FACULTY CONCEPTIONS ABOUT THE TEACHING AND LEARNING OF PROBLEM SOLVING IN INTRODUCTORY CALCULUS-BASED PHYSICS

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This is to certify that I have examined this copy of a doctoral thesis by

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And have found that it is complete and satisfactory in all respects,

and that any and all revisions required by the final

examining committee have been made.

PATRICIA HELLER

Advisor

Signature

Date

GRADUATE SCHOOL

DEDICATION

To my wife, Jill Terwilliger, for her love and support throughout this long process.

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ABSTRACT

Researchers and curriculum developers have developed a wide variety of curricular materials and instructional strategies that have been shown to be effective in improving student problem solving performance. Relatively few physics faculty, however, have chosen to use them. One likely reason is that these curricular materials and instructional strategies do not align with the ways that faculty think about the teaching and learning of problem solving.

This study is the first stage of a research program to understand faculty conceptions of the teaching and learning of problem solving. Interviews with six physics faculty from a large research university were used to generate an initial explanatory model of faculty conceptions. The interview was designed around three types of concrete instructional artifacts (3 instructor solutions, 5 student solutions, 4 types of problems).

Based on an in-depth analysis of the interview transcripts, a model of faculty conceptions was developed that consists of 14 general features. The basic relationships between these 14 general features are described in a concept map that is common to all six faculty. For example, there are three distinct ways that faculty think students can learn how to solve physics problems: (1) by solving problems on their own; (2) by using feedback while/after working on problems; (3) by watching someone else solve problems or describe how to solve problems.

Concept maps are also used to describe each of the 14 general features. For some of the general features, all six faculty have similar conceptions. For example, they all classify their students in terms of intelligence/natural ability and learning characteristics (e.g. motivation, study habits, etc.) and use these characteristics to explain why some students succeed and some students fail. For other general features, there is more than one distinct conception. For example, the model shows three different ways that these faculty conceive of the problem solving process: (1) three think of it as a linear decision-making process; (2) two think of it as a process of exploration and trial and error; and (3) one thinks of it as an art form that is different for each problem.

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CHAPTER 1: INTRODUCTION

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

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

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

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

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

Background

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

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

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

Ways of learning about teachers' conceptions

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

Prior research into Teachers' Conceptions

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

The Relationship Between Teachers' Conceptions and Their Instructional Choices.

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

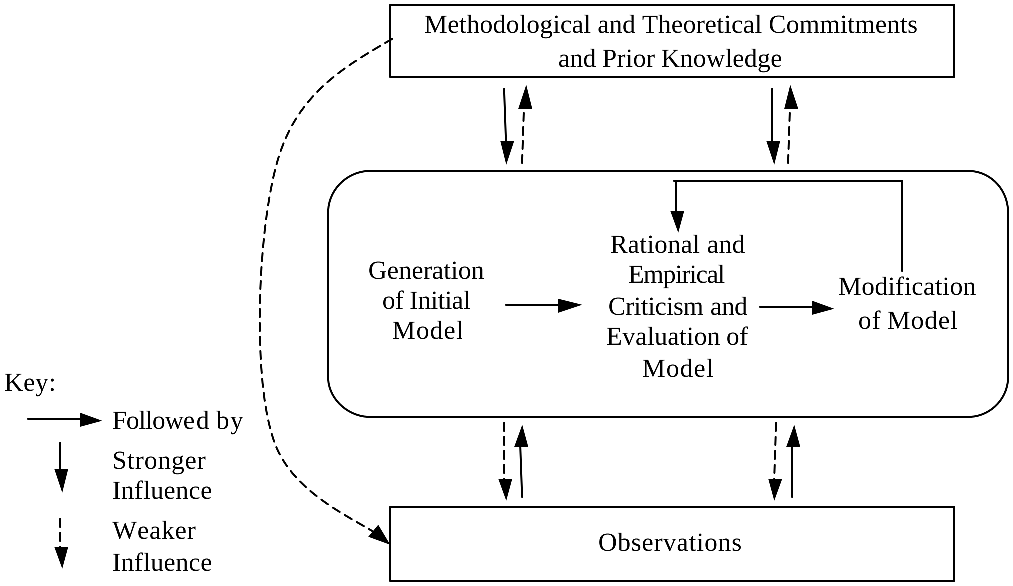
The Nature of Teachers' Conceptions

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

Model Generation and Testing

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

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



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

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

As Clement describes,

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

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

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

Phenomenographic Investigations of Thinking

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

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

Research Questions

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

> Goal of Study: Generate, if possible, a viable explanatory model of the conceptions that a small sample of research university faculty has about the phenomena of the teaching and learning of problem solving in introductory calculus-based physics.
>
> Research Questions
>
> 1. What are the general features of this explanatory model and how are these general features related?
> 2. For each of the general features of the explanatory model:

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

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

Research Design and Analysis

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

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

Significance of the Study

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

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

Limitations of the Study

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

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

The Research Team

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

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

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

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

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

Important Terminology

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

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

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

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

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

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

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

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

Overview of This Dissertation

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

Chapter 2: Review of the Literature

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

Chapter 3: Methods

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

Chapter 4: Results and Conclusions

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

Chapter 5: Implications

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

Bibliography

Appendices

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)

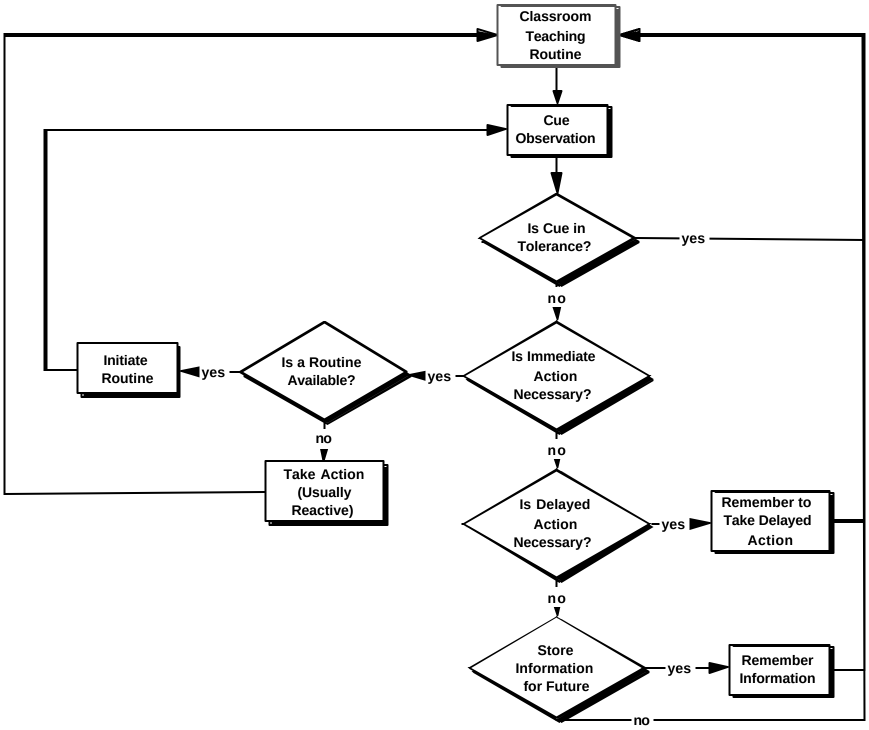


Figure 2-1 is a model of teachers' interactive decision-making created by Shavelson and Stern (1981) in their review of the literature. This model has several important features based on the research literature. There is substantial and consistent evidence that, on average, teachers make one interactive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

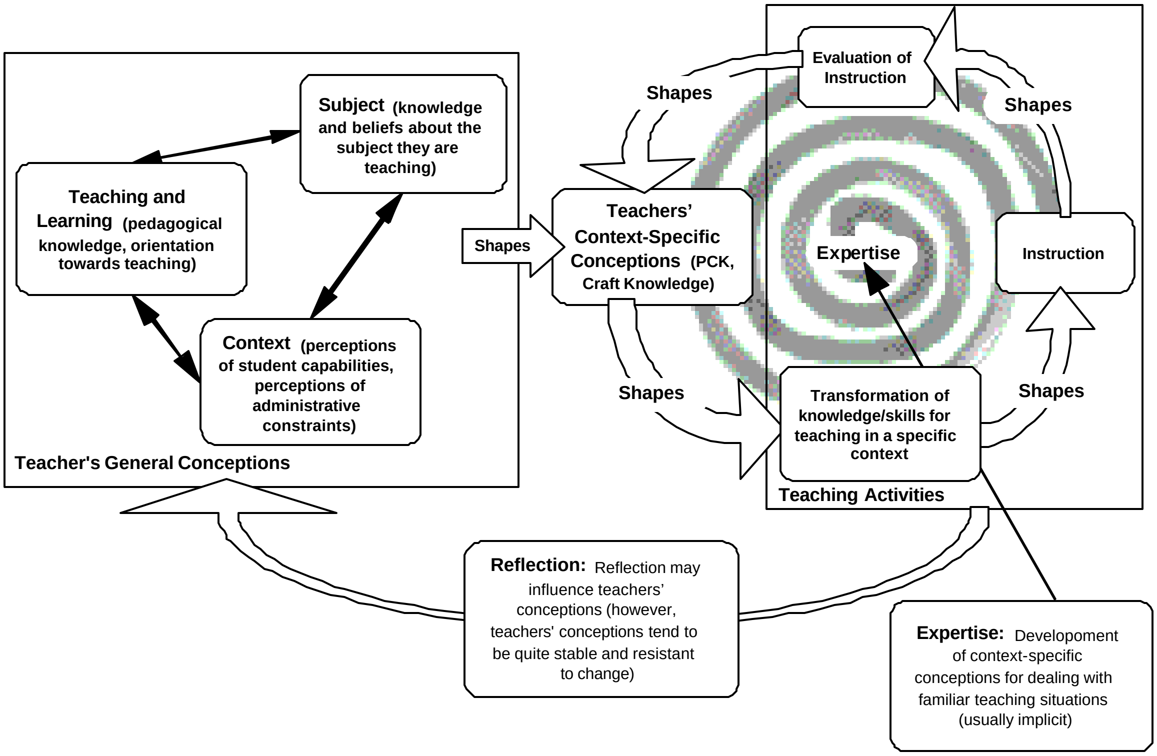
The most important result of the research on teachers' decision-making is the realization that teachers work in a rich and complex environment and make a large number of decisions. Teachers, however, do not deliberately make many of these decisions. Despite many efforts, this research agenda failed to 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

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[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.

Conceptions of the Teaching Context

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 little 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).

CHAPTER 3: METHODS

This chapter will discuss the methodological assumptions upon which this study was based as well as describe the interview tool, the interview participants, and provide a description of the data analysis.

Methodology

The methodology chosen for this study was based on similar methods used in prior studies of student conceptions of physical phenomena. Although the research team was not familiar with the phenomenographic research tradition (see Marton, 1981; Marton 1986) while conducting the study, the goals and assumptions used were of a phenomenographic nature. Thus, I will describe the methodology in terms of phenomenography in an effort to make the assumptions and goals of the study more coherent for the reader and to facilitate the comparison of this study to other studies. This is not the only study that has unknowingly used phenomenographic methodology based on a thoughtful analysis of the problem at hand and the research goals. Marton (1981, 1986), in fact, attempts to define this research tradition retrospectively to include a large portion of Piaget's earlier empirical work. This work by Piaget and the work on student conceptions that followed it have served to guide our thinking while developing and conducting this study.

Goals of the study

This study is the first phase of a larger research program designed to develop an explanatory model of physics faculty conceptions about the teaching and learning of problem solving in introductory calculus-based physics. Because there is little prior information available in this area, this study was designed to be a generative study (see p. 5). The goal of this study is to use a small sample of university faculty to generate an initial explanatory model of faculty conceptions that can then be tested and modified in future phases of this research program. The ultimate goal of this research program is to develop a model that will describe the range and frequency of faculty conceptions of the teaching and learning of problem solving in introductory calculus-based physics and the effect of context variables (e.g. type of institution) on these conceptions.

The research questions for this study are:

1. What are the general features of an initial explanatory model of faculty conceptions of the teaching and learning of problem solving in introductory calculus-based physics, and how are these general features related?
2. For each of the general features of the explanatory model:
    a. What are the conceptions (the ideas and the relationships between ideas) that are used by these faculty to understand this general feature?
    b. What are the qualitatively different ways that these faculty conceptualize this general feature?

All phenomenographic studies, including this one, take a second-order perspective (Marton, 1981; Marton & Booth, 1997). What this means is that the object of study is the way in which physics faculty experience the phenomena of the teaching and learning of problem solving, and not the phenomena itself. In addition, the interest, at this point, is not on whether the faculty conceptions are "correct" or "incorrect", but rather on building a model that describes the types and range of these conceptions.

There is a long tradition of research in science education that seeks to understand how students make sense of physical phenomena. Frequently this research into *student conceptions* makes use of clinical interviews in which students are asked to explain how they interpret a particular situation (e.g., Driver & Easley, 1978; Wandersee, Mintzes, & Novak, 1994). Much of this research has been described as being of a phenomenographic nature (Marton, 1981; 1986). Based on the standard research methods of this research tradition, this study makes use of a semi-structured interview based on instructional artifacts, and attempts to get physics instructors to externalize their thinking about a variety of situations related to the teaching and learning of problem solving. The interviews were transcribed and used as the primary data source (Marton, 1986). The analysis was open-ended and designed to aid in the discovery of the organizational features of the phenomena as the research subjects conceptualize it (Marton, 1986). In many phenomenographic studies, the final product of the analysis is a set of categories of conceptions that describe the qualitatively different ways that the research participants conceive of the phenomena of interest (Marton, 1986; Marton & Booth, 1997). This study, however, went one step further to construct an explanatory model that shows how these conceptions are related. This model was constructed and explicated using concept mapping techniques (Novak, 1998; Novak & Gowin, 1984).

Phenomenography

Phenomenography is a research tradition that was developed in the early 1970's by Ference Marton and colleagues "out of common-sense considerations about learning and teaching" (Marton, 1986, p. 40). The general goal of a phenomenographic study is to develop an understanding of the qualitatively different ways that people can think about (conceptualize) some specific portion of the world (Marton, 1986). These qualitatively different ways of thinking about a phenomena are often referred to as "categories of description". A category of description, then, is a piece of the researcher's model of an individual's conceptions (Bowden, 1995).

There are two basic assumptions that all phenomenographic researchers use to guide their research. One assumption is that there are a limited number of qualitatively different ways that people view a particular phenomena. Marton (1986, 1997) argues that 20+ years of phenomenographic research support this assumption. This assumption has been well supported in many studies of student conceptions of physical phenomena in such diverse areas as simple circuits, the shape of the Earth, the nature of gravitation, and many others (Wandersee et. al., 1994). For example, in a review article, Wandersee et. al. (1994, p.182) describes five distinct models of a simple circuit employed by students. The second basic assumption is that a single person may not express all aspects of a conception (Marton, 1997; Sandberg, 1995). As Sandberg (1995, p. 158) writes, "in some cases a specific conception cannot be seen in its entirety in data obtained from a single individual, but only within data obtained from several individuals." Thus, phenomenographic researchers combine data from more than one person in order to better understand the different ways of thinking about the phenomena.

Although phenomenography did not develop out of phenomenology, there are many similarities (Marton, 1981). The epistemological foundations are the same. For both research traditions, there is no objective, real world out there. Rather, human knowledge is based in their conceptions of reality (Sandberg, 1995). Researchers in both traditions seek to reveal the nature of human experience and awareness in order to understand these conceptions of reality (Marton, 1997). Also, in both traditions, the goal of the research is to develop a model that *describe*s the conceptions, not a model that *explains* the cause or function of these conceptions (Larsson, 1986).

Although researchers in both traditions seek to describe the subjects' conceptions of a phenomena, there are differences in the types of descriptions that are sought. Phenomenology seeks to build a model of the essence of the phenomena. This essence is the common set of conceptions that all of the research subjects had about the phenomena. Phenomenography, on the other hand, seeks to build a model of the different ways that people experience the phenomena (Larsson, 1986; Marton, 1997). Thus, in this study, the main goal is not to understand what all of the instructors have in common in their conceptions about the phenomena of the teaching and learning of problem solving. Rather, the goal is to understand the different ways that these teachers experience the phenomena.

The two traditions also differ in the richness of the descriptions sought. When describing the essence of a phenomena, phenomenology seeks to capture the richness of the conceptions. For the phenomenographer, however, the goal is to describe only the critical aspects of the way that the phenomena is experienced.

Procedure

This study consisted of three distinct phases: (1) Development of the interview tool; (2) Scheduling and conducting the interviews; and (3) Analysis of the interview data.

Development of the Interview Tool

The interview tool was developed over a period of about 8 months beginning in September of 1999. From the outset, the desire was to model the interview after studies of student conceptions in which students are asked to explain how they interpret a particular real-world situation (see Driver & Easley, 1978; Wandersee et. al., 1994). In addition, as described in Chapter 2, like students, instructors' conceptions are context-dependent and different conceptions may be activated in different situations (see Calderhead, 1996). Thus, it was decided that the interview should be based on several common situations in which instructors find themselves interacting with students via physics problems. After some brainstorming and discussion, three situations were identified as being almost universal among physics instructors: 1) Instructor makes available example problem solutions; 2) Instructor evaluates student solutions; and 3) Instructor assigns problems for students to solve. In addition to being universal, these three situations were quite distinct and could conceivably lead to the exposure of different conceptions among the interviewees.

In addition to the possibility of eliciting different conceptions by varying the context, prior research suggested that different conceptions might be elicited by varying the concreteness of the task. Thus, it was decided that, in each interview situation, the questions should range from general questions (e.g. What are your reasons for grading student problem solutions?) to questions based on specific instructional artifacts (e.g. What grade would you assign to this student solution? Why?).

Basing The Interview Tool on One Physics Problem

Having concrete parts of the interview meant having concrete artifacts for the instructors to examine. Initially, it was thought that these artifacts should be based on different physics problems. It was quickly realized, however, that it would be too time-consuming for the instructor to become familiar with more than one problem. Thus, it was necessary to find a problem that could reasonably be given in an introductory physics course at all of the different kinds of institutions where interviews were planned and that was rich enough to allow for interesting discussions.

Figure 3-1: Problem upon which interview artifacts were based (Homework Problem)

> You are whirling a stone tied to the end of a string around in a vertical circle having a radius of 65 cm. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a maximum height of 23 meters above the lowest point in the circle. In order to do this, what force will you have to exert on the string when the stone passes through its lowest point one-quarter turn before release? Assume that by the time that you have gotten the stone going and it makes its final turn around the circle, you are holding the end of the string at a fixed position. Assume also that air resistance can be neglected. The stone weighs 18 N.

It was decided that the best place to look for such a problem would be on the final exams given at the University of Minnesota. In addition to having problems that were designed and approved by a panel of 5-6 physics instructors, the Physics Department has a policy of keeping student final exam solutions for 3 years – thus providing a source of authentic student solutions to the given problem.

Based on an analysis of two years of University of Minnesota final exam problems, the problem used in the interview (see Figure 3-1) was selected based on the number of important physics concepts needed to solve it, and on the potential for students to work the problem in many different ways. The problem was sent to colleagues at several other institutions to verify that it was one that could conceivably be given to their students. All reports came back that, although this problem was on the hard side, it could indeed be given to their students.

Developing Interview Artifacts

As described above, artifacts were used during the interview to bring the discussion to a concrete level. The development of the interview artifacts was based on two criteria: (1) they had to span the range of common instructional practices, and (2) they had to span the range of problem-solving processes found in the research literature.

Instructor Solutions

In a review of instructor solutions posted on the web, it was found that almost all solutions fell into one of two basic types. The first type is a brief, "bare-bones" solution that offers little description or commentary. This type of solution frequently leaves many of the minor steps to be filled in by the reader. This is the type of solution that is typically found in textbook solution manuals. Instructor Solution 1 was modeled after this type of solution. All of the instructor solutions can be found in Appendix A.

The other common type of solution was more descriptive than the bare-bones type of solution. In this type of solution all of the details of the solution were explicitly written out. Instructor Solution 2 was modeled after this type of solution.

The types of instructor solutions described above, although providing a good representation of the range of actual instructor solutions, were missing two aspects of instructor solutions that are recommended by some curriculum developers (e.g. Heller et. al., 1992; Van Heuvelen, 1991a) based on physics education research. First, both of the previously described solutions proceed from the given information to the desired information. Research (see review by Maloney, 1994) has shown that problem solvers typically proceed from the desired information and attempt to relate it to the known information. Secondly, neither of the previously mentioned solutions described why particular steps were being done by describing an approach to the solution before starting with calculations. Thus, Instructor Solution 3 was created that starts from the desired information and that describes the approach first before starting with calculations.

Student Solutions

The selection of student solutions began with an analysis of approximately 250 student final exam solutions to the interview problem from one section of Introductory Calculus-Based Physics at the University of Minnesota. The solutions were categorized along several dimensions based on the features of the solutions themselves and a review of the research literature on expert vs. novice problem solving as described in Chapter 2. The final set of five student solutions included evidence of knowledge organization (around surface features vs. general principles), types of knowledge (e.g. declarative, procedural), types of analysis (e.g. qualitative, algebraic manipulations), and general decision-making processes (directing towards goals, evaluation and revision). They also varied in the correctness of the physics involved, as well as the amount of explanation.

It would have been desirable to have enough student solutions so that each varied from another on only one dimension. This, however, would have made the interview unacceptably long. In pilot testing, it was empirically found that 5 or 6 student solutions is the most that could be examined and graded in the available amount of time. Each of the solutions in the final set of five student solutions (see Appendix B) differs from the other solutions in more than one way. Care was taken to allow the interviewees reactions to these variations to be as meaningful as possible. For example, student Solution D has all of the parts of the solution found in Student Solution E, including the correct final answer. In Student Solution E there is not enough information to determine whether the student solved the problem correctly. In Student Solution D, however, it is clear that the student makes two compensating mistakes that lead to the correct final answer.

To help the instructors quickly assess the student solutions, boxed comments were added to each solution that described any definite error made in the solution.

Problem Types

The development of the different types of problems used in the interview was based on an analysis of problem types used in traditional and innovative courses. In addition to the Homework Problem, four others were added. There was a problem that included a diagram and was posed in three sections that required students to solve one sub problem at a time (Problem A), a multiple-choice problem (Problem B), a problem that was set in a "real-world" context (Problem C), and a problem that asked for qualitative types of analyses (Problem D). Appendix C shows the different problem types as they were used in the interview.

Pilot Testing of the Interview Tool

The ideal interview would be clear, flow well, and take less than 1½ hours to complete. More importantly, it would be able to elicit conceptions from instructors who differ in their practice, level of expertise in teaching physics, and knowledge of the physics education research literature.

Several versions of the interview were developed and pilot tested. The pilot testing included: (1) 4 physics graduate students; (2) 1 post-doctoral research associate from another institution who works in the field of physics problem solving; and (3) 2 University of Minnesota physics instructors who had recently taught the algebra-based introductory course, but had not recently taught the calculus-based course. After each pilot interview, the participant was asked about the experience and given an opportunity to offer suggestions about changes that might make the interview flow better or allow additional relevant information to come out. The videotape of each pilot interview was also viewed by the research team to determine whether it was successful in eliciting the types of information that were desired, and to determine where changes should be made.

A number of refinements were made in the interview protocol during this process of pilot testing. For example, in the early versions of the interview, the instructors were asked to solve the problem upon which the interview artifacts were based during the interview process. It turned out that, under the pressure of the interview, many instructors were unable to correctly solve the problem. In order to avoid this difficulty without using a trivial problem as the basis for the interview, it was decided that the problem would be sent to the instructors prior to the interview (thus, the problem became known as the "homework problem"). It was also found that, in order to keep the instructors' attention focused for the entire 1½ hour interview, there needed to be a coherent story line for the interview along which each question and part flowed smoothly and logically from the previous questions. To accomplish this, modifications were made to the interview protocol to change the ordering of the interview situations. In addition, one of the early goals of the interview was to distinguish between the instructors' likes and dislikes about the instructional artifacts and compare these to the instructors' use of the artifacts. Based on the pilot testing, it turned out to be too cumbersome to completely accomplish both of these tasks. It was not natural for instructors to distinguish between liking a particular aspect of an instructional artifact and using artifacts that contained that aspect. Thus, attempts to make this comparison were dropped from some of the interview situations.

The Final Interview Tool

The final interview consisted of four parts. The first 3 parts of the interview each dealt with one of the 3 types of artifacts. Each of these parts started with a general question about how and why the instructors use the type of artifact. The artifacts are then introduced and the interviewee was asked how they compare to the materials actually used in their classes, and to explain their reasons for making those choices. Each part concluded by asking the instructor to reflect upon the problem-solving process as represented in the artifact (e.g. What important problem-solving features are represented in the instructors' solutions? What processes were suggested by students' solutions? What processes do different problem statements require?). During the first three parts, the interviewer wrote an individual index card for each feature of the problem-solving process that the instructor mentioned (using the words that the instructors used). In the 4th part of the interview the instructor was asked to categorize the index cards into categories of their choosing. Several questions were asked regarding these categories (e.g. "Why do these go together? How would you name this category?", "For a student who had troubles with each of these categories at the beginning of the course, what do you think they could do to overcome them?", "Which of these things is it reasonable to expect most of your students to be able to do by the end of the introductory calculus-based physics course?"). The full text of the interview protocol can be found in Appendix D.

Scheduling and Conducting the Interviews

Since the goal of this study is to understand faculty conceptions of the teaching and learning of problem solving in introductory calculus-based physics, it was decided that the potential pool of interview subjects would be limited to those instructors who had taught the introductory calculus-based physics course within the last five years. Further, since there is no reason to expect physics instructors in Minnesota to be different from

Table 3-1: Six interview participants from the University of Minnesota

	Gender	Years of Teaching Experience	Number of Times Taught an Introductory Calculus-Based Physics Course
Instructor 1	M	10	10
Instructor 2	M	No answer	79
Instructor 3	M	2	1
Instructor 4	M	43	15
Instructor 5	M	23	5
Instructor 6	M	30	1

physics instructors in other parts of the United States, the potential pool of interview subjects was limited to those who could be visited and interviewed in a single day (i.e. they lived less than a three-hour drive from Minneapolis, MN as computed by Netscape on-line driving directions). Each randomly selected candidate was contacted, either in person or by telephone, by a member of the research team, and asked if they would participate in the study. Of the 35 instructors that were contacted, 5 declined to be interviewed (1 did not want to participate in an NSF-sponsored study, 1 did not want to participate in a videotaped interview, and 3 cited a lack of time). Our final sample consisted of 30 instructors (from the 107 possible) roughly evenly divided between the following groups: 1) Community College Instructors; 2) State College Instructors; 3) Private College Instructors; 4) Research University Instructors – UMN Twin Cities Campus.

As previously discussed, this dissertation will focus on the six interviews conducted with Research University Instructors. It was decided to start with the Research University instructors since: (1) they all work in the same environment and, thus, are likely to hold more conceptions in common than any of the other groups (Barnett et. al., 2001); and (2) prior studies (Foster, 2000) and informal contacts due to proximity allowed the research team to know more about these instructors than any of the other instructors. Table 3-1 provides a list of the six interview participants from the University of Minnesota along with important demographic information.

The interviews were conducted during a period of approximately 1 month (April, 2000). Prior to the interview each instructor was mailed a packet that included (see

Appendix E): (1) a cover letter confirming the interview time and location; (2) the Homework Problem; and (3) the Background Questionnaire. Either Charles Henderson or Edit Yerushalmi conducted each interview. Before each interview began, the interviewee was asked to read and sign a consent form as required by the Human Subjects Committee (see Appendix F). During the interview a tripod-mounted video camera was positioned in such a way that the video recorded the working surface upon which the interview artifacts were discussed. A bowl of M&M peanut candies was provided for the instructors to snack on during the interview.

