge about how a student can move from their initial state to the desired outcome.

<u>Knowledge About the Initial State of the Student</u>

Map 3 (Students' Current State, p. 120) shows that all of the instructors believe that students enter their introductory calculus-based physics course with poor problem solving skills. As discussed previously (p. 181), these instructors' beliefs are in agreement with the findings of research on physics students' problem solving skills.

<u>Knowledge About the Desired Learner Outcomes</u>

All of the instructors indicated that they wanted students to improve in their quantitative problem-solving skills as a result of taking the introductory calculus-based physics course. As discussed earlier, the instructors in this study have a basic understanding of the basic types of knowledge/skills involved in solving physics problems (p. 187). They, however, tend to lack an explicit picture of how these types of knowledge and skill are used in the problem solving process (p. 181).

The instructors did tend to recognize features of good problem solving when they saw it. Map 9 (Appropriate Example Solutions, p. 143) shows that four of the instructors favored Instructor Solution 3 (the explicit reasoning solution used in the interview) over the other two solutions. As described in Chapter 3 (p. 66), this solution contained several features of good problem solving as described by the research literature. Although the instructors tended to favor this solution, none of them were able to clearly explain why. Thus, although these instructors could identify good problem solving when they saw it, they did not have the explicit knowledge of the problem solving process to allow them to identify desired student outcomes in terms of problem solving.

Knowledge About How a Student Can Move From Their Initial State to Reach the Desired Outcome

There has been some research on how students can learn how to solve problems and how teachers can facilitate this process (Beriter et. al., 1992; Collins et. al., 1991; Maloney, 1994; Reif, 1995a). The instructors in this study, however, have little understanding of these areas. As discussed earlier (p. 185), and consistent with prior research, what these instructors know about learning how to solve physics problems appears to come primarily from their own experience as physics students. One possible scenario is that physics instructors know that they were largely confused by their introductory physics course, but that as they continued to take physics courses, they gradually began to form a more coherent picture of physics knowledge and how to use this knowledge to solve physics problems. They attribute their time spent practicing (i.e. struggling with problems) to their eventual success in learning how to solve physics problems by the time they completed their undergraduate or, in some cases, graduate training. There are two aspects of learning problem solving that the instructors in this study are not explicitly aware of: learning problem solving is a non-linear process, and it is possible to identify intermediate states of student performance in learning problem solving.

Learning problem solving is a non-linear process. The instructors in this study know that students learn how to solve physics problems by solving physics problems. They are caught in a paradox, however because they don't understand how students can get this experience solving physics problems unless they already know how to solve physics problems. That is, they don't understand the non-linear nature of learning how to solve physics problems. As described above (p. 190), there is evidence in the interview to suggests that all of these instructors, although they may tangentially mention the necessity of prior experience, do not have this well incorporated into their conception of how an introductory student can solve physics problems. As discussed below, research has shown that there are ways instructors can provide support so that students can get experience solving problems before they have enough experience or PERFORMANCE MONITORING skills to successfully solve problems on their own.

There are intermediate states of student performance in learning problem solving. The second aspect of learning problem solving that the instructors in this study are not explicitly aware of is the nature of intermediate states of student performance between their initial state (novice) and the desired outcome (expert). All of the instructors realized that teaching a complicated skill like problem solving cannot be accomplished in a single year-long course. Although the instructors believe that if a student sticks with physics long enough, they will eventually become expert physics problem solvers, none of the instructors appeared to be clear about where a student should be after the introductory physics course and how this will put them on the path towards expertise.

Knowledge of Teaching Strategies

Researchers have developed an understanding of techniques that can be used to teach a complex skill like problem solving. These researchers (e.g., Beriter et. al., 1992; Collins et. al., 1991; Schoenfeld, 1992) know that, to successfully teach problem solving, it is necessary to: (a) make the thought processes involved in problem solving explicit for students; (b) provide support so students can get the needed experience solving problems; and (c) slowly remove the support and increase the difficulty and diversity of the tasks. The instructors in this study did not appear to have an explicit understanding of any of these.