Teaching context of interview participants

All six instructors interviewed for this study had recently taught the introductory calculus-based physics course at the University of Minnesota and were asked to focus on this course during the interview. An understanding of the context in which these instructors teach is necessary for understanding the interview results.

During the past 12 years the Physics Education Research Group at the University of Minnesota has introduced significant changes to the structure of the introductory calculus-based physics course (Heller & Hollabaugh, 1992; Heller, Keith, & Anderson, 1992). The course can be thought of in terms of the three components of lecture, discussion sessions, and laboratories. The basic structure of each of these components was the same for each of the instructors interviewed. There are typically 5 sections of the introductory calculus-based physics course that meet at various times throughout the day, with each section having between 80 and 300 students.

Lecture

The lecture portion of the class met three times a week for 50 minutes in a large lecture hall with auditorium-style seating. There were no constraints put on the lecturer as to how this time should be spent. There was, however, a common agreement among the lecturers as to the general topics that should be covered by the end of the course.

There would typically be 3-4 individual quizzes given each semester during lecture time. These quizzes would be written by the instructor or graduate student TAs and were almost always graded by TAs. The final exam for the course typically consisted of 5 problems for students to solve and 20-30 multiple-choice questions. A common final exam was mutually developed by the instructors of all 5 sections of the course.

Discussion Sessions

Discussion sessions met once a week for 50 minutes and were led by TAs. In discussion sessions, approximately 18 students solve the same problem in small, cooperative groups. Either the instructor or the TAs prepared the problem. The expectation was that the problems used were “real” problems (as described in Chapter 2, p. 57). The day prior to an individual quiz in lecture, a group quiz would be given in the discussion sessions. All students in a group received the same grade on the group quiz. All TAs received training provided by the Physics Education Research and Development Group about how to write real-world problems, how to arrange groups, and how to manage group discussions.

Laboratories

Laboratories met once a week for two hours. Students who did not pass the laboratory could not pass the course. The laboratories were taught by the same TA the students had for their discussion session and students worked with the same groups. Students were required to purchase a laboratory manual that was written and developed by the Physics Education Research and Development Group. During each laboratory session, each group was expected to complete one or two laboratory problems. These laboratory problems typically asked the students to quantitatively solve a real-world problem and then compare their answer to results generated in the laboratory. Either the instructor or the TAs decided which laboratory problems should be completed each week. Every two or three weeks each student was required to write an individual laboratory report for one of the laboratory problems. The TAs graded these reports. All TAs received training provided by the Physics Education Research Group about how to grade laboratory reports, how to arrange groups, and how to manage group discussions.

Analysis of the Interview Data

This section will describe how the data gathered during the interview were used to generate an initial explanatory model of faculty conceptions of the teaching and learning of problem solving in introductory calculus-based physics. As described by Clement (2000), there are four levels of knowledge used in the sciences and social sciences: (1) Primary-Level Data; (2) Observed Behavior Patterns and Empirical Laws; (3) Researcher's Explanatory Models; and (4) Formal Principles and Theoretical Commitments. The goal of this study was to reach the third level of knowledge by creating an explanatory model of faculty conceptions. The levels of knowledge are illustrated in Table 3-2 using Clement's (2000) description of the knowledge developed from a physical science study of gases. This is compared to a piece of knowledge about the way instructors conceive of instructional resources developed from the current study.

As Clement describes in his explanation of the study of gases, "merely being able to make predictions from the empirical gas law stating that pressure times volume is proportional to temperature (Level 2) is not equivalent to understanding the explanation for the behavior of gas in terms of an imaginable explanatory model of billiard ball-like molecules in motion (Level 3). The model provides a description of a hidden process, or mechanism, that explains how the gas works and answers 'why' questions about where observable changes in temperature and pressure come from. On its own, the empirical law PV=kT does none of these things….The model not only adds significant explanatory power to one's knowledge but also heuristic power, which stimulates the future growth of theory" (Clement, 2000, p. 550). In a similar way, the current study seeks to go beyond a description of the patterns found in the interview data (Level 2) to generate an explanatory mental model that will allow us to answer "why" questions about where these patterns in the interview data come from.

Table 3-2: Four levels of knowledge compared for a physical science study and the current study. This table is based on a table created by Clement (2000, p. 550).

		Physical Science: Study of Gases	**Science Education: Study of Instructor Conceptions of Instructional Resources**
Theories	*4. Formal Principles and Theoretical Commitments*	$P = \frac{\frac{1}{3}Nm\overline{v^2}}{V}$ (Refers to theory of molecules)	Teachers work in a complex environment and have many perspectives with which they view their work. These different perspectives often suggest conflicting teaching actions. (note: This is an example of a possible formal principle emerging from past research on teachers' conceptions of teaching and learning, see Chapter 2, p. 50.)
	3. Researcher's Explanatory Models	Colliding elastic particle model	Instructors have three perspectives about the characteristics of the resources they provide students to help them learn problem solving: (1) their effect of a characteristic on student learning, (2) the instructor time required to provide the characteristic, and (3) the match with student preferred characteristics. Perspectives 2 and 3 are sometimes in conflict with Perspective 1.
Observations	*2. Observed Behavior Patterns and Empirical Laws*	$PV = kT$ (Refers to observations of measuring apparatus)	<u>Resource of Appropriate Example Solutions.</u> Subjects have three perspectives about the characteristics of the example problem solutions they write/select/post to help students learn problem solving: (1) the effect of a characteristic on student learning, (2) the instructor time required to write/select/post problem solutions with a specific characteristic, and (3) the match of the solution characteristics with the characteristics that students prefer. Sometimes subjects express concern that the characteristics of problem solutions that have a good effect on student learning are also too time consuming to write or do not match student preferences. ….[The same pattern was observed for the two other resources of: (a) appropriate problems instructors provide for students to solve, and (b) individualized responses (feedback) provided while/after students solve a problem.]
	1. Primary-Level Data	Measurement of a single pressure change in a heated gas	Individual instructor statements during the interview about three different types of example instructor solutions: • "I think Instructor Solution 3 [explicit reasoning] explains better how choices were made about when to use the energy approach versus the force approach." (RU5, statement #56) • "To pick five homework problems, copy the solutions from the solution manual [which are like Instructor Solution 1 – bare bones], and get it put on the web takes about two hours. To use more complex solutions would take much longer, and I don't have the time." (RU5, statements #45, 46)

Initially it was thought that the analysis of the interview data would proceed more or less like an orally delivered survey. It was soon realized, however, that the interview data were far too rich and varied for this method of analysis to be effective. After much experimentation with different analysis methods, a set of categories and categorization procedures was developed based on a system analysis of the teaching/learning environment. These categories were used to break down the interview data into units for further analysis. These units were then categorized and interconnected using concept map representations. In this section, I will briefly describe some of the things that were considered and tried in the development of the final analysis method and then describe the final method in some detail.

Transcription

During July, 2000 a professional was hired to transcribe the audio portion of each interview. This transcription was then verified and corrected by a member of the research team. During this verification, notes about visual cues were added to the transcript (e.g. what the interviewee is pointing to when he is talking). Paragraph numbers were also added to the transcript.

Experimenting With Analysis Methods

Beginning in the Summer of 2000, the research team began to experiment with different analysis methods in an attempt to find an appropriate way to handle the data. The process was by no means a linear one, however, an attempt will be made here to characterize some of the potential analysis characteristics that were explored. This period of experimentation allowed the research team to become familiar with the data and to explore the types of questions that might be fruitful to answer using the data. The final analysis method involved aspects of many of these methods and was greatly assisted by the familiarity with the data that was gained during this period of exploration.

Using Units of Action

One of the earliest analysis schemes was to break the transcript into units of action. The unit of analysis was taken to be the smallest piece of text that can be rephrased as a statement describing an action of a student or an instructor. In this scheme actions could be either external (observable actions) or internal (thoughts, emotions, etc.). Each of these units of action was then categorized into a fairly elaborate categorization scheme that included what the action was related to (related to solving problems, related to learning to solve problems, not related to problem solving), when the action occurs (before, during, or after the course), who executes the action (student, instructor), why the action takes place (reason give, no reason given), whether the action actually takes place (exists, does not exist, exists under certain conditions, unclear), instructor's attitude towards the action (positive, indifferent, negative, unclear), type of action (external, internal cognitive, internal affective, unclear). Links between units of action were kept track of when one unit was an example of another unit or when one unit was a reason for another unit. Each subcategory was then analyzed for the important themes.

The main difficulty with this analysis method was that it was difficult to rephrase each of the interview statements as actions. For example many times during the interview instructors discussed things that they liked or did not like about particular instructional artifacts. Their likes and dislikes did not necessarily correspond to an action. Also, since the rigid categorization system was based on a theoretical understanding of teaching and learning it did not match well with the ways that instructors think and thus proved difficult to adequately categorize each instructor statement.

Argument Structure Analysis

This method was based on Toulmin's argument structure categories (Toulmin et. al., 1984; Voss et. al., 1983). Each part of a sentence that could be was categorized as either a claim (fundamental assertion), warrant (reason or generalization supporting the claim), ground (reason based on experience that supports the claim), backing (support for warrant based on authority), qualifier (indicates strength, weakness, or conditions upon which a claim or warrant is applicable), example (example to support a warrant or claim), or detail (further details about a warrant or claim). These categories were then displayed diagrammatically with each category having its own symbol. This type of analysis was very detailed and time consuming. Furthermore, it was soon obvious that the instructors frequently made claims without any support. This lack of support was an important realization, however, one that would best be incorporated into a different analysis method.

Using Teaching Episodes

This method was based on Reif's (1995a) statement of the instructional problem as one of taking the student from some initial state through a transformation process to some final state. In this method, the interview was broken into teaching episodes. Each teaching episode was a discrete train of thought during the interview. Each of the ideas in the teaching episode was then put into one of four categories: initial state of student, instructor action, student action, and final state of student. Each teaching episode was displayed in four columns, each representing one of the four categories. Attempts were made to find similar teaching episodes and group these episodes to arrive at a small number of ways that the instructor approached the instructional problem. It was found, however, that these four categories were inadequate to understand the range and complexity of the instructors' actions and beliefs. For example, this model did not allow for cyclical interactions where the instructor would do something (e.g. assign a homework problem), the student would do something (e.g. work on and turn in the completed homework problem), and the instructor would do something in response (e.g. give a lecture on the concepts that he noticed students missed in their homework). Also, as with the other methods mentioned so far, these four categories did not represent the way instructors think about instruction. Many times only one or two of the categories would be used for a particular episode.

Converging on the Final Analysis Method

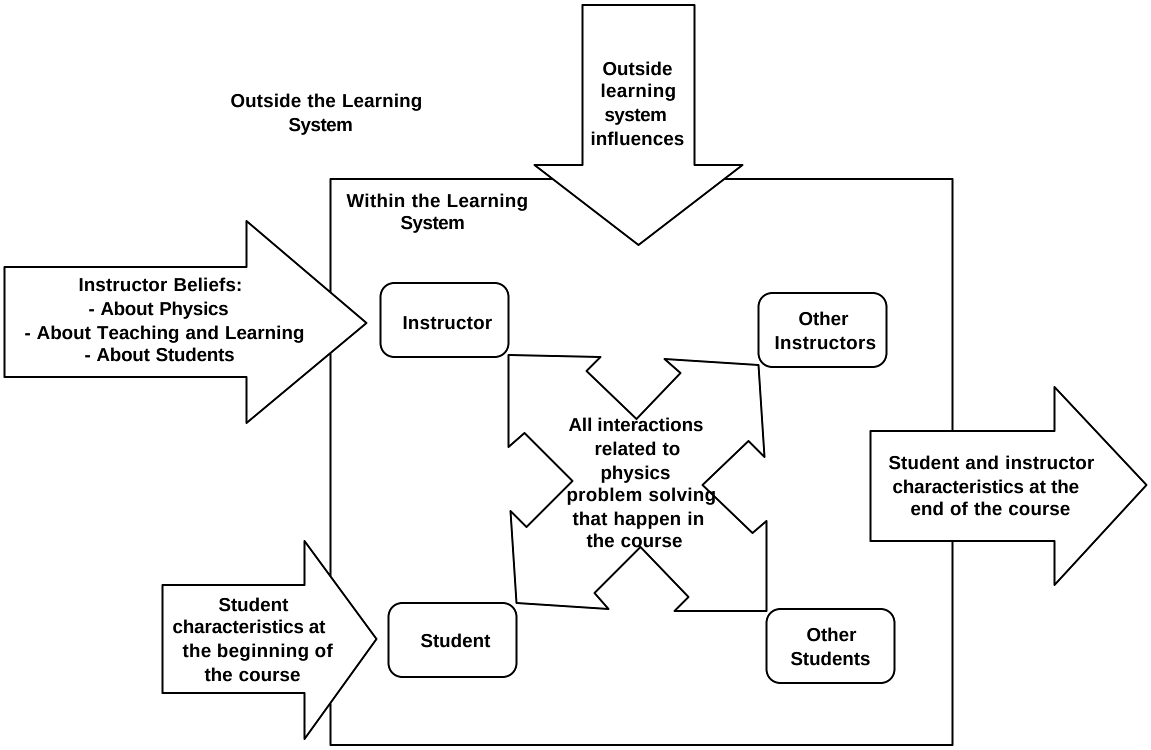
Although there are a wide variety of qualitative research methods used, most methods consist of at least three distinct parts (Miles & Huberman, 1994): a) breaking the text into some sorts of units; b) categorizing the units; c) looking at the categorized units in a way that increases understanding of the data.

Unit of Analysis

The unit of analysis used in the final analysis was a single idea expressed by the interviewee. Hycner (1985) calls these "units of relevant meaning" and describes them as "those words, phrases, non-verbal or para-linguistic communications which express a unique and coherent meaning clearly differentiated from that which preceded and follows" (p. 282). He suggests making all possible units of relevant meaning and then deciding which ones can inform the research interests and which can be discarded (Hycner, 1985). Attempts at proceeding in this manner, however, resulted in some ambiguities in deciding what sections had "coherent meaning". This ambiguity led to the production of many units that were not of use in the analysis as well as the missing of some relevant units. In order to reduce this ambiguity a categorization scheme was developed to aid in the making of units of relevant meaning. A unit of relevant meaning (hereafter referred to as a "statement") is thus defined as a single idea expressed by the interviewee that fits into the categorization scheme. As suggested by Hycner (1985), the guidelines for writing these statements were to "crystallize and condense what the participant has said while still using as much as possible the literal words of the participant" (p. 282).

Several categorization schemes were attempted, but it was found that they were too cumbersome to use effectively, or they failed to capture all of the information of interest. The categorization scheme that was finally used was based on a system view of the learning environment. From this perspective, the learning environment consists of various elements (instructors and students) and interactions between these elements (teaching and learning). This can be shown diagrammatically (see Figure 3-2). Based on this representation the following seven categories were created. Each category was

Figure 3-2: System diagram of the learning environment that was used to develop categories to guide the construction of statements from the interview transcript.



created in the form of a question to help keep their meaning clear and, thus, were called Question Categories:

- **Question Category #1: What are the possible learning environment interactions?** These are any interactions between the participants in the learning environment within the context of the introductory physics course. These interactions can be mediated via spoken (e.g. lecture, individual conversations) or written materials (e.g. instructor solutions, grading).

- **Question Category #2: What reasons does the instructor have for his instructional choices?** Of the possible learning environment interactions the interviewee typically indicates that he does choose to initiate some of them and not to initiate others. Although the reasons for these choices are not represented in the diagram, these reasons were of particular interest for this study.

- **Question Category #3: What does the instructor think students are like?** This category describes instructor beliefs about what characteristics students have when they enter the learning environment or while they are in the learning environment.
- **Question Category #4: What general conceptions does the instructor have about physics and the teaching and learning of physics?** This category describes what characteristics the instructor has when he enters the learning environment. These conceptions can be about physics, problem solving in physics, the teaching and learning of physics, or other relevant beliefs. Note that these conceptions are those that are explicitly stated by the instructor. Other conceptions will be inferred later in the analysis.
- **Question Category #5: What outside factors influence the learning environment?** Outside factors are things that influence the learning environment, but do not come from within the learning environment (e.g. time pressures due to other responsibilities, fixed classroom arrangement, etc.).
- **Question Category #6: What student outcomes does the instructor desire from the course? How do they compare to actual outcomes?** This category describes instructor conceptions about what characteristics students should have when they leave the learning environment and how these characteristics compare with reality.
- **Question Category #7: How satisfied is the instructor? If not satisfied, what could be done about it?** This category describes the instructor's evaluation of the course when he leaves the learning environment. Along with this evaluation of the course, this category includes possible improvements and reasons given for or against such improvements.

Breaking The Transcript Into Statements

Once the unit of analysis was decided on, the next step was actually breaking each transcript into statements. Charles Henderson and Vince Kuo created all of the statements. Initially, both of the researchers worked on making statements out of the same passages and then compared their work. Upon comparison, differences were discussed and an agreement was reached as to what statements should be made. The criterion for agreement was not that the statements be exactly the same, but rather that they convey the same information. Initially the statements agreed at about the 70% level. By the end of the first transcript (Instructor 1), the statements for the entire transcript agreed at the 86% level before discussion and at the 100% level after discussion. By the end of the second transcript (Instructor 2), the statements for the entire transcript agreed at the 93% level before discussion, and again at the 100% level after discussion. This pre-discussion level of agreement was considered to be acceptable and the remainder of the transcripts were broken into statements by only one of the researchers.

There were several procedural decisions that were made to assist in the making of statements. In order for statements to be meaningful on their own, it was often necessary to add context to a statement. How much context to add was largely a matter of balancing -- keeping enough context so that the statement could be fully understood, but not to have so much context that the statements become overly long or overly repetitive. Statements ranged in size from short three word sentences, to more complex sets of 3 or 4 sentences.

Making statements involves some degree of interpretation. There is always the danger of changing the meaning of the interviewee's statement. To minimize this problem, it was decided that all statements would be made using, as closely as possible, the original words from the transcript. Also, a code was attached to each statement so that the original text from which it came could be easily referred to. Finally, some parts of the interview could not be understood (e.g. the interviewee stopped talking in the middle of a sentence before completing a thought). These were left as is and made into statements.

The logistics of making statements was also an important consideration. After some initial trials using the qualitative research software N*Vivo, it was decided that the statements would be most flexibly created, stored, and used in the multi-purpose spreadsheet Excel. Excel has the advantage of being able to store the statements as lists with different columns representing characteristics of the statements. Thus, statements can easily be sorted into lists having particular characteristics.

Goal of Analysis

Once the transcripts were made into statements, the initial analysis plan was to proceed as described by Marton (1981, 1986) and create groups of similar statements within each question category and then give each group a name that characterizes it. Thus, one or more descriptively named groups within each question category would characterize each instructor. Comparisons could then be made between instructors to identify which groups most of the instructors had in common. An analysis could also be done to determine if groups in one question category relate to groups in another question category (e.g. do certain conceptions about students correspond to certain learning environment interactions). The data could then be displayed in chart form for easy reference.

This analysis method, although sounding promising when described abstractly, posed several problems in actual practice. The number of groups within each question category turned out to be considerably larger than the 3-5 that had been expected. There was not a lot of similarity among the 6 instructors in the groups that were formed in each question category, and, perhaps most importantly, there were too many connections and richness in the data that this method did not capture. It seemed as though we were attempting to force the data into a scheme that did not fit it well and that did not allow for useful comparisons among instructors. We then began to describe the data diagrammatically using concept maps.

Representing Data Using Concept Maps

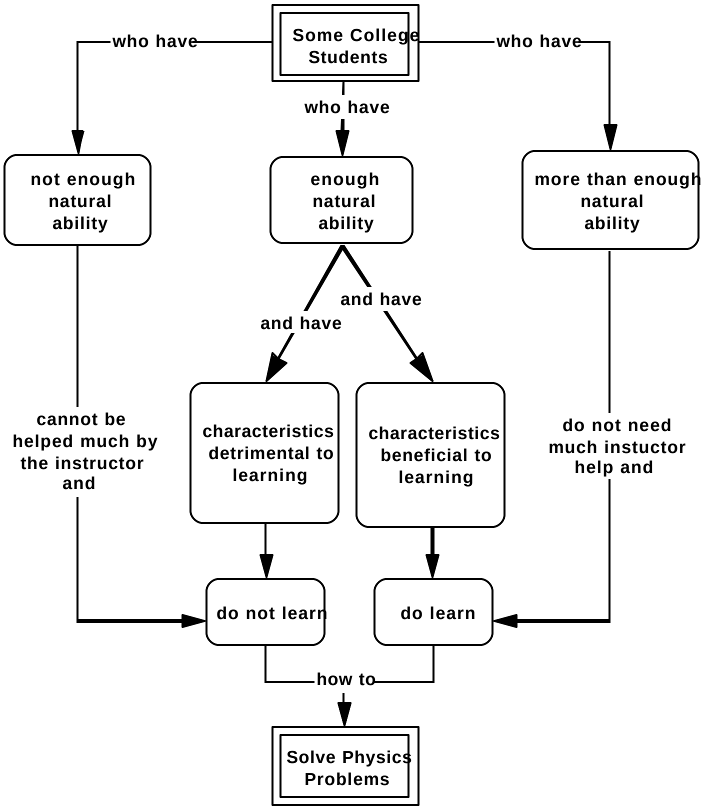
The final analysis method involved representing each instructor's conceptions in a series of concept maps and then combining these concept maps to form "composite" concept maps that represented the conceptions of the group of six instructors.

Concept Maps

Concept maps were developed by Novak and Gowin (1984) as a way to understand student conceptions about physical phenomena. In their traditional form, concept maps are a collection of concepts (each concept is typically represented by a single word) connected by lines representing relationships between concepts (Novak & Gowin, 1984). The links between concepts are usually labeled to indicate the type of relationship. Because the data in this study is very complex, when there was no danger in doing so, multiple concepts and their linking words (i.e. statements) were frequently grouped together in a single box. In Novak and Gowin's concept maps there was only one type of box that represented all concepts. In our concept maps there were several different types of boxes to represent different types of concepts (or groups of concepts) in order to make more information quickly available to the reader.

Figure 3-3 shows an example of a concept map that resulted from this study. This map is used to describe the model generated for instructors' conceptions of what student qualities relate to their success or failure in learning how to solve physics problems. Sequences of connected boxes and links on the concept map can be read like a sentence with the arrows indicating the direction. For example, starting to the left of the "Some College Students" box, the sentence can be read as: "Some college students who have not enough natural ability cannot be helped much by the instructor and do not learn how to solve physics problems." Although the grammar of this sentence is not quite right, the meaning is clear – the sentence describes an instructor conception that some students in their class do not have enough natural ability to learn how to solve physics problems. This concept map will be described in more detail later.

Figure 3-3: Composite concept map that describes instructors' conceptions of "Some College Students".

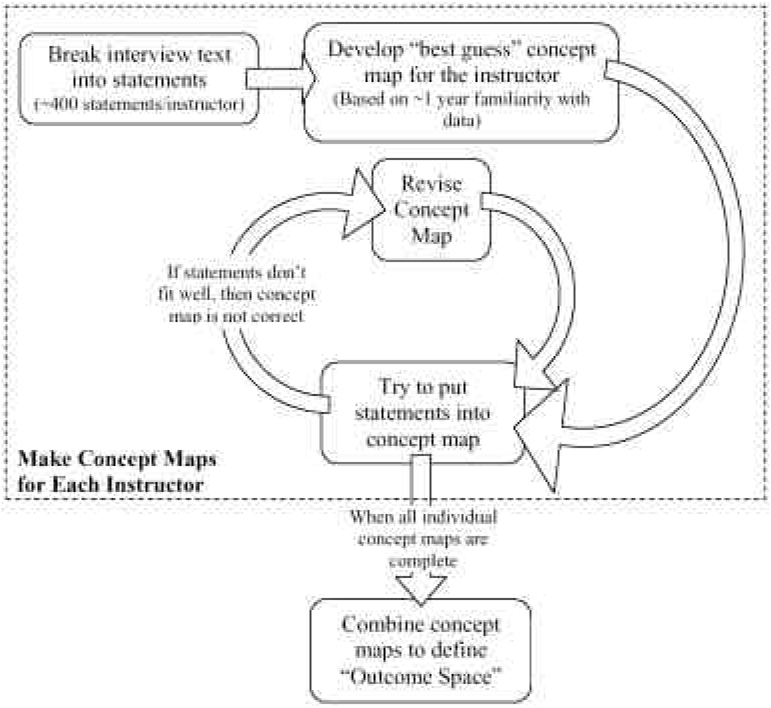


Concept maps have an advantage over prose writing in that a large number of interconnections can be represented rather compactly. Further, concept maps make very explicit connections between statements. Because the goal of this study is to generate an initial explanatory model, having explicit connections will allow future studies to confirm or reject important links.

Developing the Concept Maps

Because of the large amount of information that needed to be contained in the concept maps, a main map was developed to capture the general features of a particular instructor's conception(s) of teaching and learning. Each of the general features on this main map was elaborated in detail using "feature" maps. The concept maps were created using the software package Inspiration.

Figure 3-4: Procedure for Developing Feature Maps



<u>Procedure</u>

The concept maps were developed through an iterative process. Initially, the research team spent several weeks exploring and debating different ways of representing the interview data.

After this exploration phase, concept maps were developed using the iterative procedure shown in Figure 3-4. Concept maps were first developed separately for each instructor. All of these individual concept maps were constructed by either Charles Henderson or Vince Kuo. This process involved going through each of the interview statements and placing it into one or more of the concept maps. It was incorporated into an existing map, box, or link whenever possible and added as a new map, box, or link when the statement expressed an idea not yet represented. In addition, the identifying number of each statement was added to the concept map box or link as a way to track the ideas and monitor the number of times similar statements were made during the interview.

There were an average of 390 statements from each interview. Of these, on average, 77% were used in the concept maps. Statements that were not placed on the concept maps were labeled with the reason for their exclusion:

- Not Understandable. (9% of statements)

  Example: "so this is a, you know…" (RU5, statement #131)
- Understandable, but not relevant to this study. (7% of statements)

  Example: "Students were generally helped significantly by their lab grade." (RU3, statement #266)
- Procedural Talk. (3% of statements)

  Example: "Can I write on this?" (RU1, statement #145)
- Statements too vague to be placed anywhere. (2% of statements)

  Example: "I would encourage SSB on some of the things they're doing here" (RU3, statement #248)
- Social Talk. (1% of statements)

  Example: "Is this part of the office now?" (RU1, statement #217).

The percentage of statements in each of these categories was similar for all of the instructors.

Verification of Individual Concept Maps

Once each of the individual concept maps was complete, the individual concept maps were checked for thoroughness and accuracy. This happened in two ways. One way was that each concept map was checked for clarity by having a researcher not involved in constructing the map scrutinize the map. Any problems were reported to the concept map author along with suggestions for improvements, often involving evidence from the statements or interview data. Any disagreements were mutually resolved. Another way that the individual concept maps were verified was based on a comparison of all of the feature maps for a particular feature across all of the instructors. Concepts that were included in some of the maps but not in others were scrutinized and, when warranted, the researcher would return to the statements or transcript to find evidence for the missing conception or clarify the existing conception.

Developing Combined Concept Maps

As Figure 3-4 shows, once all of the individual concept maps were completed, these maps were combined to form a composite map, which is an explanatory model of these instructor's conceptions. The composite maps were created to show the range of ideas expressed by the instructors during the interview. Notations were made on each idea and link to show which of the six instructors held that particular conception. All of the combined concept maps were created by Charles Henderson and scrutinized by the research team. Extensive revisions were done to make the maps understandable by a variety of possible readers.

Categories of Knowledge/Skill Related to Problem Solving

In developing the combined concept maps, it was necessary to develop meaningful categories to describe the types of knowledge/skill related to problem solving that the instructors talked about during the interview. As discussed earlier, throughout the interview, the interviewer wrote an individual index card for each feature of the problem solving process that the instructor mentioned. In the 4^h part of the interview the instructor was asked to categorize the index cards into categories of his choosing. An examination of the results of this sorting task showed that these instructors made very similar categories (a list of the note cards and their categorization for each instructor is shown in Appendix G). This led to the development of four categories of knowledge/skill related to problem solving that were used in the combined concept maps: (a) physics concepts (e.g. have a good sense of what centripetal acceleration does); (b) approach to solving a problem (e.g. having a strategy and being able to verbalize it); (c) specific techniques (e.g. being able to draw free-body-diagrams); and (d) performance monitoring (e.g. being aware of when there is a difficulty).

Identifying Qualitatively Different Ways of Viewing each General Feature

In keeping with the standard goals of phenomenographic research, one of the main outcomes of this study is a set of the qualitatively different conceptions that these instructors have about the particular aspect of the phenomena of the teaching and learning of problem solving. These qualitatively different ways of conceiving each general feature were initially developed by Charles Henderson based on a comparison of the different instructor concept maps for a particular general feature. The goal of this part of the analysis was to identify different ways that the instructors conceptualize the phenomena, rather than simply describing one particular way differently, or in more or less detail. This was a difficult, interpretive process that involved many iterations and modifications based on discussions with members of the research team.

Viability

According to Clement (2000), viability refers to the "explanatory power and usefulness of an explanatory model". Considering the viability is a way to address the question of "how good is the model?" In qualitative research there is no universal way to answer this question of the "goodness" of the research (Creswell, 1994). Other researchers use different terms to refer to this question such as validity, reliability, trustworthiness, credibility, etc. (Creswell, 1994; Miles & Huberman, 1994).

Clement (2000) describes four criteria that can be used to evaluate the viability of an explanatory model: plausibility, empirical support, rational (nonempirical) support, and external viability (or "tests over time"). I will discuss the viability of this study in terms of these four criteria.

Plausibility. Clement (2000) describes plausibility in terms of two criteria: explanatory adequacy and internal coherence. Explanatory adequacy refers to the ability of the model to give a plausible explanation for the empirical observations (i.e. the statements made by instructors during the interview). Internal coherence refers to a lack of contradictions within the model. The explanatory model developed in this study does meet these criteria. The model adequately explains all of the statements made by the instructors during the interview. In addition, the plausibility of the model was verified by

2 experts in the field of physics problem solving who were not members of the research team. Finally, the model is internally consistent. For example, the model does not show instructors believing that only *some* college students can learn how to solve physics problems while, at the same time, showing that *all* students get the appropriate knowledge.

Empirical Support. Clement (2000) describes empirical support as the strength of the connection between the explanatory model and the empirical observations. This strength of connection between the model and the data can come in two basic ways: through triangulation within the data set (i.e. multiple observations that support an aspect of the model), and through the strength of the connection between an individual observation and the model. Great care was taken throughout the analysis procedure to enable the research team (and the research audience) to determine the number of observations that support each aspect of the model. This was done both at the level of the individual instructor models and the composite model. When constructing concept maps for individual instructors, the statement number was kept with each box and link. These statement numbers allowed the researchers to estimate how much support existed for each piece of the concept map and to determine which part(s) of the interview this support came from. A similar system was used for the composite concept maps. On these maps, each box or link (when necessary) was labeled to indicate which instructor(s) had that conception. This information makes it easy to determine the level of triangulation that exists for each conception in the model.

In addition to showing the degree of triangulation on the concept maps, notation was used to estimate the strength of connection between the model and the interview data. When an instructor statement explicitly supported a box or a link (low level of inference required) the statement number was placed on the box or link. When no instructor statement explicitly supported a box or a link, but in reading the transcript in context, the research team viewed it as reasonable to infer that such a box or link exists (high level of inference required) a dashed line or the notation “unclear” was used.

Regardless of the strength of the connection between the model and the interview data, the "real" instructor conceptions were hidden from the research team. Thus, every box or link on the concept maps required some degree of researcher inference. One factor that can weaken the empirical support of this type of interpretive study is the possibility of the researcher imposing his own expectations on the interpretation of data. That is, an individual may not be able to "see" certain patterns in the interview data. While this sort of researcher bias cannot be entirely removed, every effort was made to minimize its effects. This was done by thorough checking and verification of the developing model by the research team at various key points in the analysis process. As mentioned earlier, each member of the research team brought a different perspective to the study. It was through discussing disagreements in interpretations that many key insights into the data were made. This process of evaluation and modification led to the creation of a model with stronger empirical support than could be accomplished by a single researcher.

Rational Support: Clement (2000) describes these nonempirical criteria in terms of the clarity of the model and its external coherence. As he suggests, it is important for a model to be clearly described and comprehensible in order for it to be a useful tool for thinking about the phenomena. As discussed earlier, this is one of the reasons that concept maps were used to describe the model. Concept maps make it clear what the general features and ideas of the model are, as well as explicitly describe the relationships between these general features and ideas.

External coherence refers to the consistency between the model and accepted theories. The model generated in this study can be shown to be consistent with the results of prior studies and theoretical commitments. This external coherence is discussed in detail in Chapter 5 (p. 179).

External Viability: Clement (2000) describes external viability as the extent to which the model can be applied to contexts outside the realm of the original model. This includes such things as: generalizability, predictiveness, and fruitfulness. These are "essentially tests of a model over time, indicating whether a model leads to further productivity in the field" (Clement, 2000, p. 565). Because this study was concerned with generating an initial explanatory model in an area where little prior knowledge existed, external viability was not a goal of the study. Future studies will need to be done to determine the external viability of this model.

An Example to Clarify the Analysis Procedure

In this section, I will present an example to clarify the analysis procedure. The example will follow a piece of interview transcript from RU6 as it gets broken into statements and then put onto a concept map. Finally, it will show how this concept map for RU6 and two other instructors' concept maps were combined to form a composite concept map.

Making Statements

After the interview, the audio portion of the interview was transcribed. Figure 3-5 shows a portion of the interview with RU6. This portion of the interview primarily informed Map 1 (Some College Students, Figure 3-9, p. 99), which contains qualities of students that the instructor explicitly relates to success or failure in learning how to solve physics problems. Table 3-3 shows how this transcript was broken into statements. Recall that statements were created to inform one of the seven question categories (see p. 79), or when the interview text could not be understood, the text was left "as is". The column labeled "Question Category" indicates what question category the statement informs or "NU" for parts of the transcript that were not understandable. The column labeled "Used?" indicates whether the statement was used in one of the concept maps ("x") or whether it was excluded for being vague ("V"), not relevant ("NR"), or not understandable ("NU"). The final column labeled "Where?" indicates what map(s) were informed by the statement.

Creating an Individual Concept Map

Figure 3-6 shows the complete Map 1 for RU6, which contains information from the statements from the example portion of the interview and other statements from other places in the interview. In each box on the concept map and on each link is the statement number that provides support for that particular idea. Thus, it is possible to track the ideas on the concept map back through the statements to the original transcript. Having the statement numbers on the individual concept maps also makes it easy to gauge the relative strength of a particular idea. It is clear how many statements provide evidence for a particular idea and also, since the statements were numbered sequentially in the interview, how far apart the statements are. If the statement numbers are very close to one-another it is likely that the idea comes from only one train of thought by the instructor. If, on the other hand, the statement numbers are far apart, it is likely that the instructor has referred to this idea in more than one time during the interview.

Figure 3-5: A piece of the interview transcript from interview situation IV, question #7. CH is interviewing RU6.

320: (CH) *Ok. I want to talk about two different kinds of students. And looking at your chart (of student improvement in each of the categories of problem solving between the beginning and the end of the course) there's students that come in knowing stuff, which is great. But there are also a lot of students who don't come in being able to handle these areas. And of those students that come in without being able to handle them, some of the students get better and some of the students don't. So I'm wondering what the difference between those two types of students is -- the students who improve during the class and the students that don't.*

322: (RU6) Well, I mean, there's certainly a lot of categories. First of all, there's the ones that just don't care, that aren't gonna get any better. And of course, there's the other extreme, the people that really have the intelligence and motivation to look into these things. I think problem solving in general is something that some people find fun, and some others don't. I mean, some people like going through, and I think probably most physicists are in it because they like doing it. And so I think the people that enjoy a challenge, that enjoy the idea of working these things out, and coming up with knowledge that they didn't have before. I mean, I think that's the sort of sense of wonder sort of thing. I think on the negative end of things there's a lot of people that just think all this stuff is just totally beyond them, they'll never be able to do it. And therefore they're not going to try. I think some people have a sort of feeling that if they're not going to be good at it, why worry about it. It's not going to be important for them. Here are these things about…there was a newspaper article that [name?] used to have on his office a long, long time ago, which was some columnist saying, "why do we have to know algebra anyway? I never see any want ads for an algebra-doer!" or things like that. So some people, they have a tendency to disparage what they can't do. And so they won't care about it. I think that's the biggest problem with teaching these big general courses, is you get that bigger fraction that just don't care.

324: (CH) *So that sounds like sort of a general attitude of some students who are going to come to class and not care, and there's nothing you can do about them. What about…I imagine that the students that do care, some of them might do different things during the course to be more successful than others. What could account for that?*

326: (RU6) Well, I think time. I think every student has the impression that their professor thinks their class is the only one and that they should spend their whole life on it. And I think some students do have legitimate problems with maybe having a job or other things like that, or they just don't have the time. And of course there are some that just don't have the ability too. I don't know at what point this gets ingrained, but it seems before we get them in college, they've either decided they know how to do math or they don't. And maybe they haven't had the background. Of course now they have to take all these tests, so you won't hear them complaining about that.

328: (CH) *Do you mean to say that there are those that really could do it but they think that they can't? Is that what you meant?*

330: (RU6) Well, maybe they could. I mean, there are skill differences and makeup differences. I think there are people that are just not ever going to be able to do math properly. And so I wouldn't discount just the native skills and intelligence from genetics or early background where a lot of these things are developed. So I think there's that. And these are tied together, though. Because I think people want to succeed, they want to perceive themselves as successful, and so if they're not good at things, or if they perceive themselves as not good at things, then they're not willing to spend the effort on it. And again, I think the idea that they're all taking 3 or 4 other classes is important here too. Because it seems pretty much human nature to put your effort into the things that you find satisfying and you go on that.

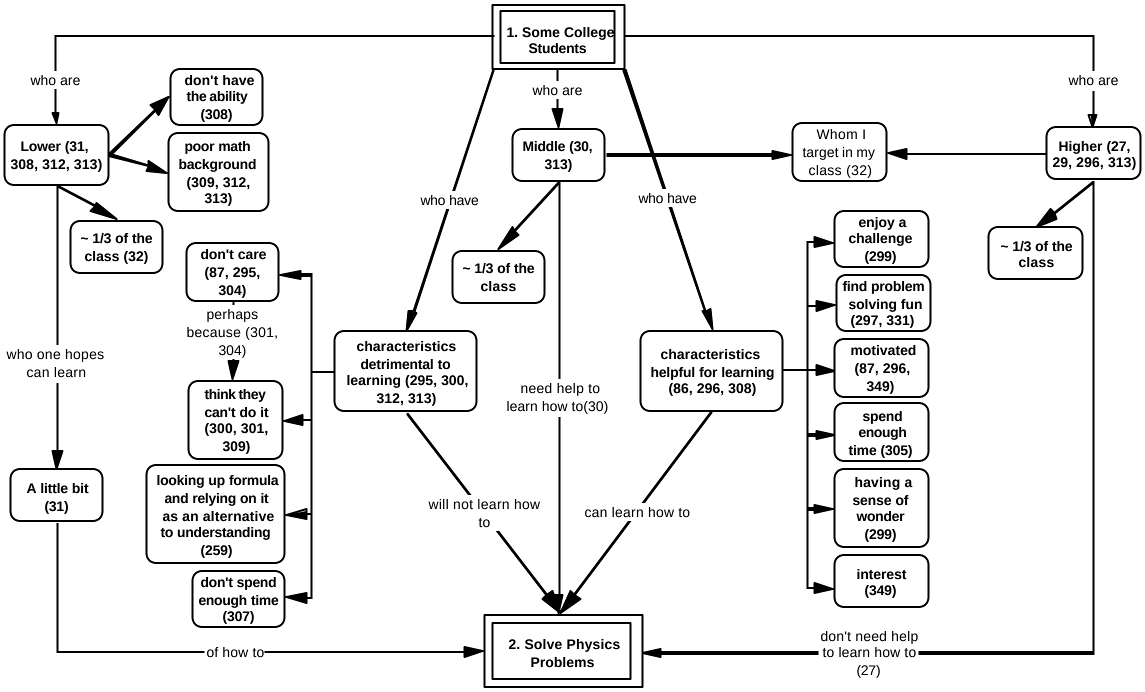
Table 3-3: Statements made from a piece of the interview transcript from RU6.

Paragraph #	Statement #	Statement	Question Cateogry	Used?	Where?
322	294	Well, I mean, there's certainly a lot of categories.	NU	V	N/A
322	295	First of all, there's the students that just don't care, that aren't gonna get any better.	3	x	Map 1
322	296	And of course, there's the other extreme (as opposed to students who just don't care), the people that really have the intelligence and motivation to look into these things.	3	x	Map 1
322	297	I think problem solving in general is something that some people find fun, and some others don't.	3	x	Map 1
322	298	(I think problem solving in general is something that some people find fun, and some others don't.) I mean, some people like going through, and I think probably most physicists are in it because they like doing it.	4	NR (this study is not concerned with why people go into physics)	N/A
322	299	(I think problem solving in general is something that some people find fun, and some others don't.) And so I think the people that enjoy a challenge, that enjoy the idea of working these things out, and coming up with knowledge that they didn't have before. I mean, I think that's the sort of sense of wonder sort of thing.	3	x	Map 1
322	300	I think on the negative end of things there's a lot of students that just think all this stuff is just totally beyond them, they'll never be able to do it.	3	x	Map 1
322	301	(I think on the negative end of things there's a lot of people that just think all this stuff is just totally beyond them, they'll never be able to do it.) And therefore they're not going to try. I think some people have a sort of feeling that if they're not going to be good at it, why worry about it. It's not going to be important for them.	3	x	Map 1 Map 3
322	302	Here are these things about…	NU	NU	N/A
322	303	There was a newspaper article that [name?] used to have on his office a long, long time ago, which was some columnist saying, "why do we have to know algebra anyway? I never see any want ads for an algebra-doer!" or things like that.	NU	NR (it's not clear why he is giving this example here or what it relates to)	N/A
322	304	So some people, they have a tendency to disparage what they can't do. And so they won't care about it. I think that's the biggest problem with teaching these big general courses, is you get that bigger fraction that just don't care.	3	x	Map 1 Map 3

Table 3-3 (continued): Statements made from a piece of the interview transcript from RU6.

Paragraph #	Statement #	Statement	Question Cateogry	Used?	Where?
326	305	Well, I think time (is one factor that accounts for some students being more successful than others).	3	x	Map 1
326	306	(Time is one factor that accounts for some students being more successful than others). I think every student has the impression that their professor thinks their class is the only one and that they should spend their whole life on it.	3	x	Map 3
326	307	(Time is one factor that accounts for some students being more successful than others). I think some students do have legitimate problems with maybe having a job or other things like that, or they just don't have the time.	3	x	Map 3
326	308	(Time is one factor that accounts for some students being more successful than others). And of course there are some that just don't have the ability too.	3	x	Map 1
326	309	I don't know at what point this gets ingrained, but it seems before we get them in college, they've either decided they know how to do math or they don't. And maybe they haven't had the background.	3	x	Map1
326	310	Of course now they have to take all these tests, so you won't hear them complaining about that.	NU	NU	N/A
330	311	Well, maybe they could.	NU	NU	N/A
330	312	I mean, there are skill differences and makeup differences (in math ability). I think there are people that are just not ever going to be able to do math properly.	3	x	Map 1
330	313	I wouldn't discount just the native skills and intelligence from genetics or early background where a lot of these things (like math ability) are developed.	3	x	Map 1
330	314	And these are tied together, though. Because	NU	NU	N/A
330	315	I think people want to succeed, they want to perceive themselves as successful, and so if they're not good at things, or if they perceive themselves as not good at things, then they're not willing to spend the effort on it.	3	x	Map 3
330	316	I think the idea that students are all taking 3 or 4 other classes is important here too. Because it seems pretty much human nature to put your effort into the things that you find satisfying and you go on that.	3	x	Map 3

Figure 3-6: RU6 Individual Map 1 (Some College Students)



Combining Concept Maps

Figure 3-6 shows the individual Map 1 for RU6. In a similar way, individual maps were constructed for all of the instructors. The individual Map 1 for RU3 and RU4 are shown in Figure 3-7 and Figure 3-8 respectively. These individual maps, along with the individual maps from the other three instructors, were combined to get the composite Map 1 shown in Figure 3-9. Note that in combining the concept maps the goal was to combine individual instructor ideas when they seemed to have the same conception and to leave the ideas separate when they seemed to have different conceptions. The wording used on the composite concept maps is the wording that the research team believes can convey the instructor conceptions most accurately and most compactly.

As an example of this process, consider the path to the left of the "Some College Students" box on each of the individual concept maps. RU6 (see Figure 3-6) describes a group of students that he calls "lower" who "don't have the ability", have "poor math background" and who he hopes can learn "a little bit" about how to solve physics problems. RU3 (see Figure 3-7) describes a group of students that he calls “hopeless” whom the instructor cannot influence. RU4 (see Figure 3-8) describes a group of students that he calls “hopeless” who lack intrinsic talent and will not learn how to solve physics problems. These three instructors all seemed to be describing the same thing – that there is a group of students in their class who lack some sort of natural ability and who won’t learn how to solve physics problems. This led to the creation of the path to the left of the “Some College Students” box on the composite map (see Figure 3-9). Notice that in the “not enough natural ability” box on the composite map that RU3 is shown as “unclear”. This is because on the individual map for RU3 (see Figure 3-7), it is implied, but not explicitly stated that these students who are “hopeless” are hopeless because of a lack of natural ability rather than some other cause. RU2, RU4, and RU6 explicitly identify the lack of natural ability as the reason that these students will not learn how to solve physics problems.

As discussed earlier, the composite concept maps were initially created by Charles Henderson and then evaluated by all of the members of the research team. The research team then discussed the maps and decided what modifications should be made.

Figure 3-7: RU3 Individual Map 1 (Some College Students)

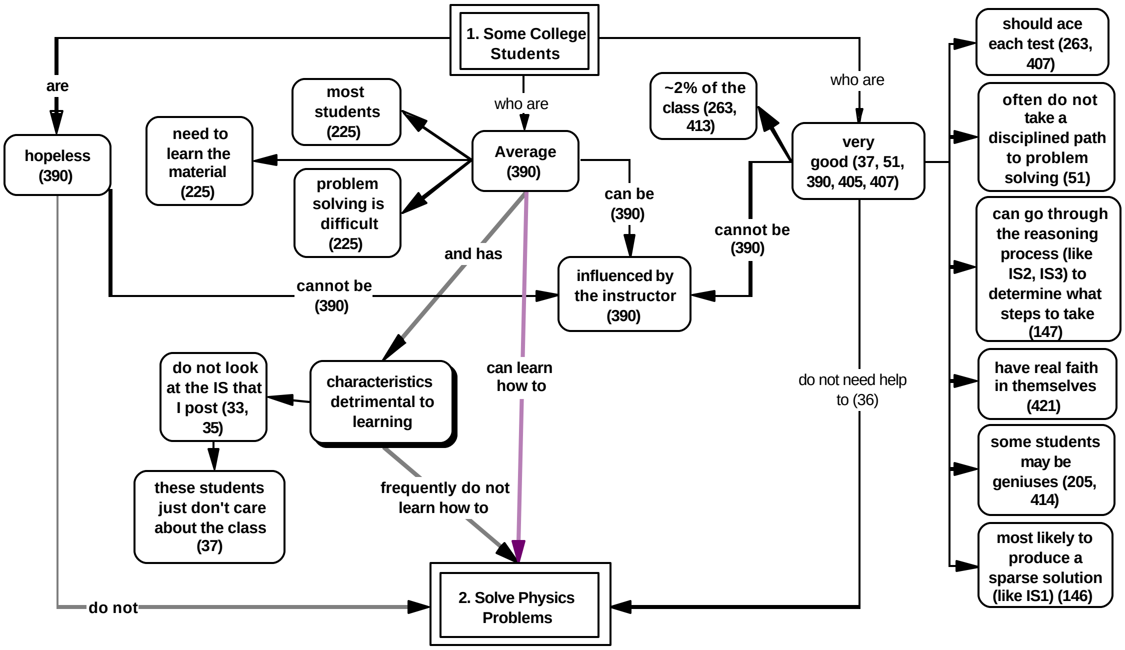


Figure 3-8: RU4 Individual Map 1 (Some College Students)

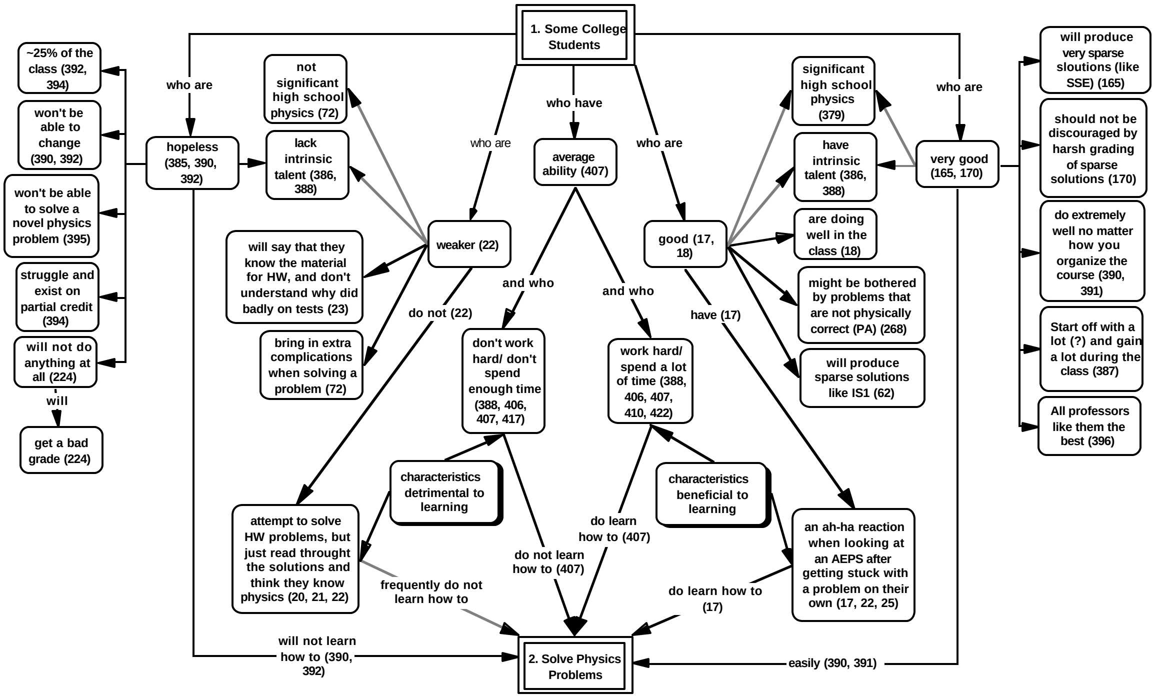
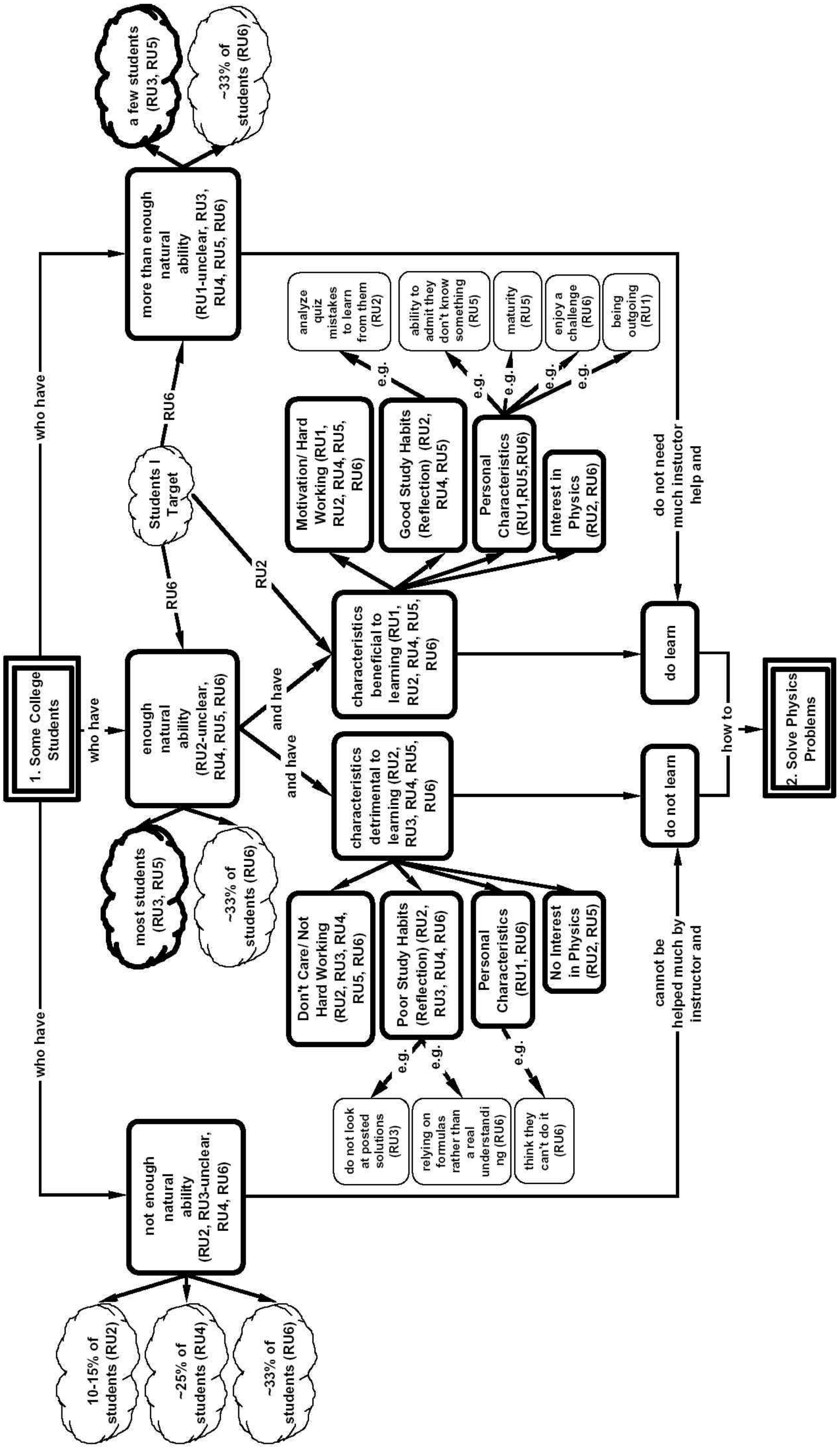


Figure 3-9: Composite Map 1 (Some College Students)



Summary

This study was a phenomenographic study involving six physics instructors from the University of Minnesota who had recently taught the introductory calculus-based physics course. The interview was designed around three types of concrete instructional artifacts that were all based on a single introductory physics problem and included both general questions about teaching and learning in introductory calculus-based physics and questions relating to a particular instructional artifact or teaching situation.

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. These concept maps were organized around a main map that contained the general features and a set of feature maps that provided further explanation of each of these general features. Once this task had been completed for each instructor, the individual concept maps were combined to form composite concept maps. These composite maps then represented the range of ideas expressed by the six instructors. Finally, based on the composite maps, a set of qualitatively different ways that these instructors think about each general feature was developed. The concept maps provide a detailed, visual model of how these instructors conceive of the phenomena of the teaching and learning of problem solving in introductory calculus-based physics. The list of qualitatively different ways of viewing each general feature provides a more general understanding of how these instructors conceive the phenomena.