Making thought processes explicit for students. As previously discussed (p. 181), the instructors in this study are expert problem solvers and do not appear to have an explicit model of the thought processes necessary for problem solving. Thus, they don't see the necessity of making these processes explicit for students. What the instructors do attempt to convey to the students about the problem-solving process are either the mechanical things (e.g. students should work the solution symbolically and then put numbers in at the end) or very vague things (e.g. problem solving involves exploration and magic). None of these actually get at the important thought processes. As discussed in Chapter 2 (p. 56), research has shown that the thought processes can be made explicit for students by having the instructor model the problem-solving process using a problem-solving framework (Heller & Hollabaugh, 1992; Mestre et. al., 1993; Reif & Scott, 1999; Reif et. al., 1976; VanHeuvlen, 1991b). The modeling shows how the students can think about solving problems based on their level of limited experience with the subject and limited PERFORMANCE MONITORING skills.

Provide support so students can get the needed experience solving problems. There was little attempt by the instructors in this study to help students get some experience solving physics problems that they can use as the basis of future learning. Map 7 (Appropriate Problems, p. 136) shows that two instructors mention limited ways that they modify the resource of appropriate problems they assign to students based on the students' current state. One said that he would break the problem into parts to help guide students to do it the right way. The other said that he would start the course with one step problems before working students up to more complicated problems.

While the goal of both of these problem modifications appears to be appropriate (to provide support so that students can get the needed experience solving problems), these modifications may do more harm than good. As Maloney (1994) suggests, these standard sorts of physics problems may actually reinforce students' poor problem-solving skills because students can often successfully solve these types of problems without understanding or using an appropriate problem-solving process. As discussed in Chapter 2, research has shown that instructors can provide support to students in the form of scaffolding and coaching that allows the students to get experience solving problems before they have enough experience or PERFORMANCE MONITORING skills to successfully solve problems on their own. Scaffolding is frequently provided using a problem-solving framework that helps guide the students while they are solving problems (Beriter et. al., 1992; Collins et. al., 1991; Heller & Hollabaugh, 1992; Reif & Scott, 1999; Reif et. al., 1976; VanHeuvlen, 1991b).

Remove the support and increase the difficulty and diversity of the problems. The two instructors in this study who did provide limited support by modifying the resource of appropriate problems that they assign to students do imply that this support is eventually removed. Otherwise, there was little evidence that the instructors thought about changing the types of problems that they assigned throughout the course. As discussed in Chapter 2, research has shown that, as students' problem-solving skills improve, the instructor can slowly remove the support (fading) until the students are solving problems on their own (Beriter et. al., 1992; Collins et. al., 1991; Heller et. al., 1992; Mestre et. al., 1993; Reif & Scott, 1999; Reif et. al., 1976; VanHeuvlen, 1991b). In addition, the students can be given increasingly more difficult problems in increasingly diverse situations to further improve their problem-solving skills (Beriter et. al., 1992; Collins et. al., 1991; Heller & Hollabaugh, 1992; VanHeuvlen, 1991b).

Specific Unanswered Questions for Future Studies

Because of the generative nature of this study, some questions were raised in the analysis process that the interview did not provide enough data to answer. These questions may prove to be fruitful areas of inquiry for future studies.

Do Instructors Think That They Teach Motivated Students?

Map 1 (Some College Students, p. 114) shows that these instructors believe that student motivation is a very important learning characteristic. In Map 3 (Students' Current State, p. 120) there is no indication of how these instructors view their class in terms of general motivational characteristics (i.e. What are the proportions of motivated and unmotivated students in the class?). This is likely due to the structure of the interview where questions about what makes a student succeed or fail in a class were asked separately from questions about the makeup of a particular instructor's class. It would be possible to structure an interview to answer both the question of what role the instructor believes motivation has in student learning and how an instructor perceives his students in terms of motivation.

Do Instructors Use the Same Three Perspectives When Thinking About All of Their Management Decisions?