CHAPTER 4: RESULTS AND CONCLUSIONS

The goal of this study is to generate an initial explanatory model of the conceptions that physics faculty have about the teaching and learning of problem solving in introductory calculus-based physics. This model is described by a set of concept maps that were designed to show the type and range of conceptions held by the six instructors that were interviewed. As discussed in Chapter 3, the main goal of this study is not to understand these six instructors in great detail (although, it could be argued that this was done), rather the goal is to describe the range and nature of the conceptions that these six instructors expressed and to begin the process of developing a model of faculty conceptions about the teaching and learning of problem solving in introductory calculus-based physics.

This chapter will present each of the concept maps, one at a time, along with a discussion of what types of information are included on the map. A written description of each map will also be included that highlights the important features of the map.

Concept Maps

As discussed in Chapter 3 (p. 82), concept maps were developed by Novak and Gowin (1984) as a way to model student conceptions about physical phenomena. Concept maps consist of a collection of boxes that contain words describing a particular concept and arrows linking these boxes that contain words describing the relationship between the boxes. Ideally, a particular path on a concept map can be read like a sentence by reading the words in the boxes and on the links of a particular path. Sometimes, because several different links may be made to a single box, the verb tense or other features of a sentence may not always follow the grammatical rules of the English language. Nonetheless, the meaning of the sentence should still remain evident.

The other feature of a good concept map is that the organization of the map provides information to the reader without requiring that any of the specific boxes or links be read. The kind of information that can be found in the organization of a concept map includes things such as how many different ways faculty view the relevant feature; and which boxes are of primary importance and which boxes contain minor details.

Concept Map Symbols

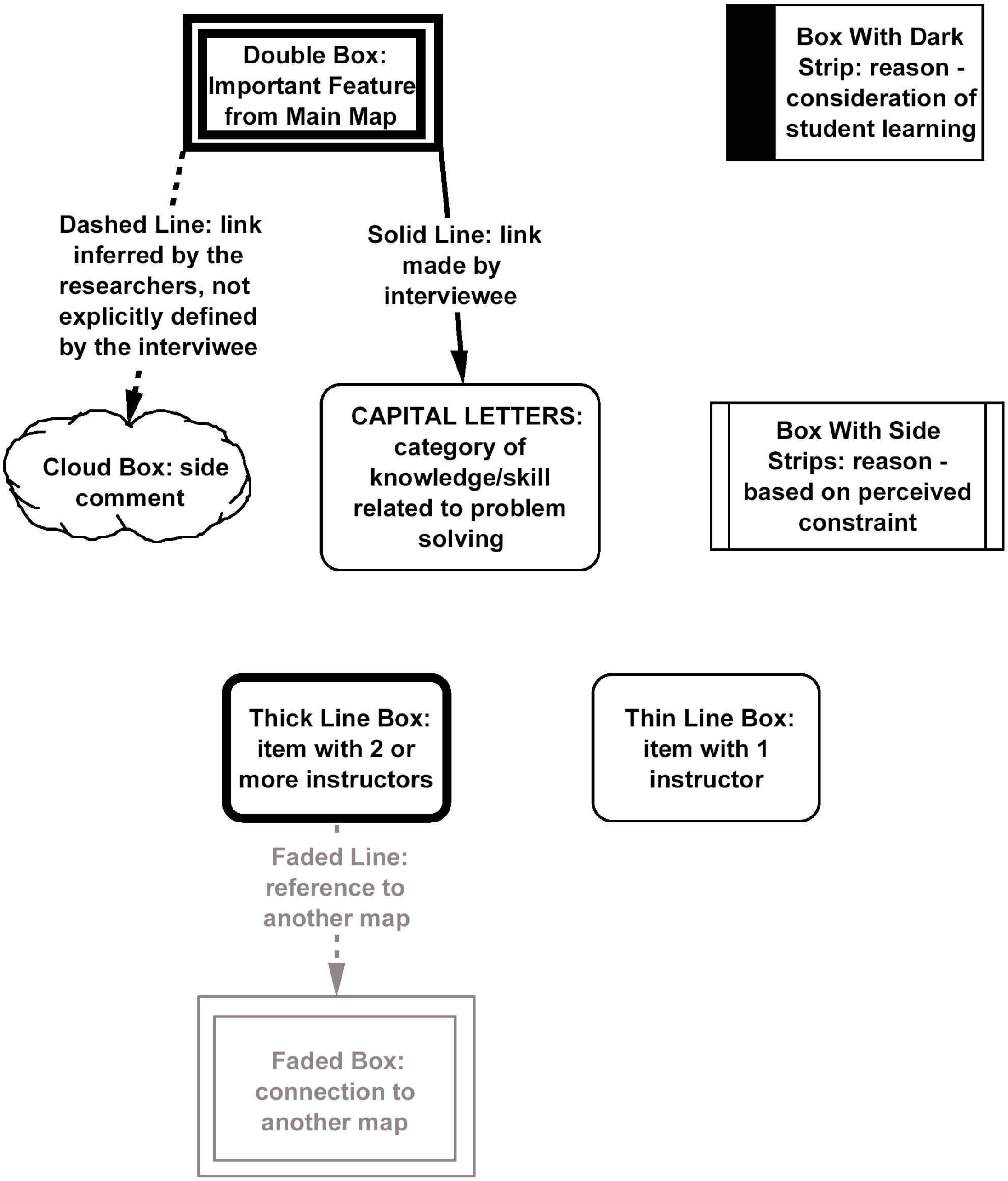
There are several different types of boxes and links that are used in the concept maps. These are designed to assist in the readability of the maps and also to differentiate between ideas and links that can be clearly attributed to the instructors and those that are imposed or inferred by the research team. The key to these symbols is presented in Figure 4-1 and the different symbols are briefly described below:

- **Double Box:** The double box contains an important feature from the Main Map that is elaborated in a feature map. Each important feature is numbered for easy reference.
- **Dashed Line:** The dashed line connects two boxes when no explicit instructor statement was made to support the link, but in reading the transcript in context, the research team viewed it as reasonable to make the inference that such a link exists (i.e. a higher level of researcher inference was used).
- **Solid Line:** The solid line connects two boxes when one or more explicit instructor statements were made to support the link (i.e. a lower level of researcher inference was used).
- **Capital Letters:** Capital letters are used to refer to categories of knowledge/skill related to problem solving. The four categories: PHYSICS CONCEPTS, APPROACH TO SOLVING A PROBLEM, SPECIFIC TECHNIQUES, and PERFORMANCE MONITORING, were based on the categorization of cards by the instructors in the fourth part of the interview. Chapter 3 (p. 87) contains more details about how this was done and what the categories mean.
- **Box With Side Strips:** A box with side strips identifies instructor reasons that are based on perceived constraints.

- **Box With Dark Strip:** A box with dark strip identifies instructor reasons that are based on considerations of student learning.
- **Faded Line** and **Faded Box:** A faded box connected by a faded line indicates a reference to another map.
- **Cloud Box:** A cloud box indicates an instructor idea or interviewer comment that is not considered to be a part of the map, but that adds some additional information that is interesting or potentially useful in interpreting the map.
- **Thick Line Box:** The thick line box represents an idea that was expressed by two or more of the six instructors interviewed. It was assumed that while an idea held by only one instructor *may* be idiosyncratic and thus not of interest for this study, an idea held by more than one instructor was likely an idea that would be found in some reasonable percentage of a larger sample of instructors (i.e. thick line boxes have a higher viability in the model).
- **Thin Line Box:** The thin line box represents an idea that was expressed by only one of the six instructors interviewed. As discussed above, this idea may be idiosyncratic to this individual instructor (i.e. thin line boxes have a lower viability in the model). These boxes remain on the maps, however, because with such a small sample, an idea expressed by only one instructor could become an important part of the explanatory model when tested with a larger sample of instructors. Also, as discussed in Chapter 3, due to the exploratory nature of the interview it was not expected that each instructor would express his complete conceptualization of an idea. Thus, in some cases these thin line boxes may represent different aspects of the same idea as expressed by different instructors.

In order to allow the reader to be able to make his own judgment of the level of empirical support for each part of the explanatory model, each box contains information about which instructors expressed that particular idea during the interview. The notation "RU1" for instructor 1, "RU2" for instructor 2, etc. is used to indicate that an idea is well supported by at least one explicit instructor statement (i.e. a lower level of researcher inference was used). The notation "RU1-unclear" is used to indicate that an idea is not well supported by at least one explicit instructor statement, but that in reading the transcript in context it is reasonable to make the inference that such a link exists (i.e. a higher level of researcher inference). Links are only labeled with instructor identifiers when necessary to avoid confusion. An instructor identifier of “unclear” on a link means the same thing as a dashed line and is used when the link is “clear” for some instructors and “unclear” for others.

Figure 4-1: Concept Map Symbols



Main Map

The first research question relates to the most general level of the model that was identified in this study:

1. What are the general features of a viable explanatory model of the conceptions that a small sample of university faculty has about the phenomena of the teaching and learning of problem solving in introductory calculus-based physics, and how are these general features related?

The Main Map (shown in Figure 4-2, p. 109) contains these general features. Each of these general features will be discussed in more detail later. There are, however, several important characteristics of the Main Map that will be discussed here.

Who Can Learn?

Instructors think that only some college students (not all college students) learn how to solve physics problems while taking their class. As discussed in more detail later, all of the instructors had the conception that a lack of natural ability or having characteristics detrimental to learning can prevent a student from learning how to solve physics problems.

Student Engagement in Learning Activities

Students learn how to solve physics problems by engaging in learning activities and their ability to engage in learning activities is affected by their current state of learning characteristics and knowledge/skill related to problem solving.

Instructors have three qualitatively different types of learning activities that students can engage in to learn how to solve physics problems: Working on problems (Path A), Using feedback while/after working on problems (Path B), and Looking/listening (Path C). Five instructors have all three conceptions. One instructor has only conceptions of Path A and Path B.

1. ***Working on Problems*** **(Path A).** Students can learn how to solve physics problems by working on appropriate problems. According to this conception,

working on a lot of problems, often called practicing, can lead to the development of certain aspects of the appropriate knowledge. In this learning activity, no feedback is required in order for learning to take place. The learning takes place solely because of the working itself. All instructors have this conception.

2. ***Using Feedback While/After Working on Problems*** **(Path B).** Students can learn how to solve physics problems by using feedback while/after working on appropriate problems. According to this conception, the use of feedback can lead to the development of certain aspects of the appropriate knowledge. Feedback can be used by students while working on an appropriate problem (i.e. coaching) or after working on an appropriate problem (e.g. delayed feedback in the form of grades on a written problem solution, which are individualized responses; or appropriate example solutions that show how the problem could be solved). Although working on problems is important, the learning takes place through the use of feedback. The working is only necessary to produce something upon which feedback can be provided. All instructors have this conception.

3. ***Looking/Listening*** **(Path C).** Students can learn how to solve physics problems by looking at appropriate example solutions or listening to lectures. According to this conception, looking and/or listening to a presentation of an appropriate example solution (e.g. the instructor working a problem on the board during class) or to a discussion of problem solving techniques or strategies (e.g. the instructor discussing how to draw a free body diagram) can lead to the development of certain aspects of the appropriate knowledge. Five of the instructors have this conception.

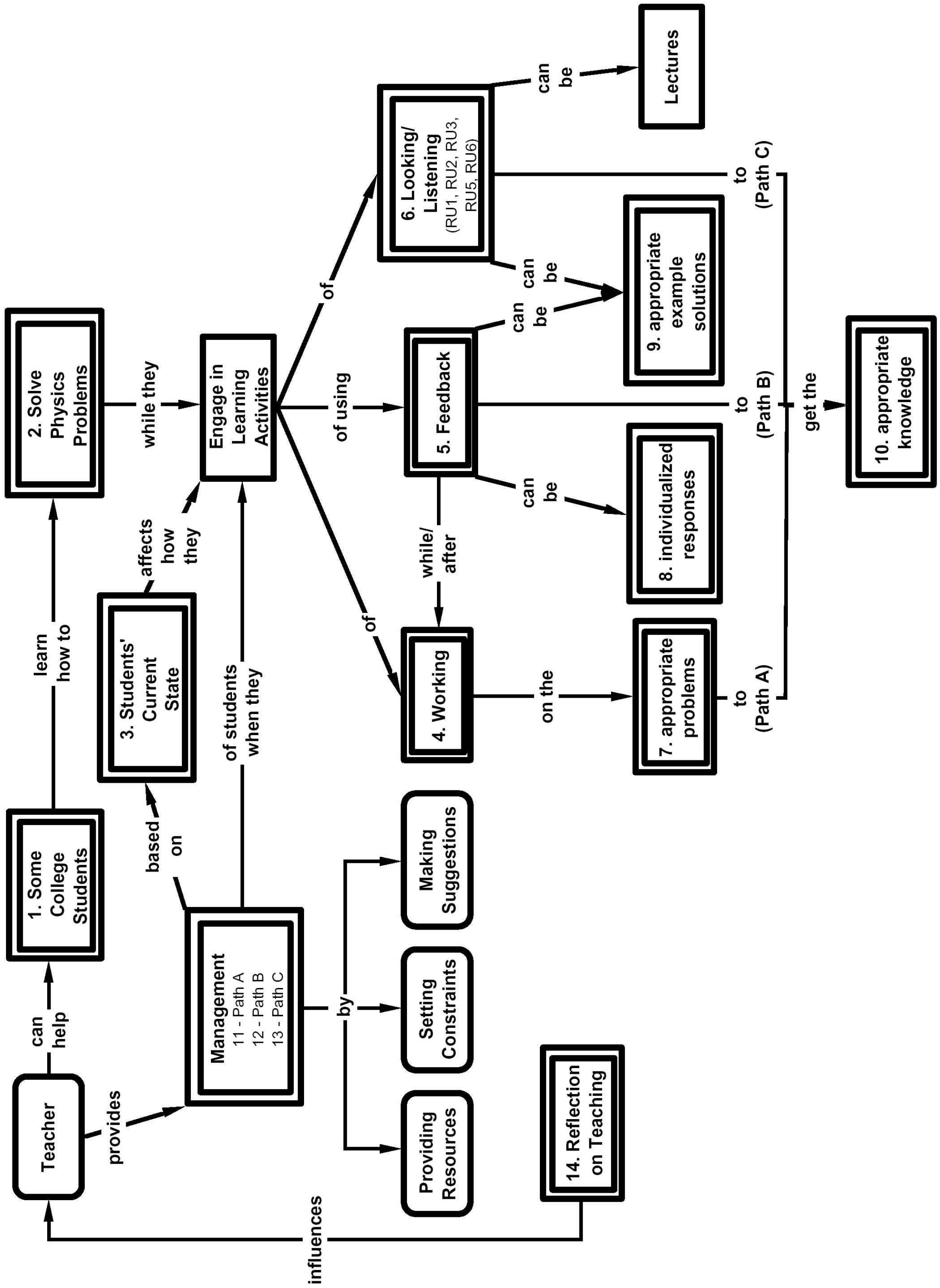
Instructor Management

Instructors see their role as managing the students while they are engaged in learning activities. In making management decisions, instructors often mentioned considering the students' current state (e.g. how likely the students in a class are to understand a particular explanation based on their current knowledge of physics). All of the instructors, on occasion, also reflected on their teaching situation or management decisions that they had made in the past. These reflections often had an influence on their current management decisions.

Instructors have three qualitatively different ways that they manage students' engagement in learning activities: Providing resources, setting constraints, and making suggestions. All instructors have all three conceptions.

1. ***Providing Resources.*** Management involves providing resources for students to use while they engage in learning activities. Common types of resources provided include appropriate problems, individualized responses, appropriate example solutions, and lectures.
2. ***Setting Constraints.*** Management involves setting constraints that encourage/require students to do certain things that the instructor thinks would be helpful for them to do when learning how to solve physics problems. Setting a constraint does not usually force a student to engage in a particular activity, but makes it difficult or awkward for the student not to. Instructors set constraints when they do things like collect student problem solutions or allocate class time for students to work in small groups.
3. ***Making Suggestions.*** Management involves suggesting that students do certain things that the instructor believes would be helpful for them to do when learning how to solve physics problems. For example, many of the instructors interviewed did not collect homework problems, but rather suggested that students try to work certain problems on their own. Instructors also described making suggestions about what students should do to succeed in the course (e.g. compare their test solutions to the appropriate example solutions). Many instructors said that they did not think the students in their class frequently followed these suggestions.

Figure 4-2: Main Map



Feature Maps

The second research question relates to understanding more details about the general features of the explanatory model:

2. For each of the general features of the explanatory model:

    a. Generate an explanatory model of the conceptions (the ideas and the relationships between ideas) that are used by these faculty to understand this general feature.

    b. Generate a small set of qualitatively different ways that these faculty make sense of each of these general feature.

The feature maps contain these details. In this section I will present and discuss each of the 14 feature maps:

Map 1: Some College Students
Map 2: Solve Physics Problems
Map 3: Students' Current State

Learning Activities Cluster

Map 4: Student Engagement in Learning Activities of Working (Path A)
Map 5: Student Engagement in Learning Activities of Using Feedback (Path B)
Map 6: Student Engagement in Learning Activities of Looking/Listening (Path C)

Resources Cluster

Map 7: Resource of Appropriate Problems
Map 9: Resource of Appropriate Example Solutions
Map 8: Resource of Individualized Responses

Management Cluster

Map 11: Management of Students' Engagement in Learning Activities of Working (Path A)
Map 12: Management of Students' Engagement in Learning Activities of Using Feedback (Path B)
Map 13: Management of Students' Engagement in Learning Activities of Looking/Listening (Path C)

Map 10: Appropriate Knowledge
Map 14: Reflection on Teaching

Some of the feature maps are too large to fit on a single page. When this is the case, I will first present a “short” version of the feature map followed by the complete version. The short version contains fewer details than the complete version and fits on a single page. The short version is designed to show the structure of the feature map and allow the reader to find the details on the complete version.

Map 1: Some College Students

This map (shown in Figure 4-3, p. 114) contains qualities of students that the instructor explicitly relates to success or failure in learning how to solve physics problems.

All instructors view the relevant feature of Some College Students in the same way. Students' success in learning how to solve physics problems depends on their intelligence/natural ability. Even when students have enough natural ability, their success depends on other characteristics related to learning.

Natural Ability

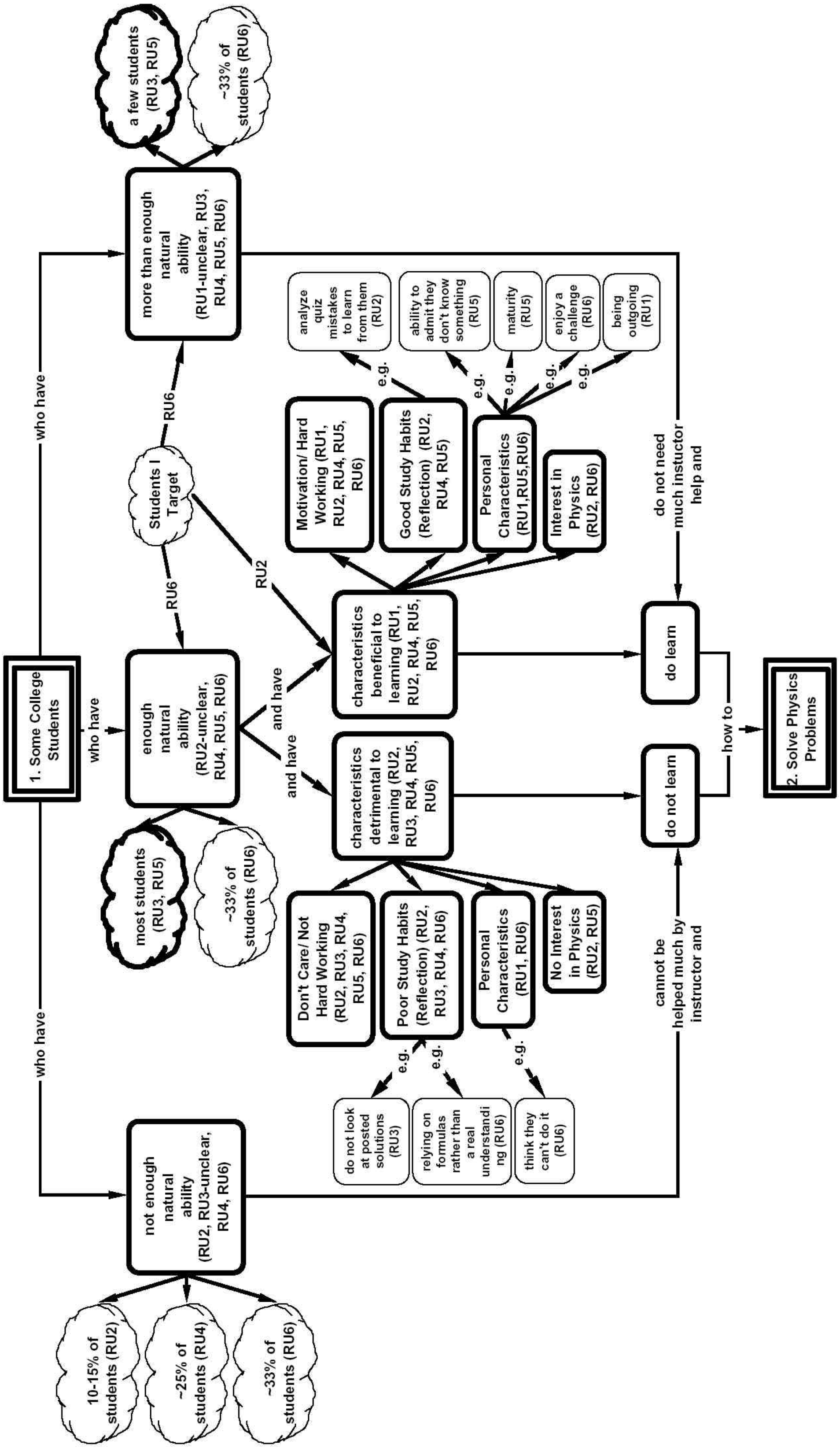
The map shows that there are two types of student characteristics that instructors use to describe whether a student will succeed or fail to learn how to solve physics problems. The first of these student characteristics is natural ability. Some students in the class do not have enough natural ability. For these students, the instructors think that there is not much that can be done to help them and that they will not learn how to solve physics problems. For example, RU4 stated: "There's a good sized share of the class that you're not going to be able to change" (RU4, statement #392). Other students in the class, however, are seen as having more than enough natural ability. Instructors believe that these students will learn how to solve physics problems regardless of what the instructor does. The third group of students is seen as having enough natural ability. For these students, whether they learn or not depends on their characteristics related to learning.

Learning Characteristics

There are some students who have beneficial learning characteristics. These students will learn how to solve physics problems. One beneficial learning characteristic is being motivated/hard working. For example, RU5 stated: "Some of the success depends on how hungry students are; how much they are willing to put themselves out for it; how motivated they are" (RU5, statement #399). Other beneficial learning characteristics include having good study habits, beneficial personal characteristics, and an interest in physics. For example, one of the personal characteristics that RU1 related to a student's success in the course was "being outgoing so they can talk to either their classmates or the teaching staff" (RU1, statement #363).

There are other students who have detrimental learning characteristics. These students will not learn how to solve physics problems. Detrimental learning characteristics include such things as not caring about the class/not being hard working, having poor study habits, detrimental personal characteristics, and no interest in physics. For example, RU3 described a poor study habit as the tendency of most students not to "actually look at the problem solutions that I post" (RU3, statement #33).

Figure 4-3: Map 1 - Some College Students



Map 2: Solve Physics Problems

This map (shown in Figure 4-4, p. 117) contains instructor conceptions about the process of solving physics problems. All six instructors have the conception that the process of solving physics problems requires using an understanding of PHYSICS CONCEPTS and SPECIFIC TECHNIQUES.

There are three qualitatively different ways that instructors characterize the problem-solving process: A linear decision-making process, a process of exploration and trial and error, and an art form that is different for each problem. Each instructor had only one conception of the problem solving process.

1. ***A linear decision-making process.*** Three of the instructors saw problem solving as a linear decision-making process where PHYSICS CONCEPTS and SPECIFIC TECHNIQUES are used in a complicated way to determine what to do next. From this point of view, problem solving involves making decisions, but the correct decision is always made. There is no need to backtrack. The three instructors with this conception of problem solving expressed varying degrees of detail about the problem-solving process. However, all of these conceptions are vague. For example, these instructors all said that an important step in the problem solving-process was deciding on the physics principles. None, however, clearly explained how this was done.

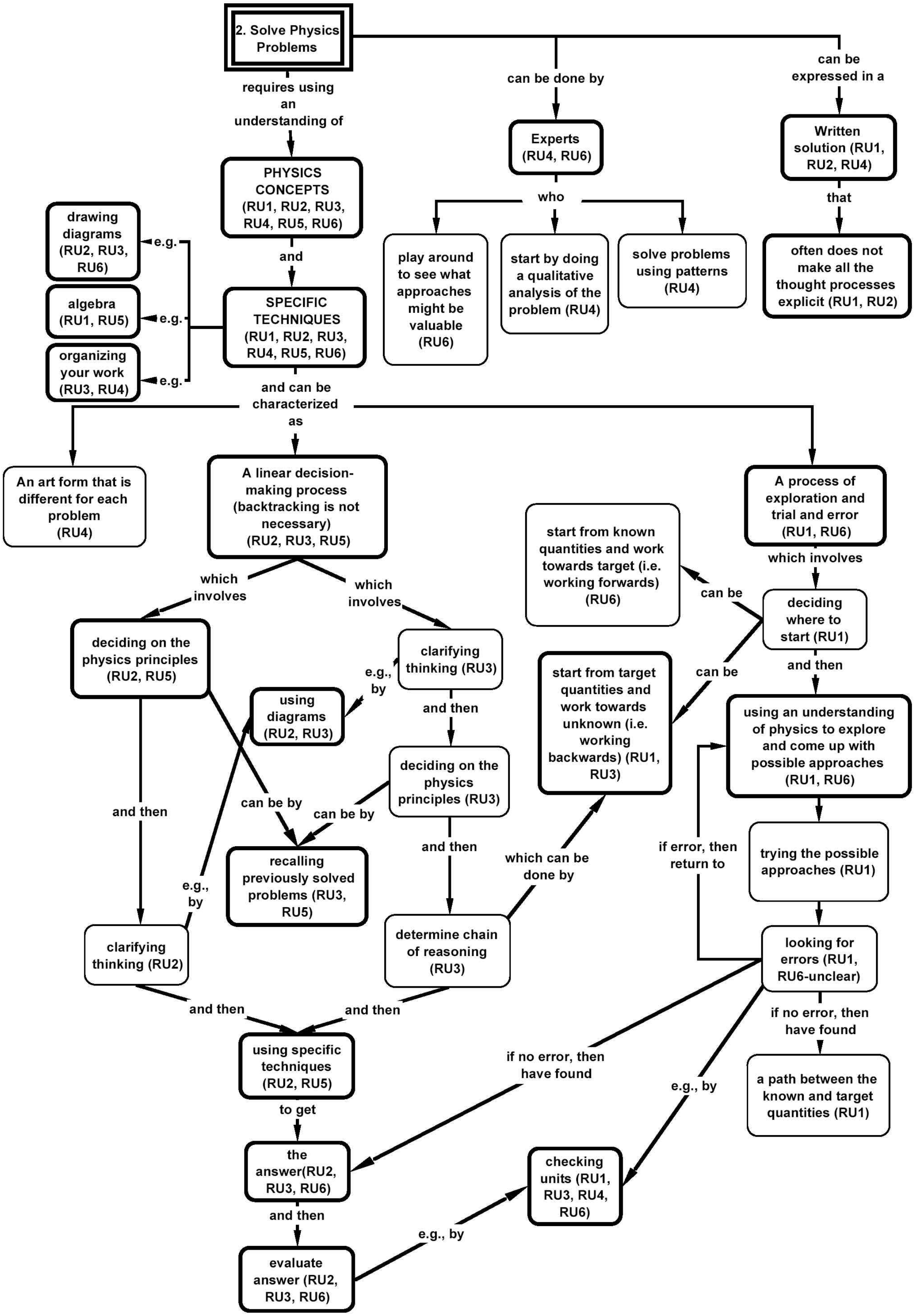
2. ***A process of exploration and trial and error.*** Two of the instructors saw problem solving as a process where an understanding of PHYSICS CONCEPTS is used to explore and come up with possible choices that are then tested. The conception is that making mistakes and having to backtrack is a natural part of problem solving. For example, RU1 said that "solving a problem is not a logical process – there's something that you have to guess and then use trial and error" (RU1, statement #27). Although these instructors were able to describe the problem solving process in more detail than those in the previous group, there were still some aspects that were not fully explained. For example, both instructors seemed unclear about how a student should come up with possible choices to try. Both

seemed to think that it involved more than random guessing from all of the concepts that had been learned in the class, but neither articulated how an understanding of PHYSICS CONCEPTS was used to come up with possible choices.

3. ***An art form that is different for each problem.*** One instructor, RU4, described the problem-solving process as artfully crafting a unique solution for each problem. He said that "solving physics problems is an art and we should think of it as an art. It does not necessarily always yield effectively to paint-by-numbers. Each physics problem has a kind of style to it, a geschtalt to it, that is it's own particular style, it's own particular situation" (RU4, statement #100, 101). He provided no details about how a student should go about doing this.

Two of the instructors explicitly distinguished between the way experts (i.e. the instructor) and students solve problems. To these instructors, experts have special approaches and/or knowledge that students do not have. In addition, three of the instructors explicitly distinguish between the solution process and the reflection of that process in a written solution. The conception is that the written solution does not accurately reflect all of the thought processes that went into solving the problem.

Figure 4-4: Map 2 - Solve Physics Problems



Map 3: Students' Current State

This map (shown in Figure 4-5, p. 120) contains instructor conceptions about the characteristics of students that are typically found in his introductory calculus-based physics classes. Unlike Map 1 (Some College Students), this map (Students' Current State) contains *all student characteristics* that instructors used to describe the students in their class. Map 1 (Some College Students) is not a subset of Map 3 because instructors would often talk about a student characteristic that was important in their success or failure in the class *without* indicating whether students in their class typically had this characteristic. For example, on Map 1, RU2 relates a student's lack success in the course to not having an interest in physics; "students may be required to take the physics course and so they reject it as much as they can" (RU2, statement #41). RU2, however did not give any indication about how many students without an interest in physics he might expect to find in a typical introductory calculus-based physics class.

All instructors view this relevant feature the same way. Students in their introductory calculus-based physics course have a mixture of beneficial, detrimental, and neutral personal characteristics related to learning, as well as poor knowledge/skills related to problem solving.

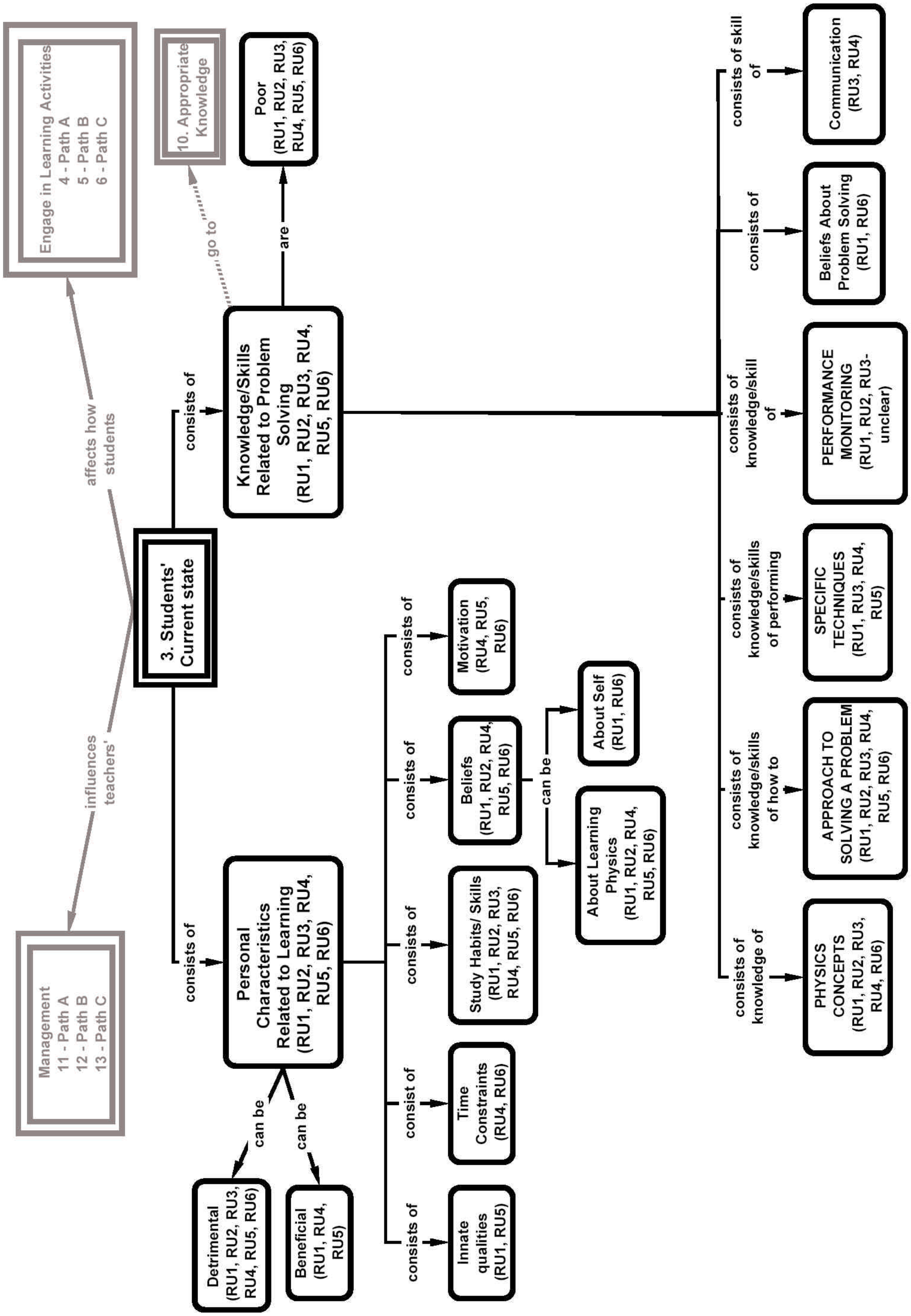
Personal Characteristics Related to Learning

All instructors mentioned study habits/skills as an important personal characteristic. Detrimental study habits/skills were mentioned by five instructors and included the conception that many students don't use instructor problem solutions appropriately. Beneficial study habits/skills were mentioned by three instructors, and included the conception that a lot of students learn how to approach certain problems by looking at the appropriate example solutions and that students tend to form study groups. Five instructors also included student beliefs about learning physics as being an important personal characteristic. These were most often seen as detrimental to learning, and included the conception that many students don't realize that physics is hard and requires a substantial amount of work. Three instructors mentioned motivation as a personal characteristic of students. The most common instructor conception about student motivation is the expectation that some students will argue about their quiz grades. All of these motivational personal characteristics were viewed by the instructors as neutral. The instructors have to be aware of the motivational characteristics when teaching, but the characteristics are neither beneficial nor detrimental by themselves. For example, the student tendency to be motivated by grades is not something that these instructors described as helping or hindering students in learning to solve physics problems. It was, however, something that these instructors realized that they had to deal with.

Knowledge/Skill Related to Problem Solving

The instructors described student knowledge/skills related to problem solving as being poor. All instructors described students as having poor knowledge/skills of how to APPROACH TO SOLVING A PROBLEM. Three instructors attributed this to students' lack of experience in solving physics problems. Five instructors described student knowledge of PHYSICS CONCEPTS as being poor. For three instructors this simply meant that students started off in the class with little physics knowledge. Four instructors described student knowledge/skill of performing SPECIFIC TECHNIQUES. All four identified SPECIFIC TECHNIQUES that they expected students to be poor at, but two also described SPECIFIC TECHNIQUES that they expected students to be good at. Although these instructors teach the same population of students, RU1 describes student algebra skills as poor and RU4 describes student algebra skills as good.

Figure 4-5: Map 3 (short) - Students' Current State



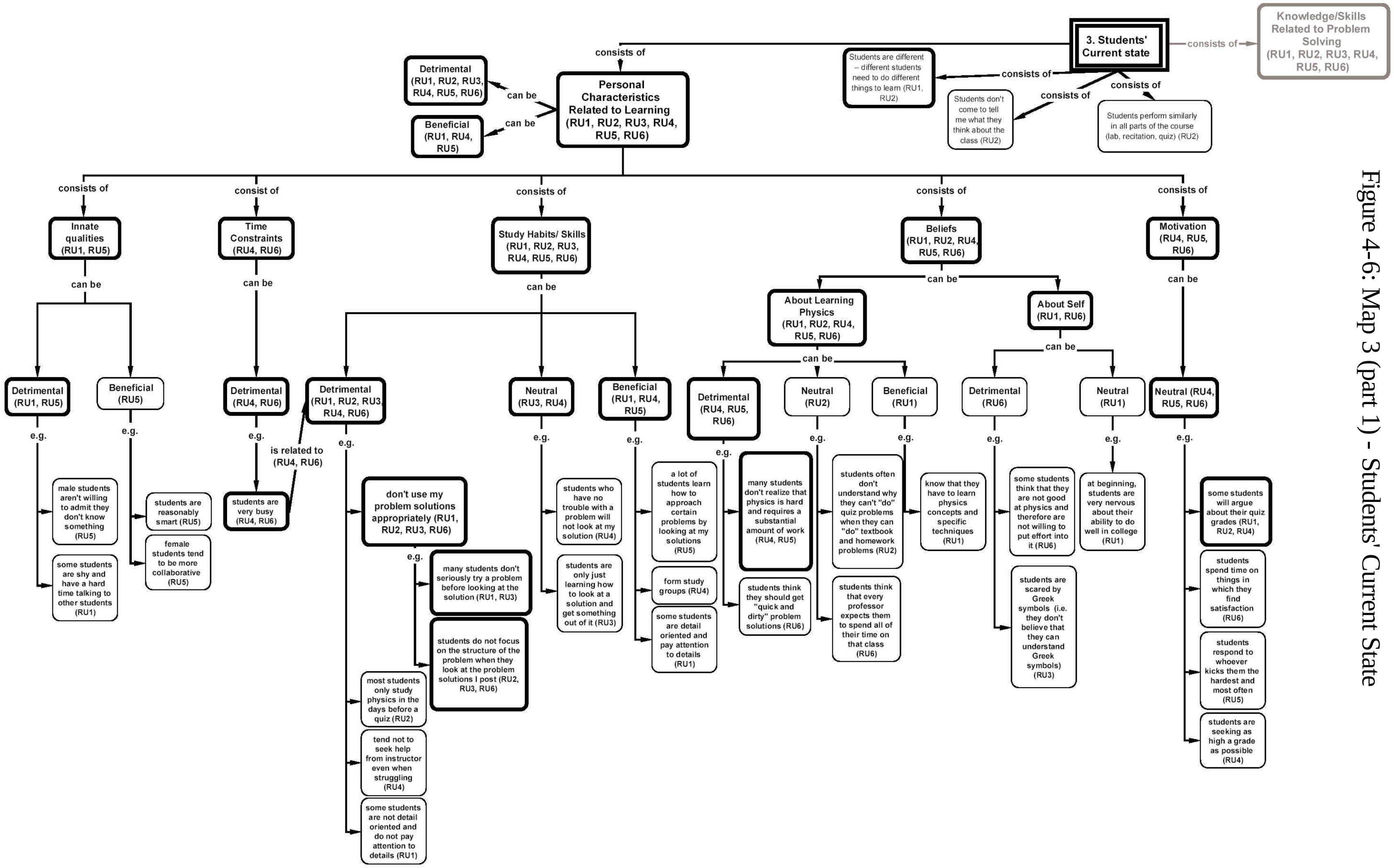
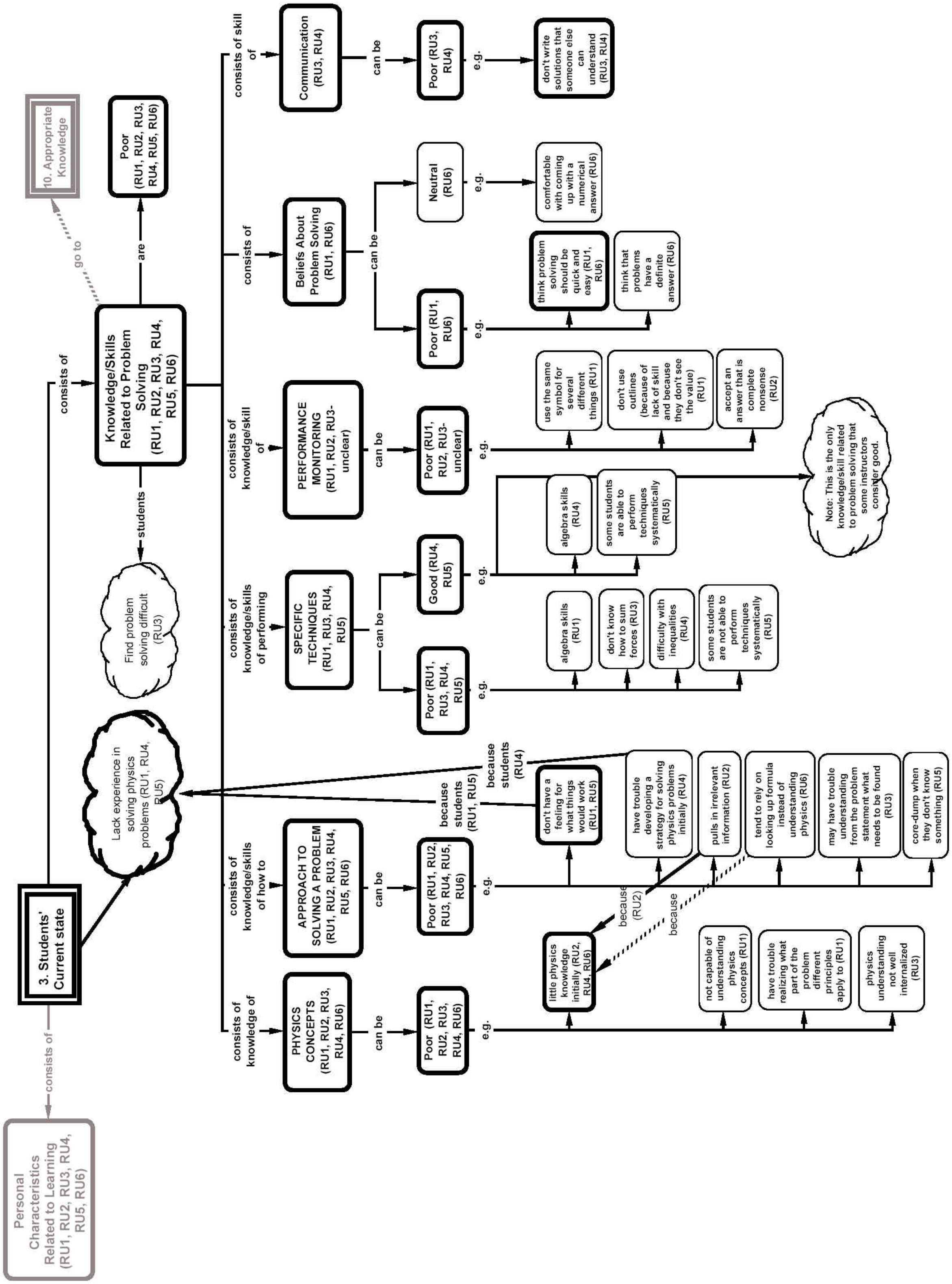


Figure 4-6: Map 3 (part 1) - Students' Current State

Figure 4-7: Map 3 (part 2) - Students' Current State



Learning Activities Cluster

As described for the Main Map (p. 106), five instructors conceptualize three distinct ways that students can learn how to solve physics problems: by working on problems (Path A) to get the appropriate knowledge, by using feedback while/after working on problems (Path B) to get the appropriate knowledge, or by looking/listening (Path C) to get the appropriate knowledge. One instructor has only conceptions of Path A and Path B. Each of these learning activities maps describe instructor conceptions of what students should do to learn how to solve physics problems. In describing these learning activities, the instructors never described any concrete mechanism by which these activities would help students learn how to solve physics problems. Thus, the term "to get" was used to describe how the instructors conceptualize the connection between the learning activities and the appropriate knowledge (see Appropriate Knowledge Map, p. 167). The research team was not able to develop a model of how the instructors conceptualize this connection. This may be because of limitations in the interview or the analysis. It may also be because instructors only have a vague conceptualization of this connection and the use of "to get" accurately reflects this vagueness.

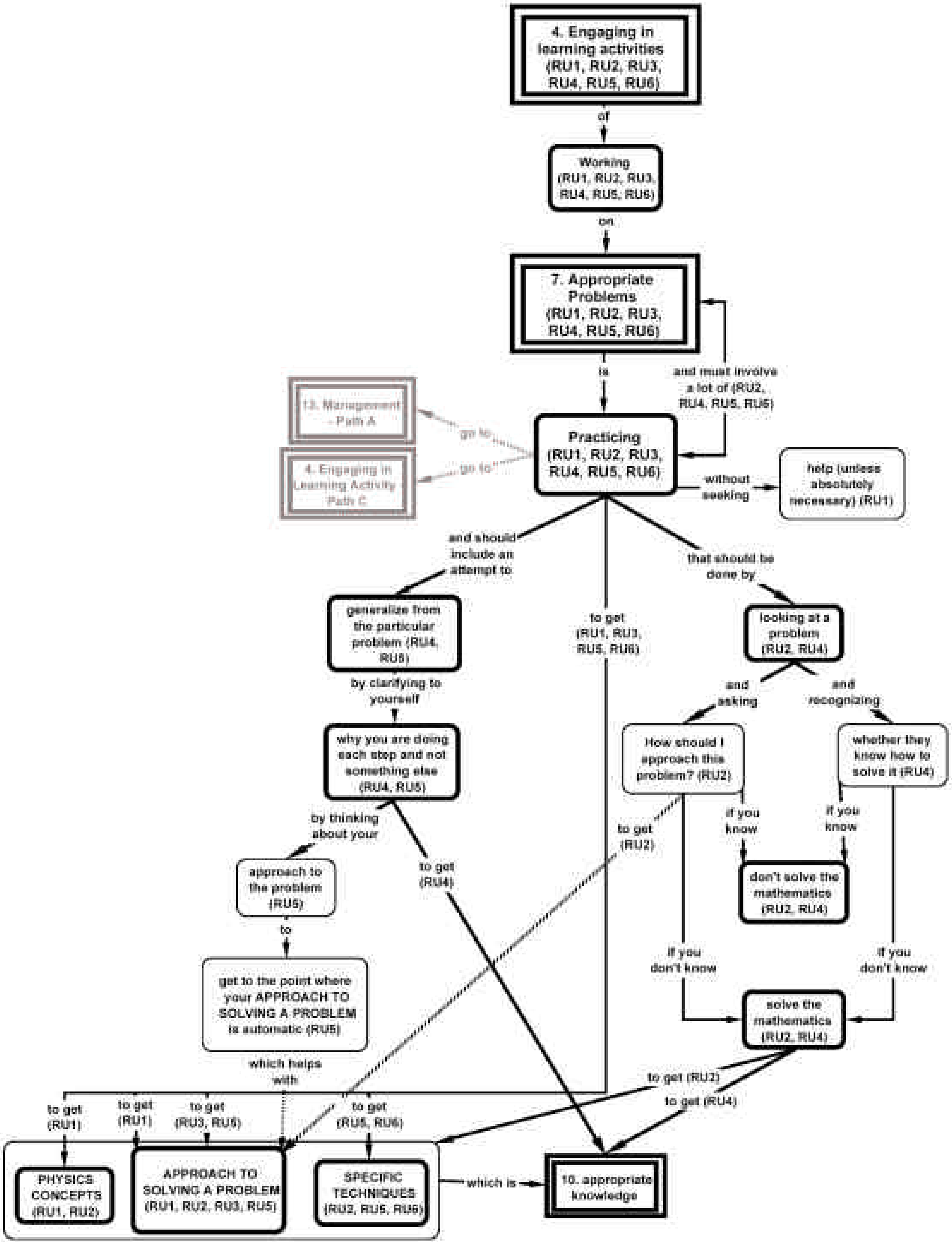
Map 4: Student Engagement in Learning Activities of Working (Path A)

This map (shown in Figure 4-8, p. 125) contains instructor conceptions about what students should do to learn how to solve physics problems by working on appropriate problems to get the appropriate knowledge. The defining feature of this path is that learning takes place solely because of the student activity of working on problems. No external feedback is required.

All instructors view this relevant feature the same way. Students can learn how to solve physics problems by working on appropriate problems.

This working on appropriate problems is frequently referred to as practicing. Three of the instructors did not provide any information about practicing except that it can be helpful for students to do in order to get certain types of appropriate knowledge. For example, RU3 said, "I think that it [APPROACH TO SOLVING A PROBLEM] is built by practice – the students will obtain it by practice” (RU3, statement #382). The other three instructors provided more information about practicing. Two instructors suggested that the goal of practicing is to generalize certain aspects of the appropriate knowledge from the particular problem that the student is working on. They suggested that this can be done by the student who is working on an appropriate problem by clarifying to himself why he is doing each step and not something else. Two instructors also described a strategy for selecting appropriate problems to solve. According to these instructors, a student should ask himself whether they know how to solve a particular problem. If they already know how to solve it, then there is no reason to write out a solution. It was unclear to the research team whether RU2 was only describing a method for selecting appropriate problems to solve or whether he was also suggesting that a student can get some of the knowledge/skills of the APPROACH TO SOLVING A PROBLEM through the act of asking himself whether he knows how to approach a particular problem.

Figure 4-8: Map 4 – Student Engagement of Learning Activities of Working (Path A)



Map 5: Student Engagement in Learning Activities of Using Feedback (Path B)

This map (shown in Figure 4-9, p. 128) contains instructor conceptions about what students should do to learn how to solve physics problems by using feedback while/after attempting to solve an appropriate problem. The defining feature of this path is that the learning takes place directly from the feedback. Working on problems is important only because it produces something upon which feedback can be provided.

There are two qualitatively different ways that instructors think students can use feedback to learn how to solve physics problems: using delayed feedback and using real-time feedback Four instructors had both conceptions and two instructors had only the conception involving delayed feedback.

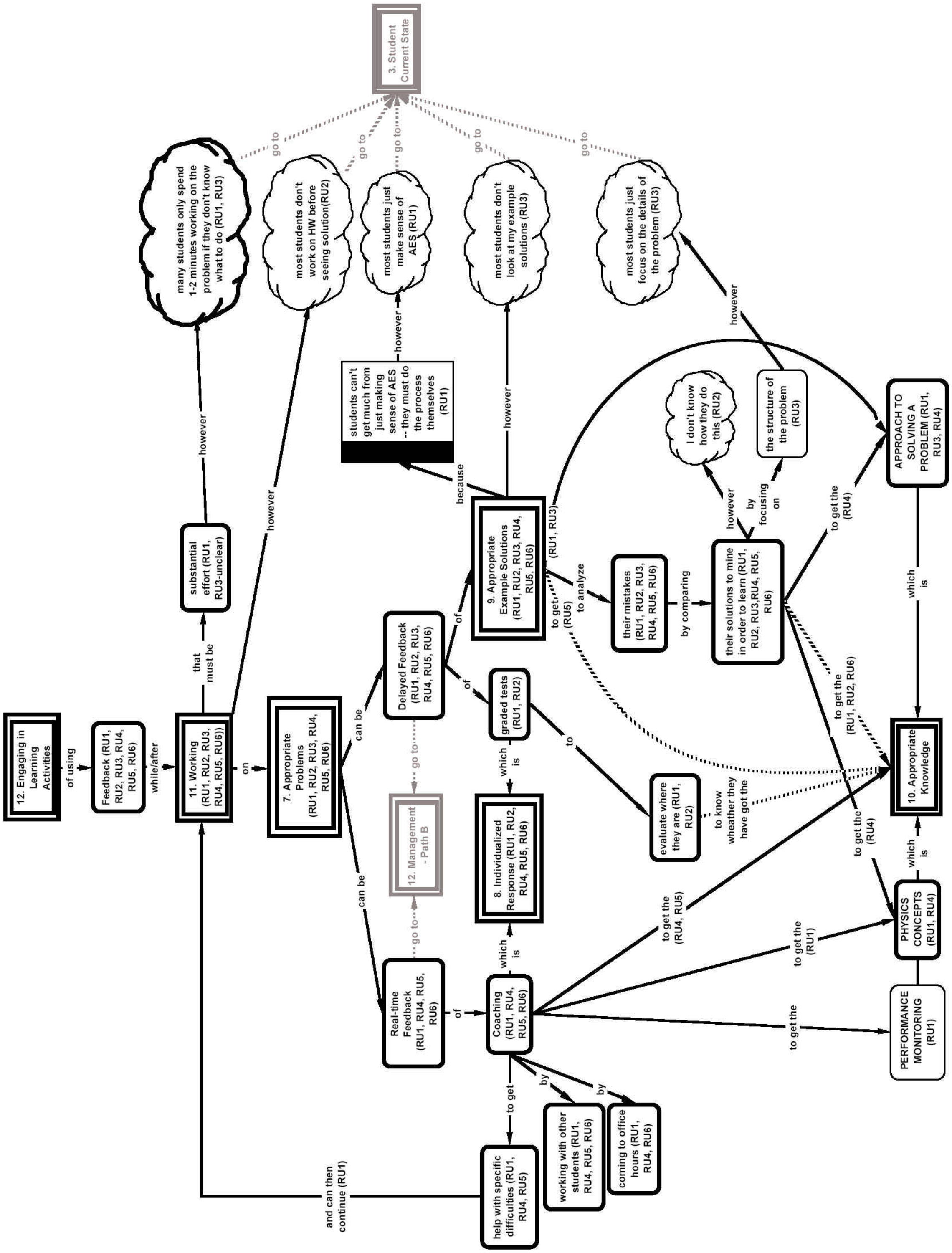
1. ***Students can learn how to solve physics problems by working on problems and then using delayed feedback.*** All of the instructors interviewed believed that students could learn how to solve physics problems by working on problems on their own (e.g. for homework or a test), and then looking at appropriate example solutions. All of the instructors suggested that students should compare their solutions to the appropriate example solutions in an effort to analyze their mistakes. One instructor added that students should focus on the structure of the problem rather than focusing on the details of the particular problem. Although all of the instructors saw this use of appropriate example solutions as being an important way that students learn how to solve physics problems, three do not think that students typically use their solutions in the most productive way. Their conception is that students do not actually put in enough effort to try a problem before looking at the solution. One of these instructors also has the conception that most students do not actually look at the appropriate example solutions, and that those who do look usually focus on the details of the particular problem rather than focusing on the general structure of the problem. For example, RU3 said, “The majority of students actually don’t look at the [appropriate example] solutions that I post.…A large fraction of students who do look at my [appropriate example]

solutions are focusing too much on the very problem at hand – What is the speed? or How high will it go? – as opposed to the structure of the problem" (RU3, statement #33, 38).

In addition to using the delayed feedback of appropriate example solutions, two instructors suggested that students should use the delayed feedback of graded tests to learn how to solve physics problems. Graded tests were mainly seen as a way for students to know whether or not they had actually gotten the appropriate knowledge.

2. ***Students can learn how to solve physics problems by working on problems while being coached by the instructor or other students.*** Four of the instructors had the conception that student use of real-time feedback while working on problems can help students learn how to solve physics problems. They typically described this real-time feedback as "coaching". Coaching is something that students should initiate by working on problems with other students or by coming to office hours to get assistance from the instructor. For example, RU5 stated, "When studying, students need to try to do the problems by themselves first, then they need to talk with other students" (RU5, statement #383).