In Maps 7-9 (p. 131), three perspectives were identified that describe the different ways that these instructors appeared to think about the resources that they provided to students: (a) the perspective of the effect on student learning; (b) the perspective of required instructor time; and (c) the perspective of the match with student preferences. As noted in the description of these resource maps, ideas expressed from one perspective were often in conflict with ideas expressed from a different perspective. My impression is that these three perspectives can actually be used to categorize all instructor management decisions (i.e. making suggestions, setting constraints, as well as providing resources). Only the instructor decisions about providing resources, however, were probed in enough detail to allow for such a categorization. It would be possible to structure an interview that would probe instructors in more detail about all of their management decisions in order to determine if categorization in terms of these three perspectives would continue to prove useful.

Is the Resource of Individualized Responses More Than One Resource?

As discussed in Chapter 4 (p. 145), although the interview was designed to probe instructor beliefs about the individualized response of grading, it was not designed to specifically gather information about other types of individualized responses. Thus, the level of detail in Map 8 (Resource of Individualized Responses) is considerably less than in the other resource maps. This map really describes four types of individualized responses: (a) delayed feedback of instructor comments on student papers; (b) delayed feedback of grades on student solutions; (c) real-time feedback of instructor coaching; and (d) real-time feedback of peer coaching. An interview could be designed to gather more detailed information about all of these types of individualized responses and their effect on learning. In particular, it would be interesting to understand more about what instructors think are the similarities and differences between instructor coaching and peer coaching.

What is the Relationship Between Beliefs About Problem Solving and Beliefs About the Teaching and Learning of Problem Solving?

One would logically expect that an instructor's beliefs about problem solving would influence his beliefs about the teaching and learning of problem solving. On the other hand, as discussed in Chapter 2, teachers' conceptions are often compartmentalized and even in conflict with one-another. Thus, there should be no expectation for all of a teacher's beliefs to be logically related. For the six instructors in this study, even though three distinct views of the problem-solving process were identified, there is no evidence that these views are related to instructor views about the teaching and learning of problem solving. However, given that the main goal of this study was to identify the outcome space for faculty conceptions, the data is not ideally suited for identifying such correlations. Now that more is known about instructor conceptions about problem solving and about the teaching and learning of problem solving, it may be possible to design a study to look for correlations between the two.

What is the Role of Each of the Learning Activities?

This study identified three types of learning activities that these instructors think are important for students to engage in to learn how to solve physics problems (see p. 122): working on problems (path A), using feedback while/after working on problems (path B), and looking/listening (path C). There is some evidence to suggest that these instructors view each of the three different types of learning activities as being useful for developing certain types of knowledge/skill related to problem solving. For example, RU6 describes UNDERSTANDING PHYSICS as "knowing the facts" (RU6, statement #240) and students can get this by "reading and listening in class" (RU6, statement #236). This is a learning activity of looking/listening. On the other hand he believed that being able to perform SPECIFIC TECHNIQUES "is really something I think you need practice to do" (RU6, statement #241). This is a learning activity of working on problems. As an exploratory study, however, this study does not have much evidence to support a relationship between instructor beliefs about the effect of the different types of learning activities on particular types of knowledge/skill related to problem solving. This would be an interesting relationship to explore in future studies.

In addition, there is also some evidence to suggest that instructors consider using feedback (path B) as the most important type of learning activity. For example, Map 12 (Management of Students' Engagement in Learning Activities of Using Feedback, p. 158) was by far the most complicated map. The instructors had far more to say about their management of students' use of feedback than their management of either of the other two types of learning activities. It is not clear, however, whether the instructors said more about this path because (a) they believed it to be the most important for student learning, (b) they thought that this was the type of learning activity that they had the most control over, or (c) the structure of the interview was somehow biased towards this path. Future studies could be designed to more carefully gauge instructor views of the importance of each of the types of learning activities as well as their views of the importance of their management of each of the types of learning activities. For example, as shown in Map 13 (Management of Students' Engagement in Learning Activities of Looking/Listening, p. 163) instructors tended to confine their management activities to providing resources. It would be interesting to try to understand why. Do these instructors not know how to make suggestions or set constraints on students' looking/listening? Do they not feel that it is their role to do so?