Figure 4-9: Map 5 – Student Engagement of Learning Activities of Using Feedback (Path B)



Map 6: Student Engagement in Learning Activities of Looking/Listening (Path C)

This map (shown in Figure 4-10, p. 131) contains instructor conceptions of how students learn how to solve physics problems by looking and/or listening. The defining feature of this path is that learning can take place without the student needing to work on problems. Five instructors think that students can learn by looking/listening. One instructor, however, does not think that students can learn how to solve physics problems by looking/listening. This instructor, RU4, strongly expressed his conception that learning to solve physics problems requires working on physics problems. He said, “I’m afraid we have cases of students who simply go and maybe not even make an attempt at these problems, but go and look at the solutions and read them and say, OK now I’ve read, or sort of gone through solutions for 50 problems, I know the physics. When, in fact, what they’re doing is merely marking time with the person who wrote the solution” (RU4, statements #20, 21). RU1 had a weaker version of this conception. He suggested that, although a student might get something from looking at an appropriate example solution, it would be better if the student actually tried working the problem for himself.

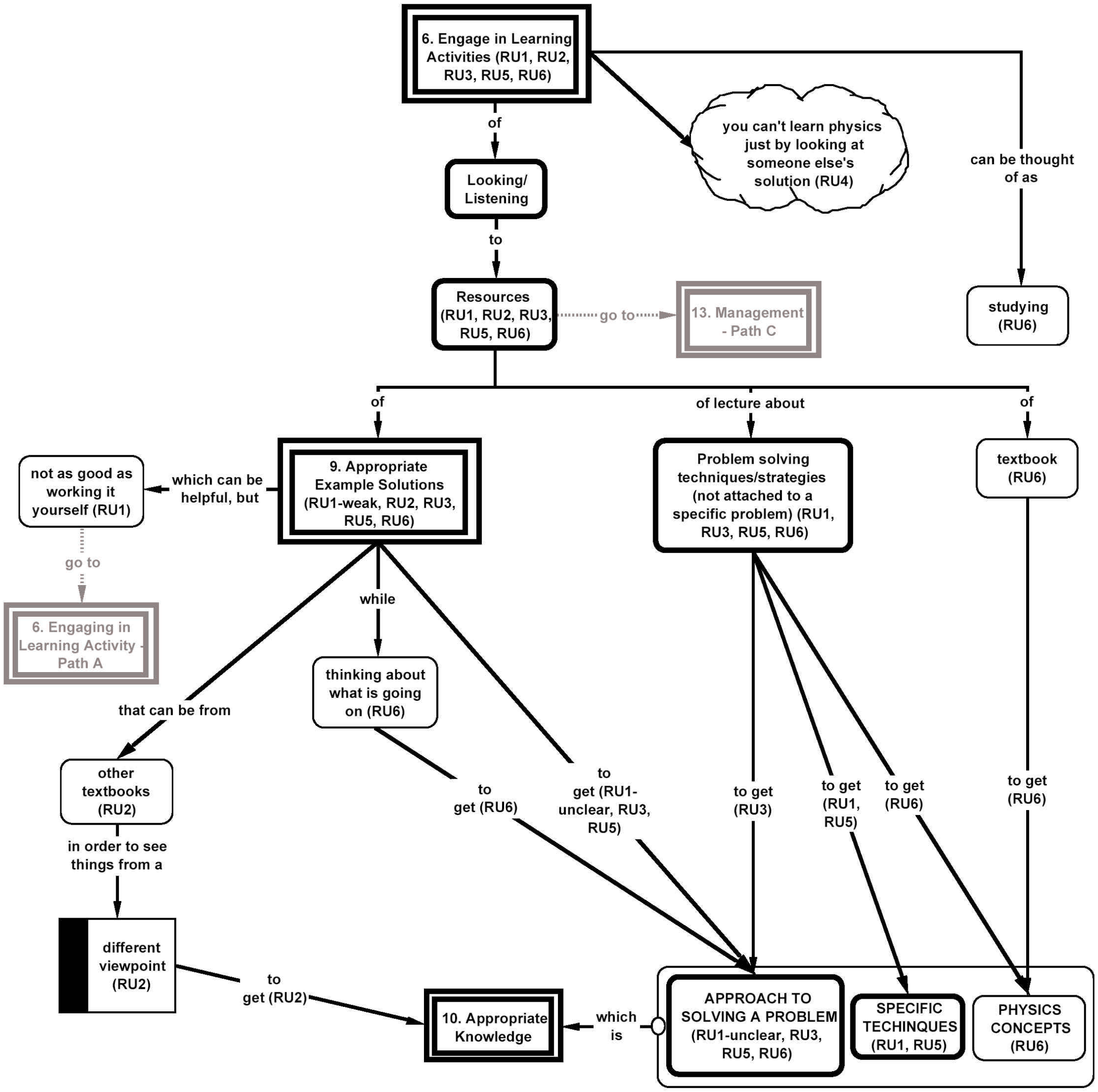
There are two qualitatively different ways that instructors think students can learn by looking/listening: looking/listening to appropriate example solutions, and looking/listening to lectures about problem solving techniques or strategies. Four of the instructors have both of these conceptions. One has only the conception involving appropriate example solutions.

1. ***Students can learn how to solve physics problems by looking/listening to appropriate example solutions.*** All five of the instructors in this group have the conception that students learn how to solve physics problems by seeing how someone else solved a problem. This is the only learning activity where there is any sort of agreement about what aspect of appropriate knowledge is gained by students. Four of the five instructors explicitly said that looking/listening to appropriate example solutions would help students improve their APPROACH TO SOLVING A PROBLEM. For example, RU6 said, “When I do an appropriate example solution on the board during class I

hope that students will get information transfer – this is the sort of way you approach a problem" (RU6, statement #20). Only one instructor mentioned any sort of procedure that students should follow in order to learn from appropriate example solutions -- that it was important for students to "think about what is going on" (RU6, statement #22).

2. ***Students can learn how to solve physics problems by looking/listening to lectures about problem solving techniques or strategies.*** Four of the instructors expressed this belief that students can learn from listening to a lecture about how to solve problems. This lecturing was not described as being attached to a particular problem. For example, RU3, suggests that from his "sermons" (RU3, statement #388) students can learn not to engage in their bad problem solving habits, such as pulling formulas out of a hat. None of the instructors mentioned any sort of procedure that students should follow in order to learn from these lectures.

Figure 4-10: Map 6 – Student Engagement of Learning Activities of Looking/Listening (Path C)



Resources Cluster

As described for the Main Map, one important way that instructors manage student engagement in learning activities is by providing resources. The next three maps describe how instructors conceptualize the resources of: (a) appropriate problems (Map 7, p. 136); (b) individualized responses (Map 9, p. 143); and (c) appropriate example solutions (Map 8, p. 149). Although lecture is shown as a resource on the Main Map, it is not described in a feature map because the interview was not designed to capture instructor conceptions about lectures. There is, however, limited information about instructor conceptualizations of lectures on the Management Feature Maps.

In this cluster, instructors have three qualitatively different perspectives of resources. All instructors have all three perspectives.

1. ***The perspective of the effect on student learning***
2. ***The perspective of required instructor time***
3. ***The perspective of the match with student preferences***

Instructors have more well defined conceptions from the perspective of the effect on student learning than they do from either of the other two perspectives. As can be seen in the following descriptions of the three Resources Maps, the conceptions that instructors express about a particular resource from one perspective are frequently in conflict with ideas expressed from another perspective.

Map 7: Resource of Appropriate Problems

This map (shown in Figure 4-11, p. 136) contains instructor conceptions about what types of problems should be worked by students and why these types of problems are desirable. Recall from Chapter 3 (p. 67) that, in addition to the Homework Problem, four other types of problems were used as artifacts during the interview. There was a problem that included a diagram and was posed in three sections that required students to solve one sub problem at a time (Problem A), a multiple-choice problem (Problem B), a problem that was set in a "real-world" context (Problem C), and a problem that asked for qualitative types of analyses (Problem D). Appendix C shows the different problem types as they were used in the interview.

From the Perspective of the Effect on Student Learning

There are three qualitatively different ways that instructors conceive of the resource of appropriate problems from the perspective of the effect on student learning: appropriate problems should encourage/require students to do certain things, appropriate problems should be based on students' current state, and appropriate problems should be based on realistic situations. Five of the instructors have all three conceptions. One instructor had only the first two of these conceptions.

1. ***Appropriate problems should help students develop certain skills by encouraging/requiring students to do/experience certain things.*** All of the instructors conceive of using problems to encourage or require students to do certain things that the instructor thinks are important for learning. Four of the instructors described appropriate problems as not giving students too much help. For example, RU3 said, "I stopped using problems like Problem A because they give too many hints, which I want students to be able to figure out on their own" (RU3, statement #252). Three of the instructors described appropriate problems as requiring students to think about the physics principles behind the problem. For example, two instructors said that problems could ask students to analyze the motion at various points rather than just get a numerical answer. Finally, two of the instructors described appropriate problems as giving students a way to verify their answer by using multiple-choice problems. These instructors said that if a student gets an answer that is not reflected in one of the available choices that the student might go back and check their work.
2. ***Appropriate problems should be based on students' current state.*** All of the instructors had the conception that the appropriateness of a problem depends on the students' current state. Four of the instructors said that appropriate problems should ask a specific question (unlike Problem C, the real world

problem). One instructor said that this would help students who had trouble reading English understand what was being asked. He explained that he was "very reluctant to put anyone in a situation where their ability to parse an English sentence has a significant impact on their grade" in a physics class (RU3, statement #302). Three of the instructors said that appropriate problems should be based on students' current understanding of PHYSICS CONCEPTS. For example, two instructors said that this could be done by having problems that are physically correct. One instructor said that "the better students would be bothered by Problem A" (RU4, statement #268) because it is physically incorrect -- the string in the problem does not break at the lowest point where the tension would be highest.

3. ***Appropriate problems should convey the message to students that physics is related to reality by being based on realistic or semi-realistic situations.*** Five of the instructors had the conception that appropriate problems should help students see the connection between the physics they are learning in class and reality by being based on realistic or semi-realistic situations. Three of these instructors said that, in their experience, some problems that attempted to be realistic are actually silly or contrived and that these types of problems should be avoided. None of these instructors, however, made it clear what constituted a silly or contrived problem and there was disagreement as to whether Problem C (the real-world problem) was silly or contrived.

From the Perspective of Required Instructor Time

Appropriate problems should be easy to create and grade. Five of the instructors interviewed expressed this conception that appropriate problems should require a minimum amount of instructor time to create and grade. There was, however, little agreement on what types of problems met this criteria, except that all five instructors said that multiple-choice problems were definitely the least time-consuming to grade. Two instructors also noted, however, that multiple-choice problems were also the most time-consuming to create.

Some of the conceptions from the perspective of instructor time conflict with conceptions from the perspective of the effect on student learning. For example, as mentioned earlier, from the perspective of the effect on student learning, RU3 said that problems should not be broken into parts (like Problem A). From the perspective of required instructor time, however, he thought that being broken into parts makes it easier to “dole out partial credit” when grading (RU3, statement #316).

From the Perspective of the Match with Student Preferences

Appropriate problems should be liked by students. Two of the instructors had the conception that appropriate problems should be liked by students. For example, RU3 said that appropriate problems should not be multiple-choice because “students disliked multiple-choice problems that I gave because they can’t get partial credit” (RU3, statement #348).

Figure 4-11: Map 7 (short) – Resource of Appropriate Problems

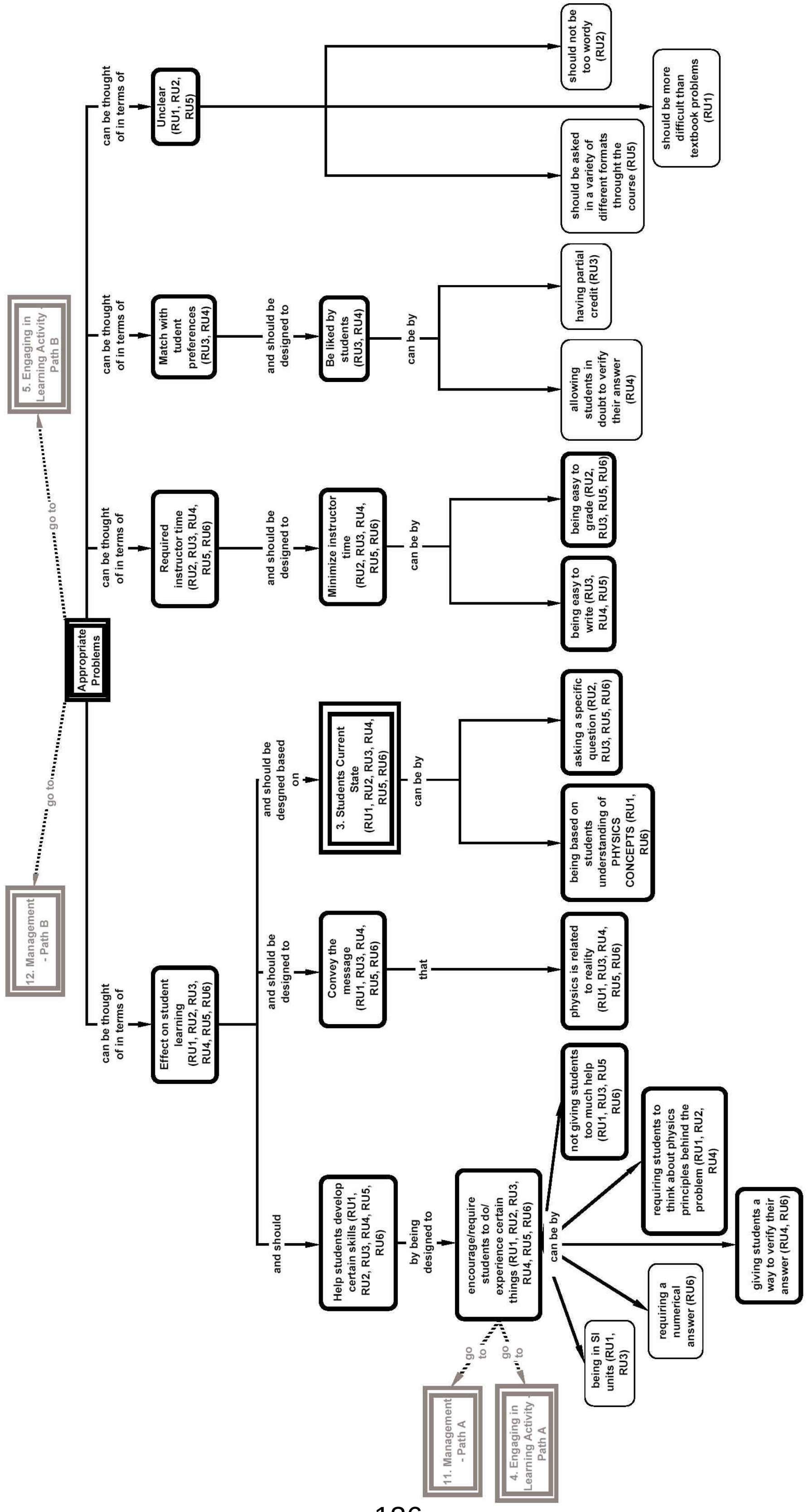


Figure 4-12: Map 7 (part 1) – Resource of Appropriate Problems

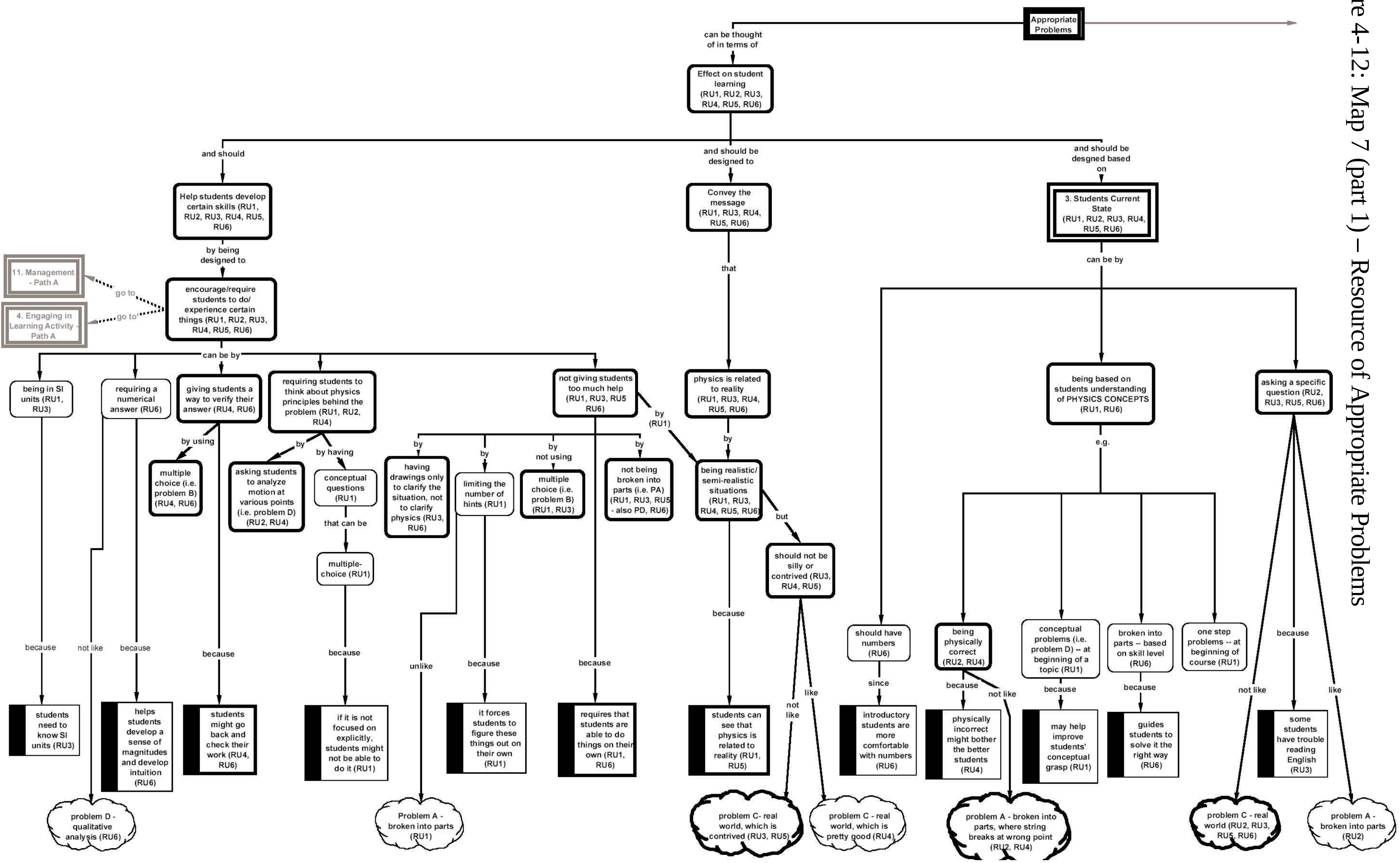
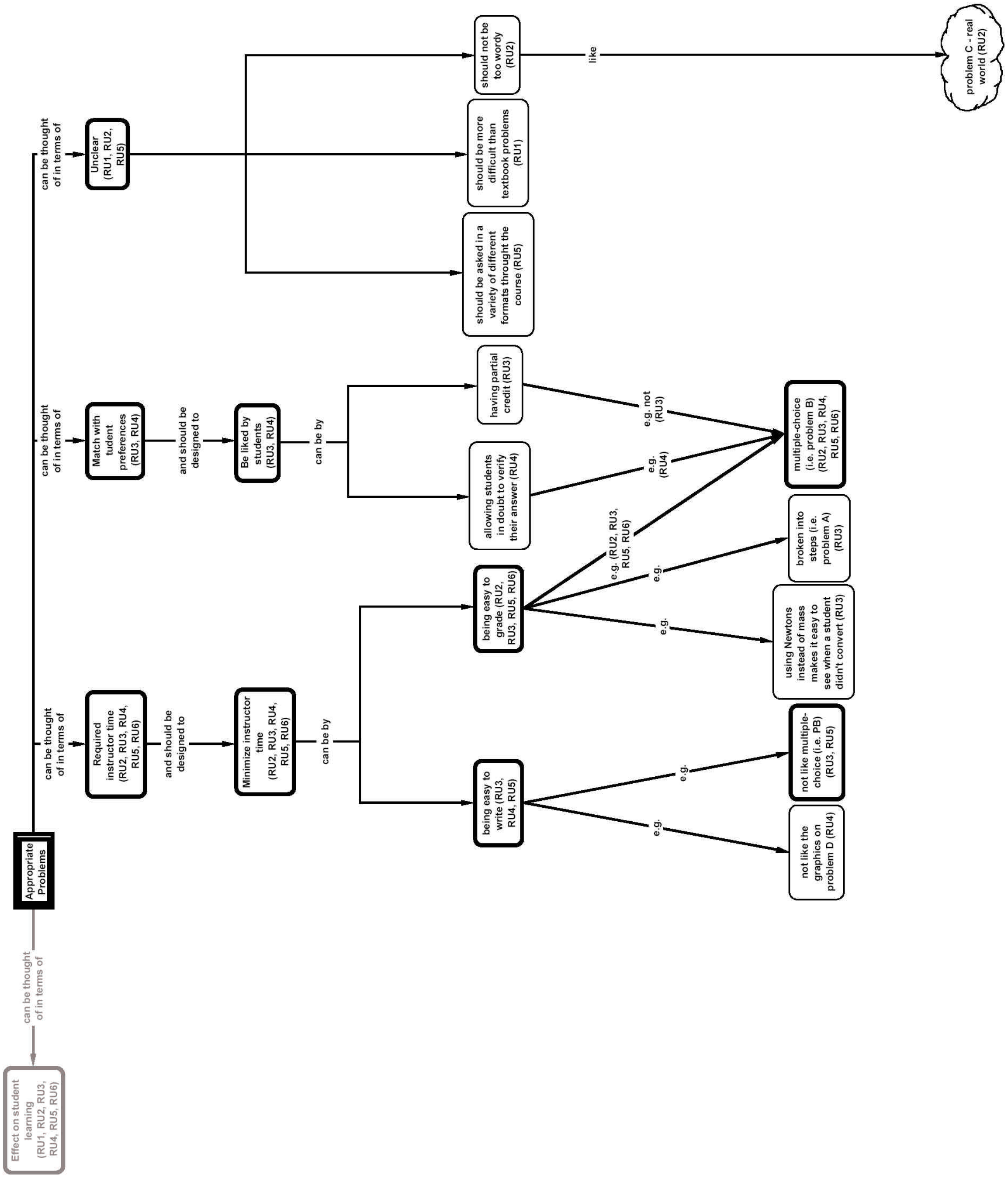


Figure 4-13: Map 7 (part 2) – Resource of Appropriate Problems



Map 9: Resource of Appropriate Example Solutions

This map (shown in Figure 4-14, p. 143) contains instructor conceptions about what types of example problem solutions should be made available to students and why these types of example problem solutions are desirable. An example problem solution can be made available to students either by handing out/posting a written solution or by solving a problem on the board during class time. Instructors think about this resource (as with the other resources) from three distinct perspectives: (1) the perspective of the effect on student learning; (2) the perspective of required instructor time; (3) the perspective of the match with student preferences.

Recall from Chapter 3 (p. 66) that three different instructor solutions were used as artifacts during the interview. Instructor Solution 1 is a brief, "bare-bones" solution that offers little description or commentary. Instructor Solution 2 is more descriptive than the bare-bones solution. All of the details of the solution were explicitly written out, but little explanation of the reasoning behind the solution was given. Instructor Solution 3 was based on research into expert problem solving and attempted to make the reasoning behind the solution explicit.

Two of the instructors described the solutions that they used as being most similar to Instructor Solution 3 (the explicit reasoning solution). Three of the instructors described the solutions that they used as being most similar to Instructor Solution 1 (the bare bones solution). Two of these, however, said that they would actually prefer to use solutions more similar to Instructor Solution 3 but did not because doing so would require time or abilities that these instructors did not feel were available. For example, RU5 said, "If I had a solution manual that had Instructor Solution 3, it would be great. I would use that" (RU5, statement #62). One instructor did not describe the type of solutions that he used. None of the instructors described using solutions similar to Instructor Solution 2 (the explicit details solution).

From the Perspective of the Effect on Student Learning

There are two qualitatively different ways that instructors conceive of the resource of appropriate example solutions from the perspective of the effect on student learning: appropriate example solution should convey information to students, and appropriate example solutions should be based on students' current state. All instructors had both of these conceptions.

1. ***Appropriate example solutions should convey information to students to help them develop certain knowledge/skills related to problem solving.*** All of the instructors had this conception. For example, RU2 stated, "Instructor Solution 2 is a fine example of a solution that you might post so that students can see what the underlying machinery is to get the answer of this problem" (RU2, statement #57). There seemed to be little agreement about what aspects of knowledge/skills related to problem solving appropriate example solutions should help develop. The only major aspect not mentioned by any of the instructors was SPECIFIC TECHNIQUES.

2. ***Appropriate example solutions should be based on two aspects of students' current state.*** All of the instructors described basing appropriate example solutions on students' current state as making it clear to the students what was happening in the solution and why. Two instructors elaborated on this conception by saying that this is important because they wanted students who were not able to do the problem to be able to understand the solution. None of the instructors thought that Instructor Solution 1 (the bare bones solution) accomplished this goal. Four of the instructors indicated that Instructor Solution 2 (the explicit details solution) accomplished this goal. Only 2 instructors, however, indicated that Instructor Solution 3 (the explicit reasoning solution) accomplished this goal and one instructor indicated that it did not.

   Four of the instructors said that appropriate example solutions should be based on students' understanding of PHYSICS CONCEPTS. For example two instructors said that the timing in the course should be considered when writing appropriate example solutions. (e.g. "Near the beginning of a class, in the beginning of the Fall, you want to impress on students the gory details"; RU6, statement #49). One instructor said that appropriate example solutions should avoid discussions of possible complications that some students will not think of.

From the Perspective of Required Instructor Time

Appropriate example solutions should be easy to write or find. Four of the instructors had this conception. They thought that appropriate example solutions should require a minimum amount of instructor time to create or find already created. All agreed that only Instructor Solution 1 (the bare bones solution used in the interview) met this criteria. This conception conflicts with these instructors' conceptions from the perspective of the effect on student learning that Instructor Solution 1 does not make it clear what is happening or why.

From the Perspective of the Match with Student Preferences

Appropriate example solutions should not be too long or complicated looking. Four of the instructors had this conception that, in order to be used by students, appropriate example solutions should not look too complicated or use unfamiliar symbols (e.g. sigmas). As one instructor described, students will be less likely to look at a solution if it looks too complicated; "The thing I worry about too detailed of a solution – like Instructor Solution 2, explicit details – is I think it kind of turns students off in some ways….So something that's a little more terse might appeal more to at least some segment of people" (RU6, statement #52).

Two of the instructors (RU3, RU6) explicitly said which of the instructor solution artifacts were too long or complicated looking. Both put Instructor Solution 2 *and* Instructor Solution 3 in this category. This conception conflicts with these instructors' conceptions that Instructor Solution 2 and/or Instructor Solution 3 would be the most helpful for student learning.

Figure 4-14: Map 9 (short) – Resource of Appropriate Example Solutions

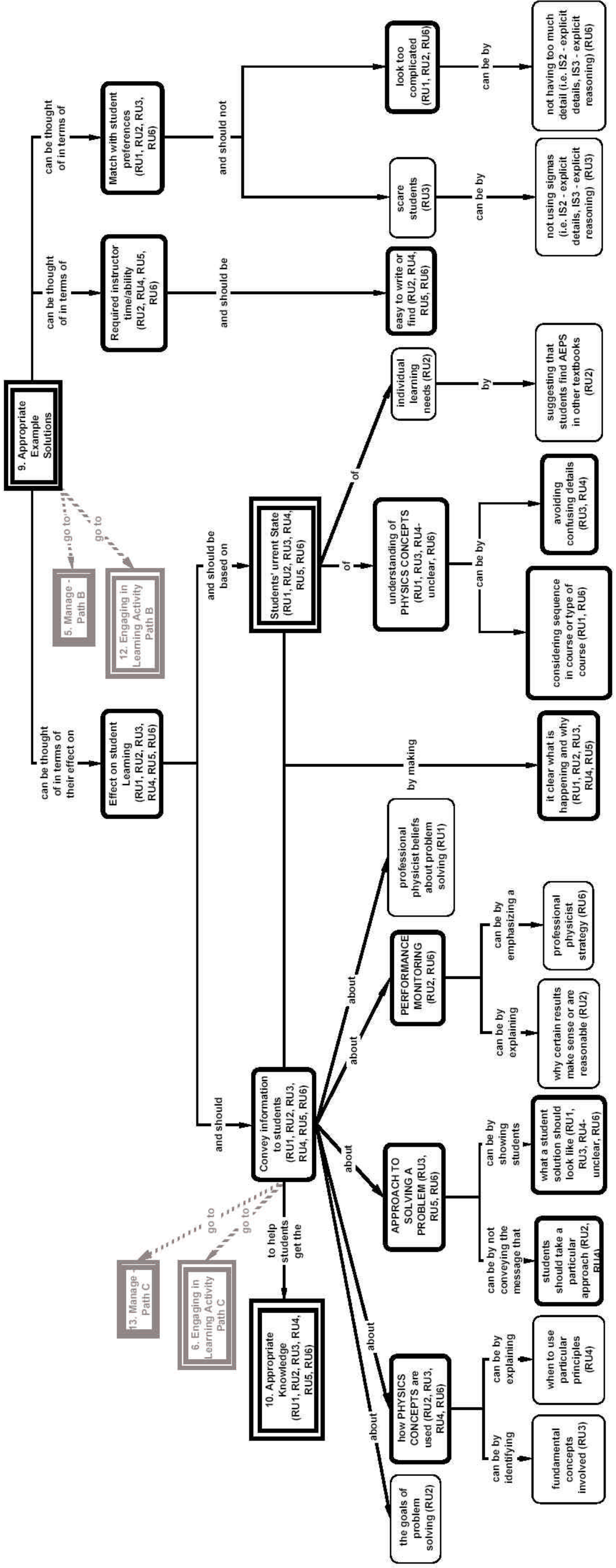


Figure 4-15: Map 9 (part 1) – Resource of Appropriate Example Solutions

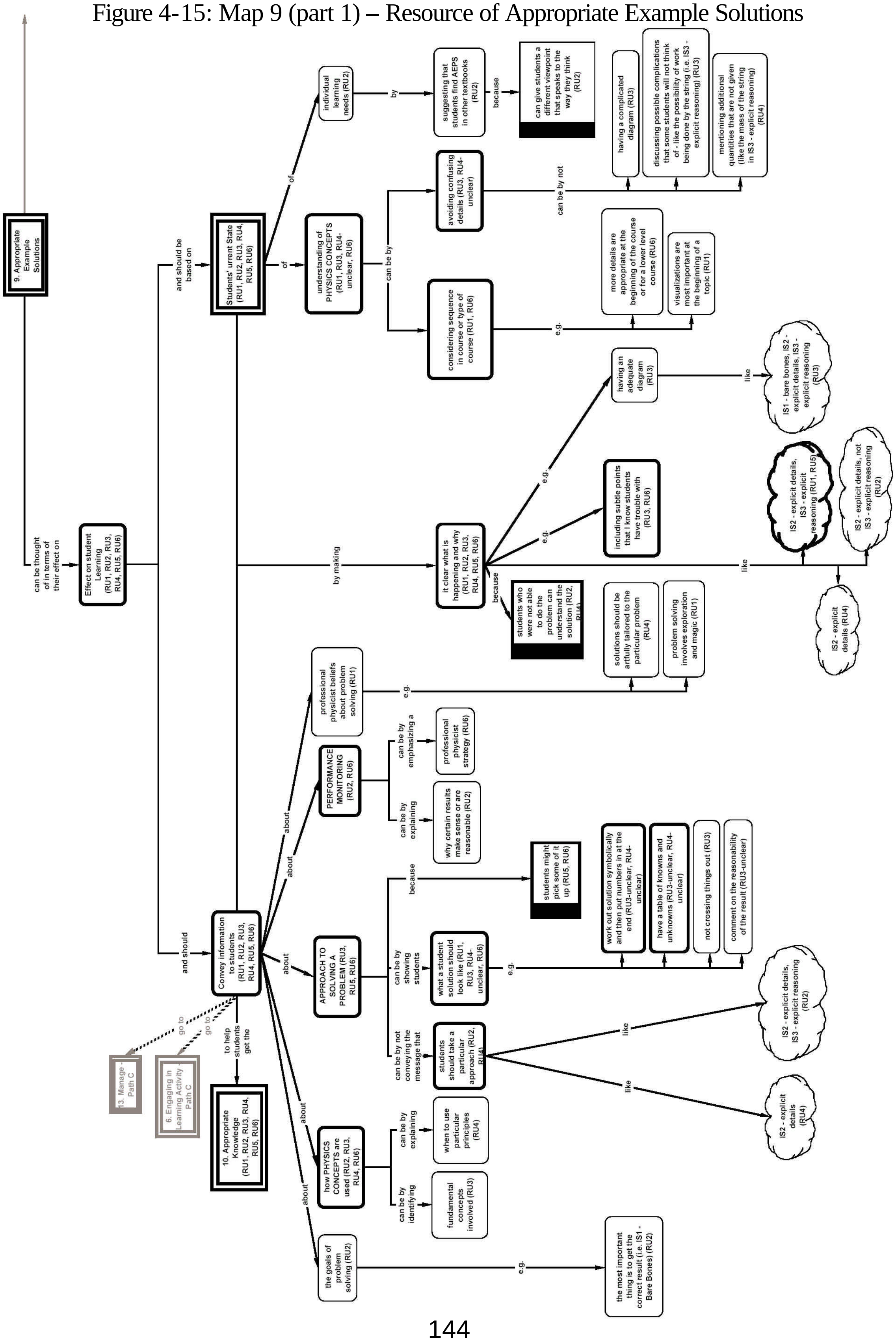
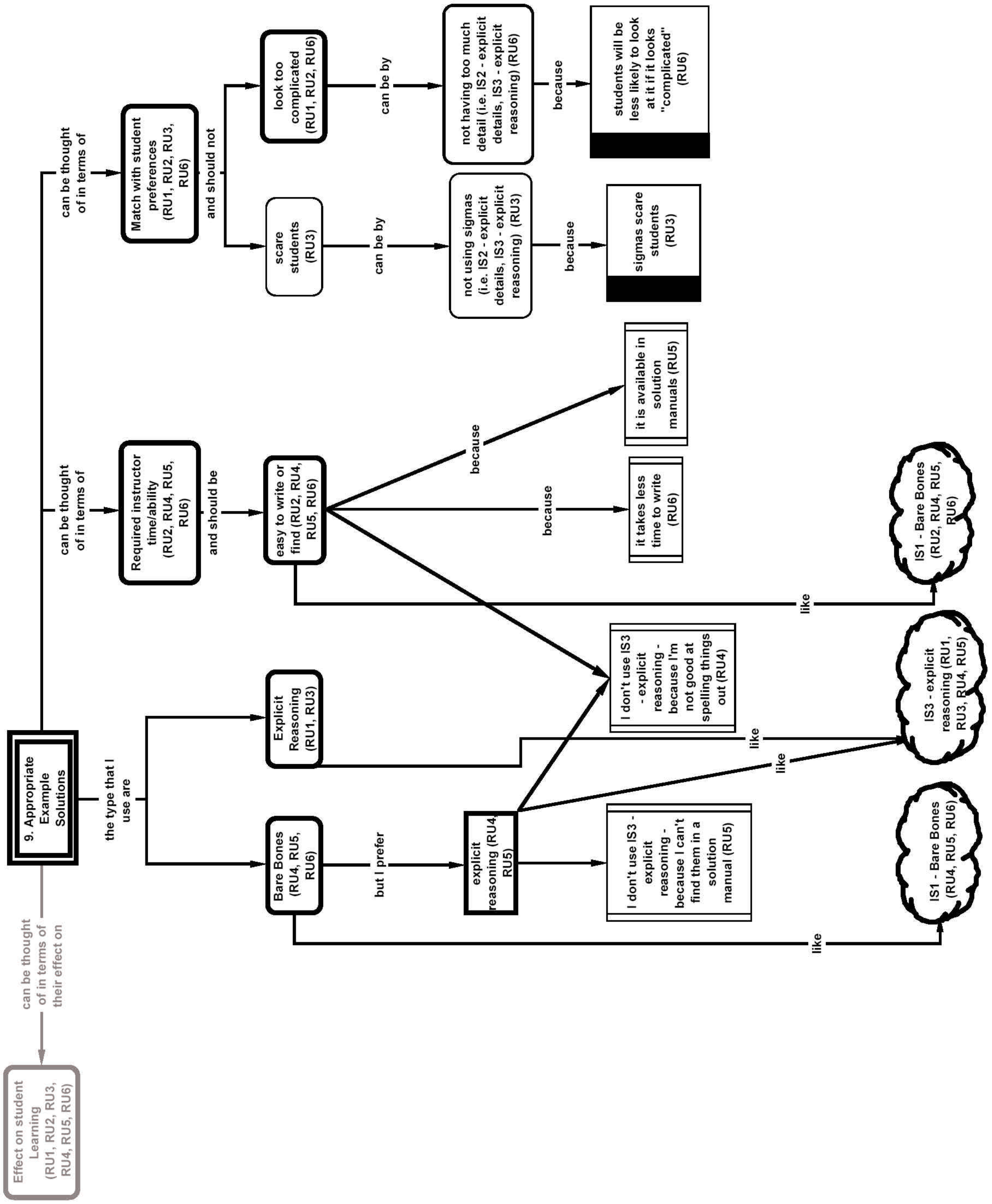


Figure 4-16: Map 9 (part 2) – Resource of Appropriate Example Solutions



Map 8: Resource of Individualized Responses

This map (shown in Figure 4-17, p. 149) contains instructor conceptions about what types of feedback should be received by students and why this type of feedback is desirable. Individualized responses refers to feedback that is specifically tailored to a particular student (or, in one case, a group of students) based on the student's success or failure in working on an appropriate problem.

Individualized responses are different than the other two types of resources (i.e. appropriate problems and appropriate example solutions). Individualized responses are the only type of resource that is associated with only one type of learning activity (using feedback while/after working on problems -- Path B). Also, individualized responses refer to a range of possible responses rather than a single type of resource like the other two resources. Finally, although the interview was designed to probe instructor conceptions about the individualized responses of grading, it was not designed to gather information about other types of individualized responses. Thus, the level of detail in this map is considerably less than in the other resource maps. Nonetheless, instructors think about this resource (as with the other resources) from three distinct perspectives: (1) the perspective of the effect on student learning; (2) the perspective of required instructor time; and (3) the perspective of the match with student preferences.

During the interview one instructor indicated that real-time feedback could be provided by the instructor during lecture. He described this as "Socratic dialogue to develop a problem solution during lecture" (RU3, statement #43). Because this instructor did not describe this situation in much detail it is unclear whether this constitutes real-time feedback or whether it is actually a form of appropriate example solutions. It was placed on this map because the instructor seemed to see this activity as being designed to provide feedback to the class that was specifically tailored to the class's success or failure in developing a problem solution.

Instructors conceive of four different types of individualized responses: grades on student solutions, comments on student solutions, peer coaching, and instructor coaching. One instructor had all four conceptions. Three instructors had three of the four conceptions: two were missing the conception of comments on student solutions, and one was missing the conception of peer coaching. One instructor had two of the four conceptions: grades on student solutions and instructor coaching. One instructor only had one of the four conceptions: grades on student solutions.

1. ***Individualized responses can be grades on student solutions.*** All of the instructors discussed providing the delayed feedback of grades on student problem solutions. During the interview instructors talked a lot about how they would grade the five student solutions. Most of these discussions focused on assessing how well the student understands the material in order to give them a fair grade. These tended to be detailed descriptions of grading practices.

   Four of the instructors did, however, give reasons for grading that were not related to providing an assessment of the student's level of understanding. These reasons were all from the perspective of the effect on student learning. Three instructors discussed grading as being important because it can shape student behavior by discouraging undesirable activities. Two instructor said that grades were important because they allowed students to know whether or not they had gotten the appropriate knowledge.

2. ***Individualized responses can be comments on student solutions about major physics blunders.*** Two of the instructors said that, in addition to providing grades on student problem solutions, they also make attempts to provide the delayed feedback of comments about major physics blunders. From the perspective of required instructor time, both instructors viewed writing comments on student solutions was very time consuming and thus, the comments had to be limited to only the major blunders. One of these instructors also explicitly related these comments to helping students learn how to solve physics problems and, if time permitted, would like to provide more of them.

3. ***Individualized responses can be coaching provided by other students during small group work.*** Four of the instructors said that real-time feedback could be provided by other students during small group work. From the perspective of the effect on student learning, two instructors conceived of small group work as being almost as helpful to students as instructor coaching. Two instructors said that small group work had great advantages over instructor coaching from the perspective of required instructor time.

4. ***Individualized responses can be instructor coaching during office hours.*** Three instructors said that real-time feedback could be provided by the instructor during office hours. One instructor, RU4, from the perspective of student learning, saw this as the key to helping students. He also, however, saw this as requiring a substantial amount of instructor time. For example. he said, "I think engaging students and getting them to do something no matter how wrong it might be, getting them to do something on their own while you help them is, I think, the key. It's labor intensive, though" (RU4, statements #338, 339). Another instructor, from the perspective of student preferences, complained that students often did not come to office hours to make use of this instructor coaching.

Figure 4-17: Map 8 (short) – Resource of Individualized Responses

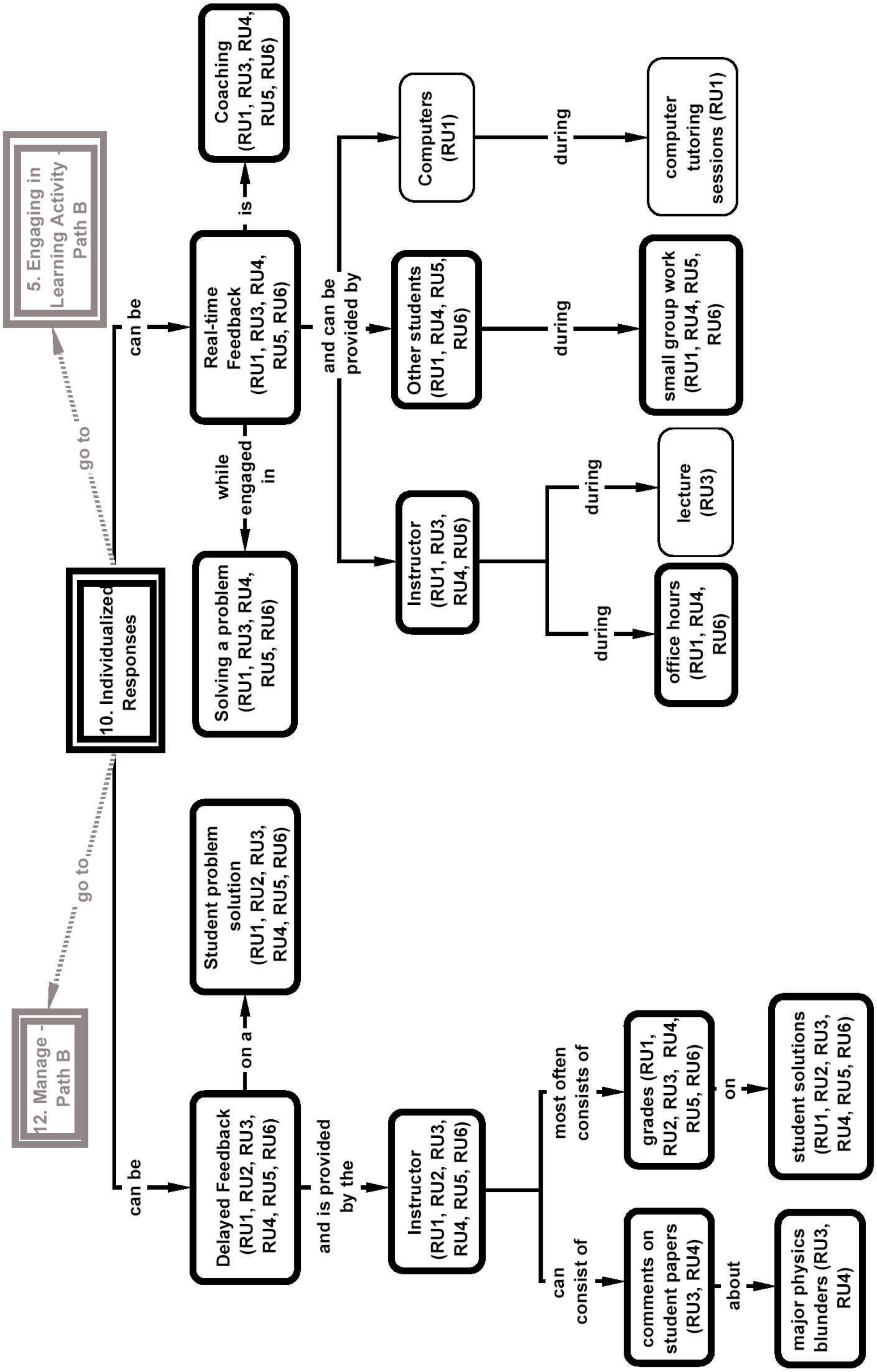


Figure 4-18: Map 8 (part 1) – Resource of Individualized Responses

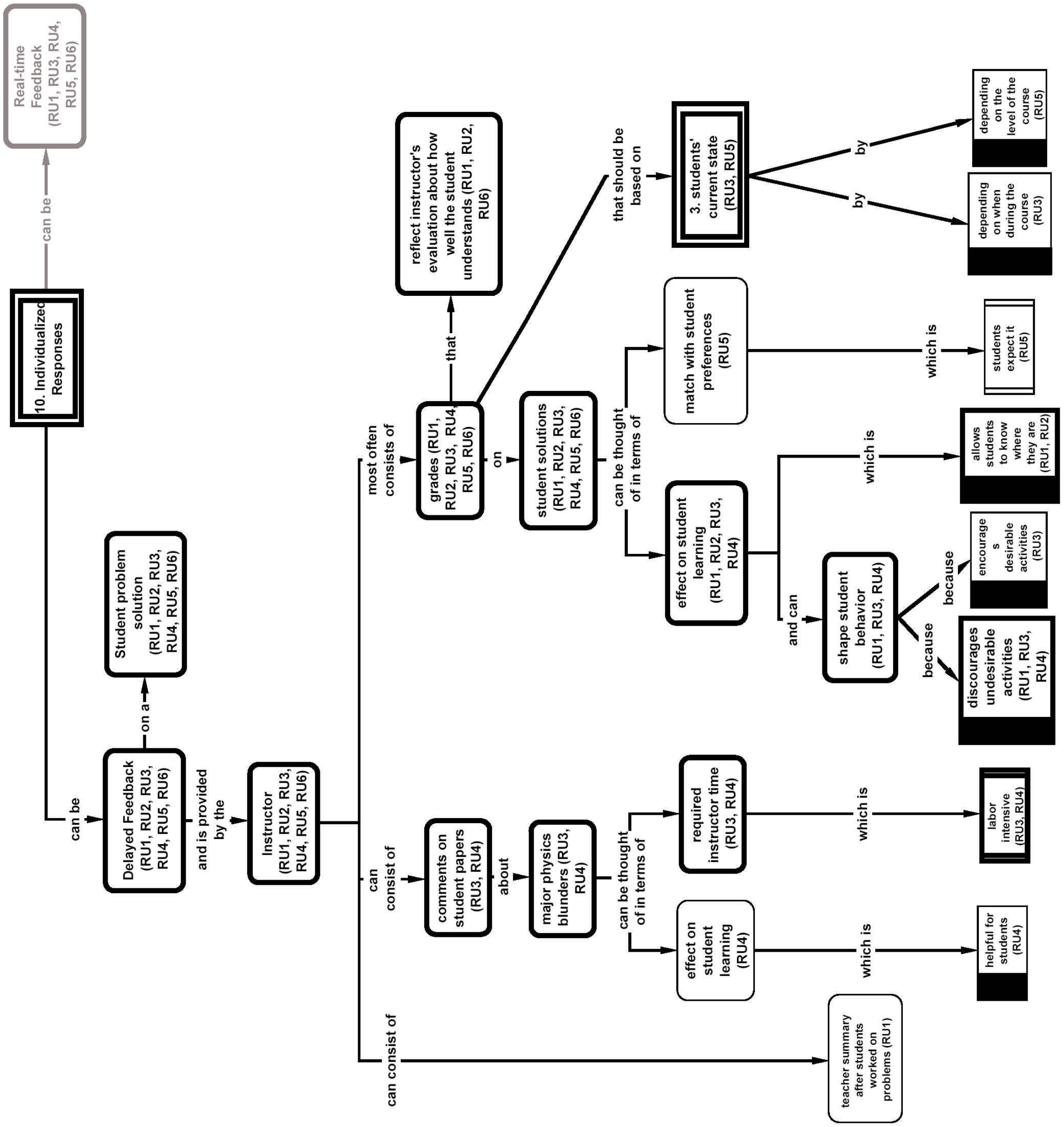
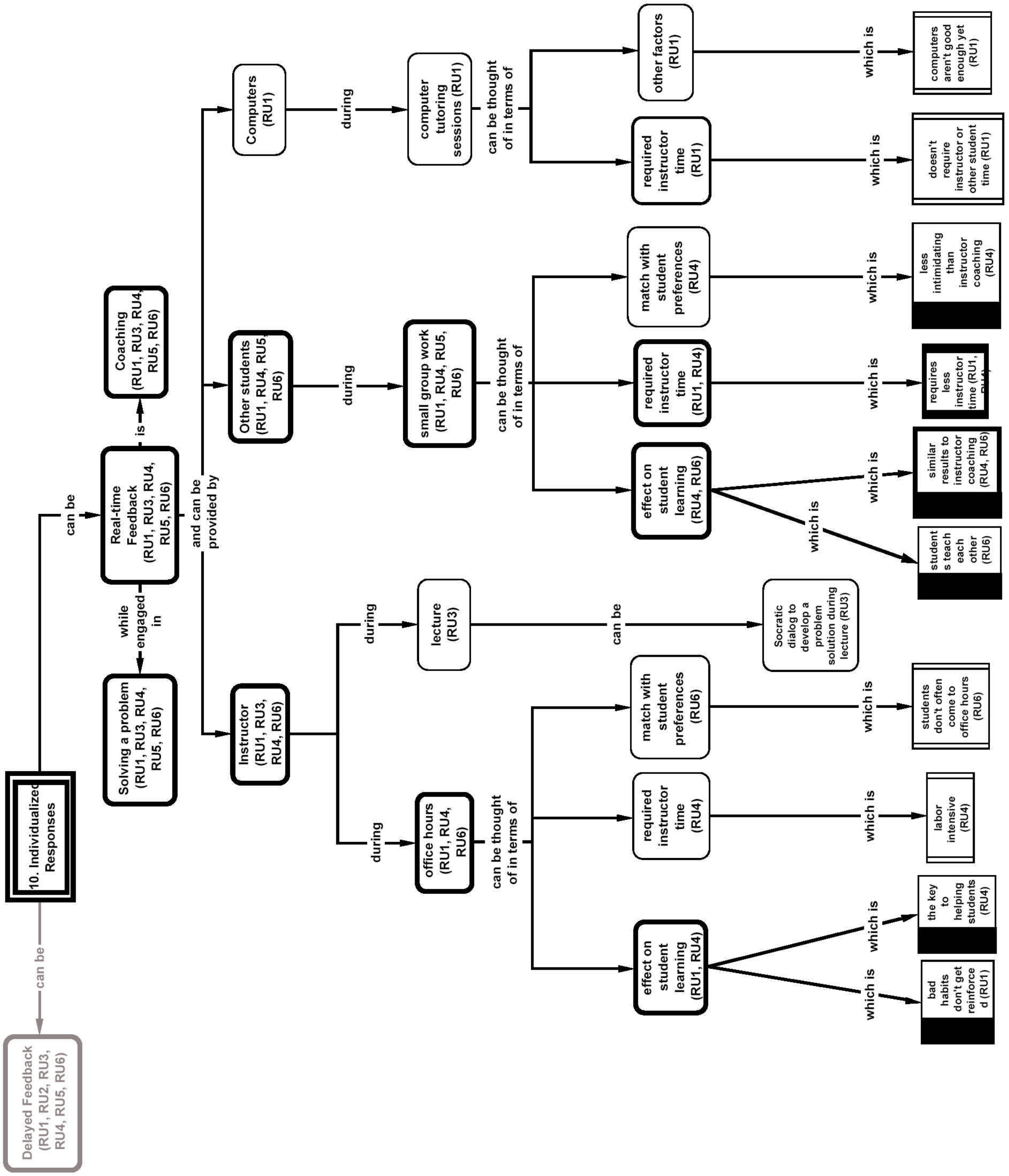


Figure 4-19: Map 8 (part 2) – Resource of Individualized Responses



Management Cluster

As described for the Main Map (p. 107), instructors see their role as managing the students while they are engaged in learning activities to get the appropriate knowledge. Instructors conceptualize three distinct ways that they can manage students: providing resources, making suggestions, and setting constraints.

The maps in the Resources Cluster describe the *form* of the resources (e.g. what an appropriate example solution should look like) while the maps in this cluster describe the *way* that instructors conceptualize the use of these resources in their teaching (e.g. when an appropriate example solution should be given to students and what, if any, constraints or suggestions should be associated with it). The maps in the Management Cluster are separated by the type of student learning activities that they seek to manage: working on problems (Path A), using feedback while/after working on problems (Path B), or by looking/listening (Path C). All instructors conceive of managing each type of student learning activity.

Map 11: Management of Students' Engagement in Learning Activities of Working (Path A)

This map (shown in Figure 4-20, p. 154) contains instructor conceptions of what types of things an instructor can/should do in order to help students get the appropriate knowledge by working on appropriate problems.

There are three qualitatively different ways that instructors conceive of their management of students' engagement in learning activities of working on appropriate problems: setting constraints on problems that students have to work, suggesting that students work on problems, and setting constraints on situations in which students work on problems. Two instructors have all three conceptions. Two of the instructors have two of the three conceptions. Two of the instructors have only the conception of setting constraints on the problems that students work.

1. ***Instructors can manage student engagement in learning activities of working on appropriate problems by setting constraints on the problems that students***

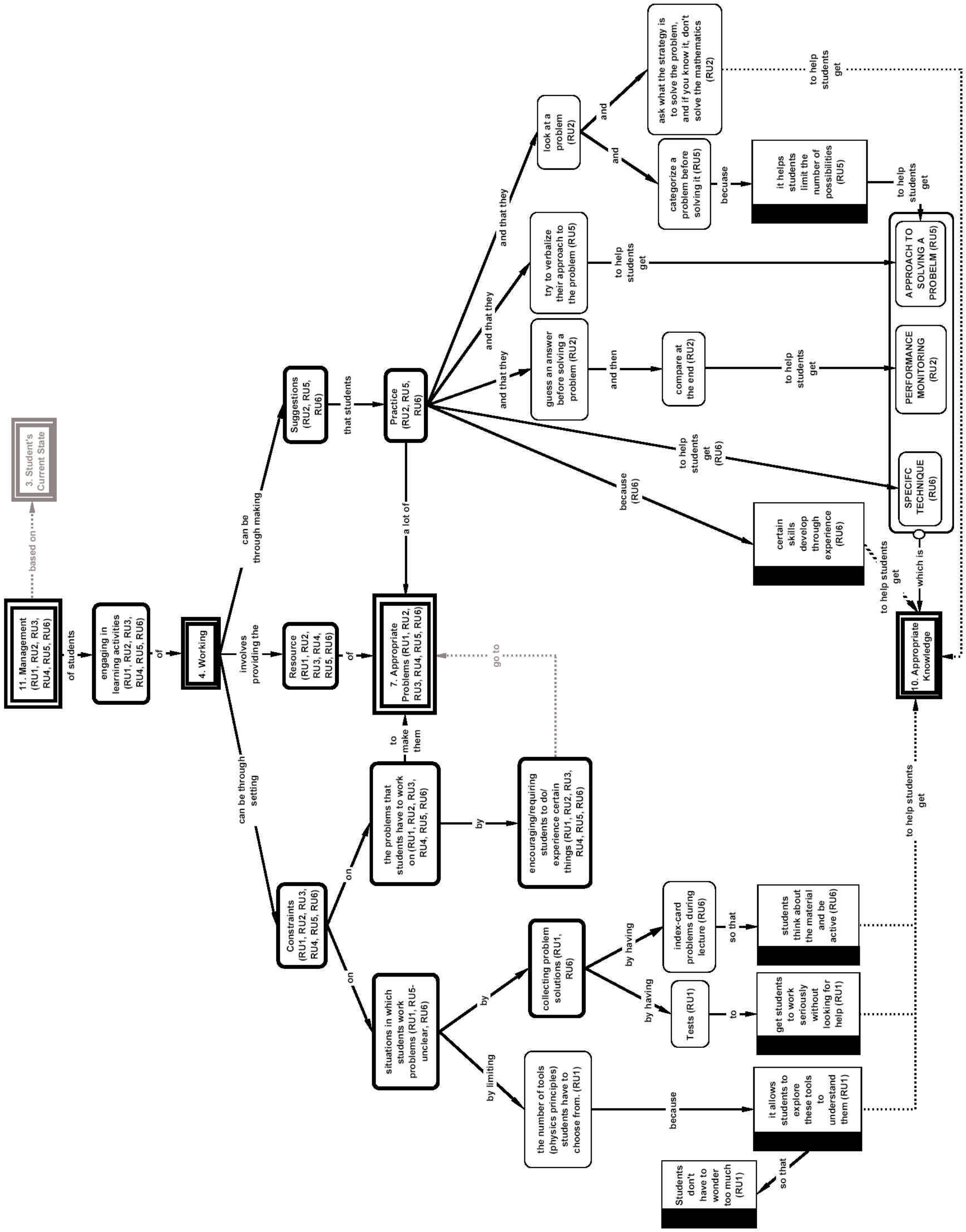
have to work. All of the instructors described designing appropriate problems that encourage or require students to do certain things that will help them learn while working on the problem. These are described in more detail on Map 7: Appropriate Problems.

2. ***Instructors can manage student engagement in learning activities of working on appropriate problems by suggesting that students work on problems.*** Three of the instructors described managing students' working on appropriate problems by suggesting that students practice working on a lot of appropriate problems. Two of these instructors also suggest particular things that students should do to enhance their practicing. For example, RU2 suggested that students should "look at the problem and then guess as to how high the stone would go or guess what the tension would be and then work the problem and then look at the guess and the answer to see whether the two are consistent, and if they're not to worry about it" (RU2, statement #290).

3. ***Instructors can manage student engagement in learning activities of working on appropriate problems by setting constraints on situations in which students work on problems.*** Two instructors described managing students' working on appropriate problems by collecting problem solutions. One of these instructors described tests as the only situation in which students worked seriously on a problem without looking for help. For example, he said, "I suspect that what the typical physics student gets out of the test is that they really seriously work on the problems. When students do homework or solve problems themselves, it's so tempting to just look at solutions after working 2 minutes if you don't know what to do" (RU1, statements #139, 140).

   One instructor also described managing students' working on appropriate problems by explicitly "limiting the number of tools (i.e. physics principles) that students have to choose from" (RU1, statement #105). His reason, related to the effect on student learning, was that limiting the number of tools allows students more time to explore and understand the tools that remain.

Figure 4-20: Map 11 – Management of Students' Engagement in Learning Activities of Working (Path A)



Map 12: Management of Students' Engagement in Learning Activities of Using Feedback (Path B)

This map (shown in Figure 4-21, p. 158) contains instructor conceptions about the types of things an instructor can/should do in order to help students learn through the use of feedback. There are actually two things that the instructor manages in this path. First, the instructor provides management in order to get students to work on problems. The instructor also provides management of the feedback the student receives. This feedback can occur while the student is solving a problem (i.e. coaching) or after the student has solved a problem (e.g. giving students an appropriate example solution).

This is, by far, the most detailed concept map in the Management Cluster. In fact, this is by far the most detailed of any of the concept maps – it contains the most ideas and the most interconnections. Based on this, one can infer that management of students' engagement in learning activities of using feedback may be what these instructors think is the most important part of their jobs as teachers.

There are four qualitatively different ways that these instructors conceive of their management of students' engagement in learning activities of using feedback: grading to shape student behavior, having students work on problems and then providing appropriate example solutions, allocating class time for students to work in small groups, and suggesting that students come to office hours. Three of the instructors have all four conceptions. One instructor has all of the conceptions except for allocating class time for small group work. Two of the instructors have two of the conceptions: grading to shape student behavior, and having students work on problems and then providing appropriate example solutions.

1. ***Instructors can manage students' engagement in learning activities of using feedback by having a test or quiz that is graded in order to shape student behavior.*** All of the instructors described having tests or quizzes that required students to work on problems and then providing feedback by grading the student solutions. Five of these instructors described the grading feedback as shaping student behavior by discouraging undesirable activities such as students not

showing their reasoning. Three instructors also said that grading can shape student behavior by encouraging desirable activities.

2. ***Instructors can manage students' engagement in learning activities of using feedback by suggesting (i.e. HW, in class problems) or requiring (i.e. a test) students to work on problems and then providing appropriate example solutions.*** All of the instructors described the importance of appropriate example solutions in student learning. As can be seen in the Student Engagement in Learning Activities of Using Feedback Map (Map 5), instructors conceive of student learning taking place when students compare their solution to the appropriate example solution.

   There are a variety of ways that the instructors get students to work on problems before seeing the appropriate example solutions. They all have tests or quizzes. Four have ungraded homework and one has graded homework. Three allocate class time for individual work and two for group work. Some instructors grade this individual or group work to be sure that the students actually do it, others do not provide this additional constraint. The appropriate example solutions are then provided as instructor solutions during lecture or as written solutions that are posted in the hallways or on the web.

   Although these instructors do conceive of many ways to constrain students to work on the problems, none of the instructors talked about any way that they constrain students' use of the feedback of appropriate example solutions. One instructor did suggest that he could ask students to turn in a corrected version of a test after seeing the appropriate example solution, but immediately dismissed this idea as requiring too much work. For example, he said, "I think it might be a good idea for an instructor to ask the student to present a corrected version of a test problem, but it requires too much effort on the part of the instructor" (RU2, statement #102).

3. ***Instructors can manage students' engagement in learning activities of using feedback by arranging class time for students to work in small groups.*** Four of

the instructors described allocating class time for students to work in small groups. The Individualized Responses Map (Map 8) provides more information about student coaching during small group work.

4. ***Instructors can manage students' engagement in learning activities of using feedback by suggesting that students come to office hours for individual coaching.*** Three of the instructors described suggesting to students that they come to office hours for individual coaching if they are having difficulties in the class. During this coaching the instructor has a student try a problem and provides assistance when needed. For example, RU4 said, "I send a student to the blackboard and quiz them. In the worst case, they're going to say 'I haven't any idea how to do this problem'.…So you say, 'alright, let's start. Draw a picture'…." (RU4, statements 327-329). The Individualized Responses Map (Map 8) provides more information about instructor coaching during office hours.

Figure 4-21: Map 12 (short) – Management of Students' Engagement in Learning Activities of Using Feedback (Path B)

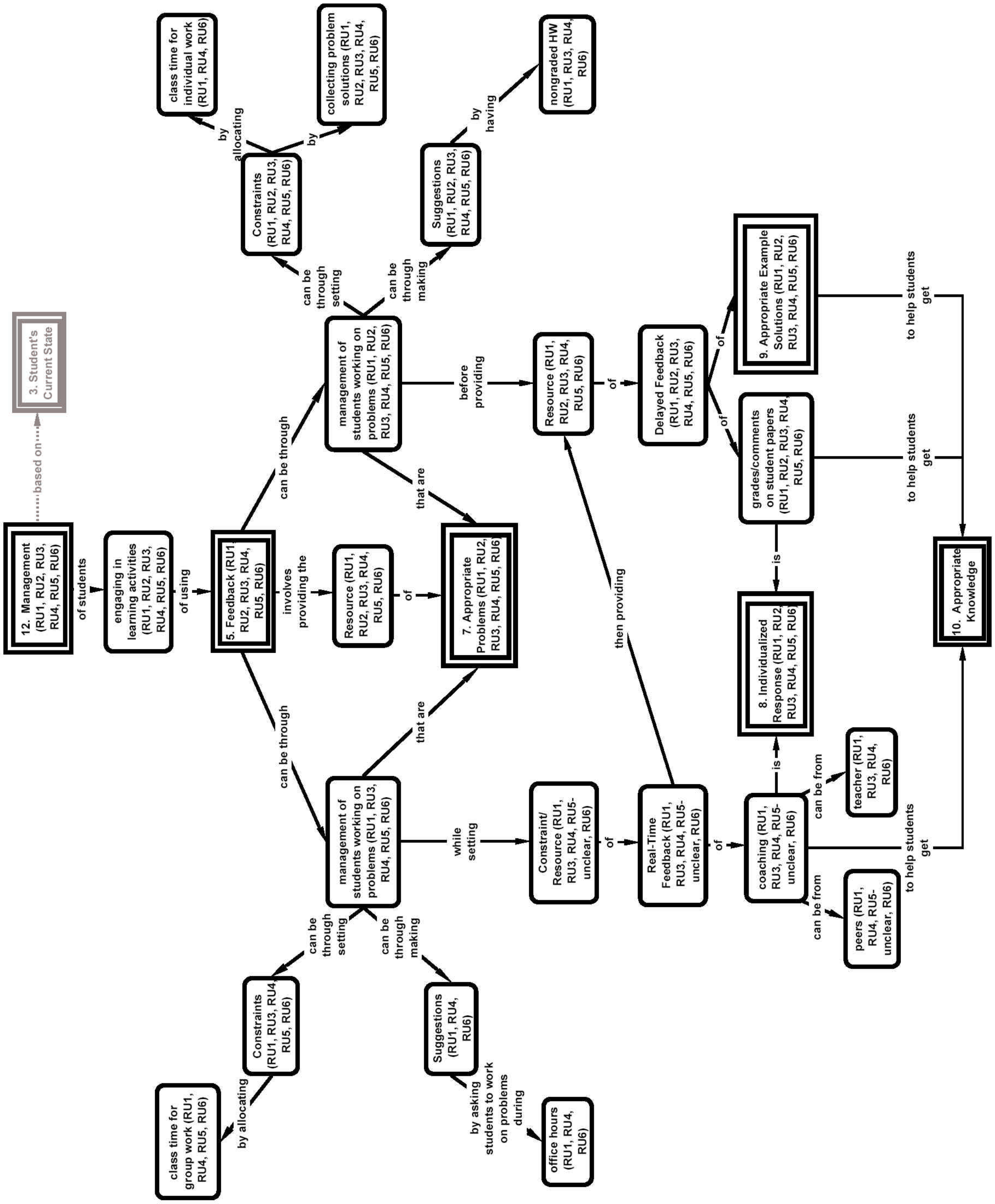


Figure 4-22: Map 12 (part 1) – Management of Students' Engagement in Learning Activities of Using Feedback (Path B)

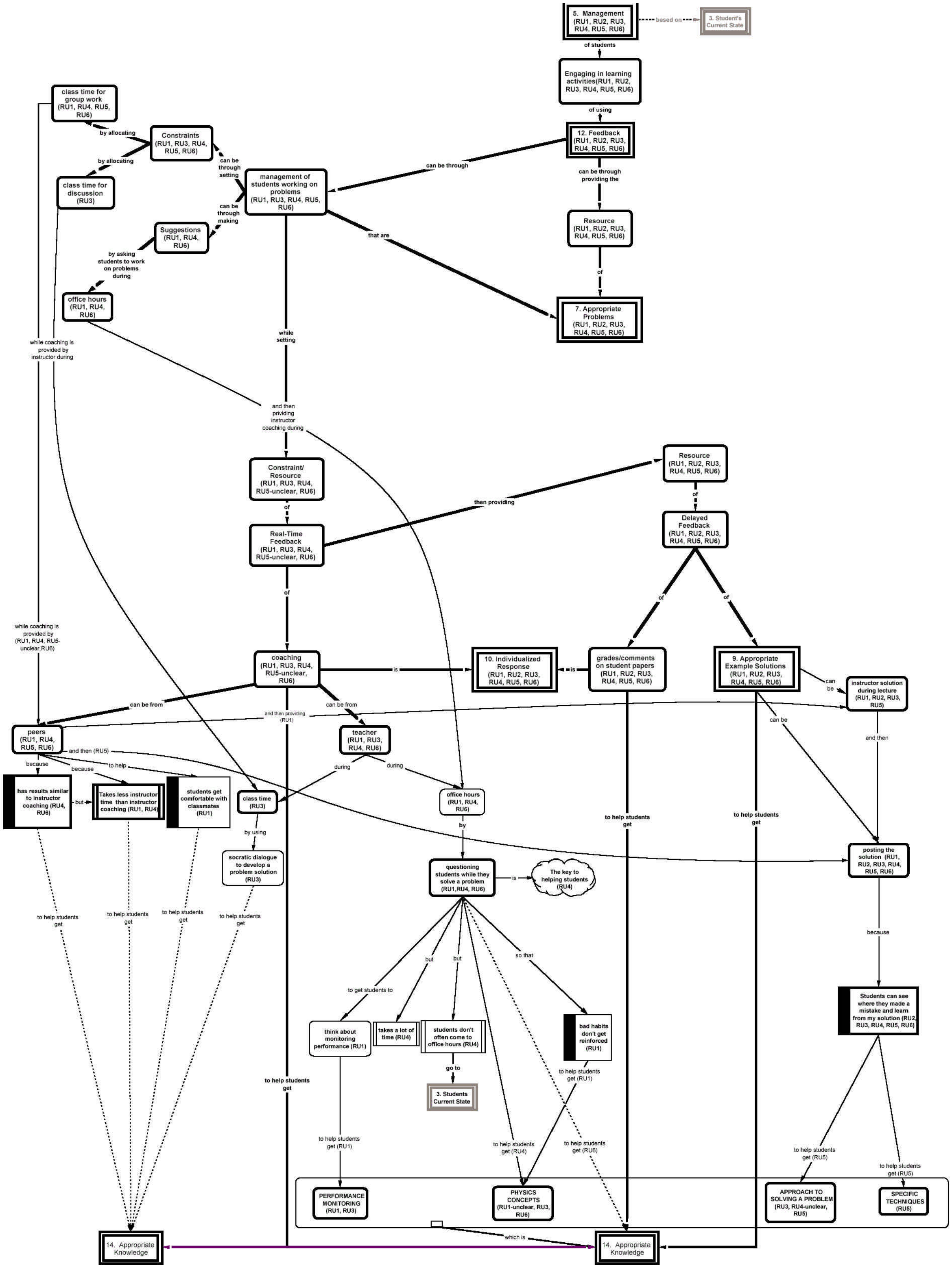
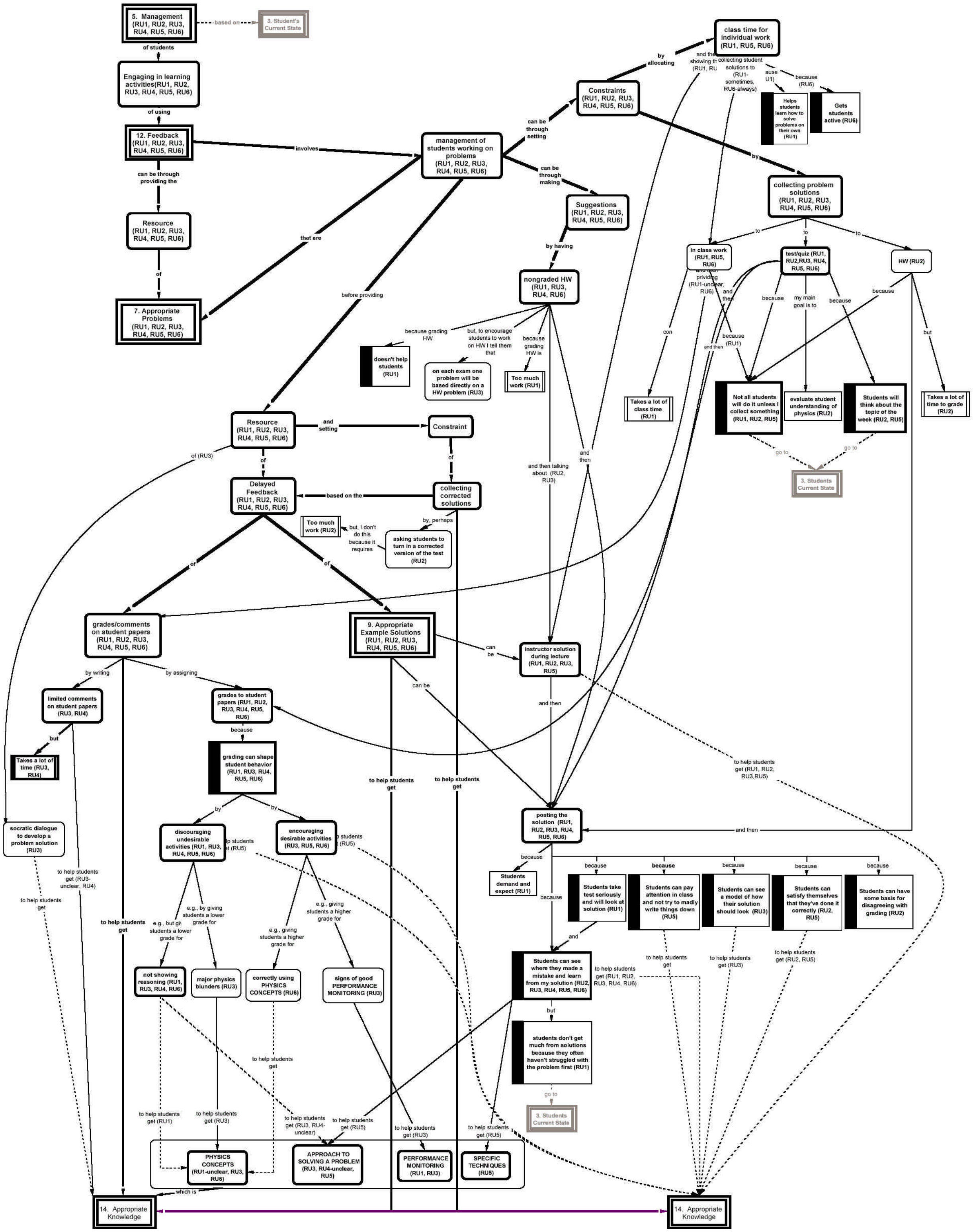


Figure 4-23: Map 12 (part 2) – Management of Students' Engagement in Learning Activities of Using Feedback (Path B)



Map 13: Management of Students' Engagement in Learning Activities of Looking/Listening (Path C)

This map (shown in Figure 4-24, p. 163) contains instructor conceptions of the things an instructor can/should do to help students learn while looking at appropriate example solutions or listening to lectures. When describing the management of students' engagement in learning activities of looking/listening, these instructors primarily talked about providing resources. They did not tend to talk about their management in terms of setting constraints or making suggestions. Only one instructor broke from this pattern. He described getting students to pay more attention to the posted appropriate example solutions by telling students that the test problems will be ones that they have seen before. The research team viewed this as setting a relatively mild constraint (as compared, for example, to having students turn in homework to be graded).

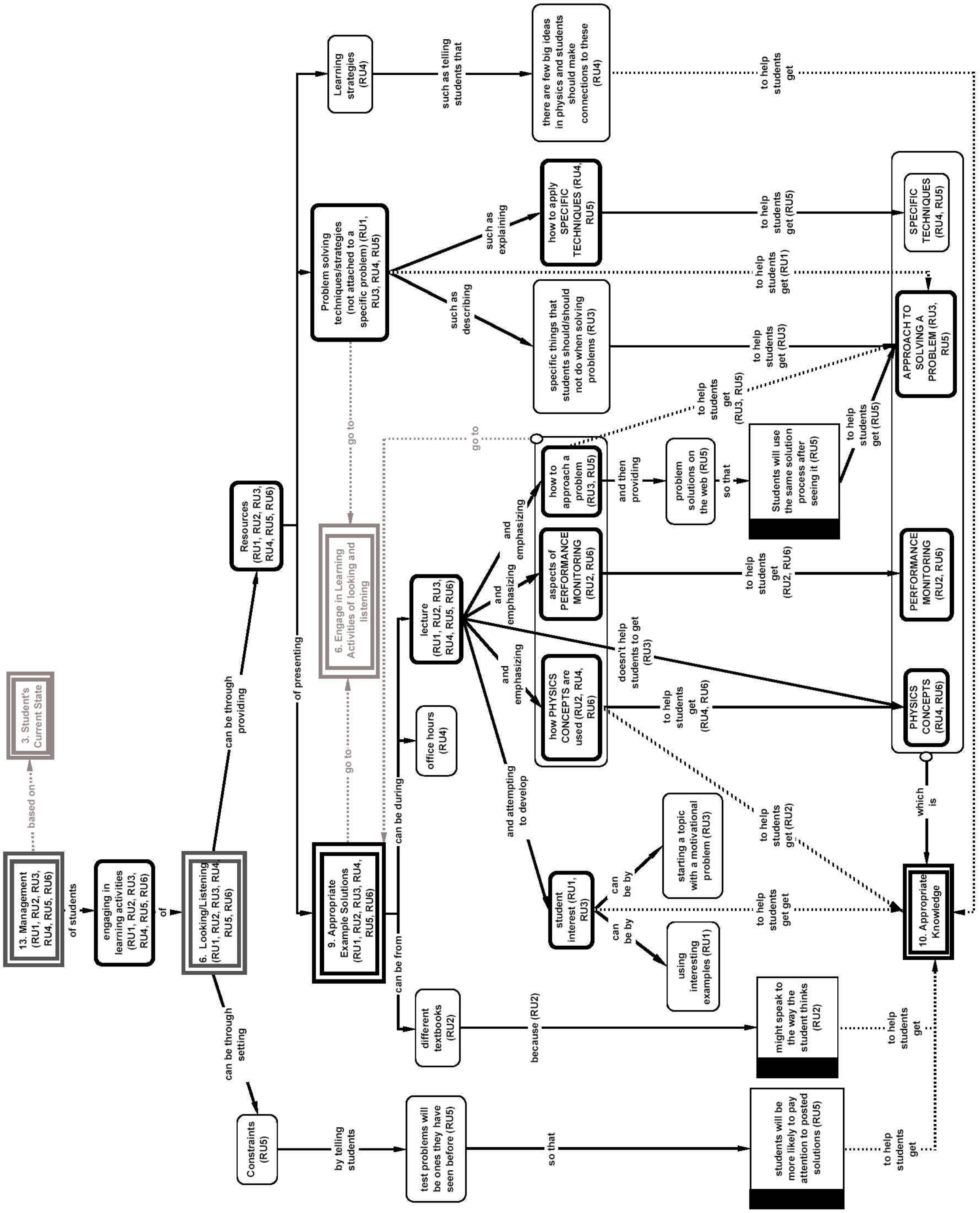
There are three qualitatively different ways that instructors conceive of their management of students' engagement in learning activities of looking/listening: solving problems on the board during lecture, talking about problem solving techniques/strategies, and solving interesting problems on the board during lecture. Two of the instructors have all three conceptions. Two of the instructors have two of the conceptions: solving problems on the board during lecture, and talking about problem solving techniques/strategies. Two of the instructors have only the conception of solving problems on the board during lecture.

1. ***Instructors can manage students' engagement in learning activities of looking/listening by conveying information to the students by solving problems on the board during lecture.*** All of the instructors described presenting example problem solutions on the board during lecture in an attempt to convey information to students. There was little agreement on they types of information that could be conveyed to students in this way. Even RU4, who said that students can't learn physics from just looking at someone else's solution (see Map 6), described solving appropriate example solutions in lecture to help students understand how PHYSICS CONCEPTS are used.

2. ***Instructors can manage students' engagement in learning activities of looking/listening by talking about problem solving techniques or strategies not attached to the solution of a particular problem.*** Four of the instructors described telling students about specific problem solving techniques or strategies separate from solving a particular problem. For example, two instructors said that they explained to students how to apply SPECIFIC TECHNIQUES. RU5, for example, said, "I can simply tell students, for example, that Bernoulli's equation has three terms in it and you could have two kinds of problems" (RU5, statement #334).

3. ***Instructors can manage students' engagement in learning activities of looking/listening by developing student interest by solving interesting problems on the board during lecture.*** Two of the instructors described presenting example problem solutions on the board during lecture in an attempt to develop student interest. The goal of these problems is not to convey information to students, but rather to motivate the students to want to understand the material. For example, RU3 said, "I'll begin a topic with what I'll call a motivational problem. The best one I can remember off the top of my head was for statics. So I put up a collapse of these walkways of this hotel in Kansas City ten years ago. A beautiful, subtle problem and have them talk it over in pairs for about 10 minutes before starting the subject and then literally go over that so a student might think 'hey yeah, maybe I should pay attention to lecture for the next couple of days.'" (RU3, statement #395). As Map 1 (p. 114) shows, most instructors view student motivation as being an important beneficial learning characteristic.

Figure 4-24: Map 13 – Management of Students' Engagement in Learning Activities of Looking/Listening (Path C)



Map 10: Appropriate Knowledge

This map (shown in Figure 4-25, p. 167) contains instructor conceptions about what types of knowledge or skills good problem solvers use to solve physics problems. There is conflicting evidence about whether or not these categories of knowledge/skill are *required* for solving physics problems. For example, elements of each of these categories can be found in Map 2 (Solve Physics Problems) as part of the problem solving process. On Map 3 (Students' Current State), however, we see that students, especially when they enter the class, have poor knowledge/skill related to problem solving. Nonetheless, instructors talk about students solving problems even very early in the course in order to get these types of knowledge/skill (see Maps 4, 5, and 6 in the Learning Activities Cluster, p. 122). The research team interprets this conflicting evidence as an indication that instructors are caught in a paradox where students need to *know how* to solve physics problems in order *to learn* how to solve physics problems. This hypothesis is discussed in Chapter 5 (p. 189).

Instructors conceive of five different types of appropriate knowledge: PHYSICS CONCEPTS, APPROACH TO SOLVING A PROBLEM, SPECIFIC TECHNIQUES, PERFORMANCE MONITORING, and professional physicist beliefs about problem solving. Three instructors conceive of all five types of appropriate knowledge. Two instructors conceive of the first four types of appropriate knowledge. One instructor conceives of only the first three types of appropriate knowledge.

1. ***Appropriate knowledge includes understanding PHYSICS CONCEPTS.*** All instructors have this conception. PHYSICS CONCEPTS includes such things as knowing conservation of energy and having a good sense of what centripetal acceleration does. Instructors expect students to get anywhere between "some" and "a lot" of this type of appropriate knowledge during a year-long introductory calculus-based physics course.

2. ***Appropriate knowledge includes having an APPROACH TO SOLVING A PROBLEM.*** All instructors have this conception. APPROACH TO SOLVING A PROBLEM includes things that are not tied to a particular

problem (e.g. having a strategy and being able to verbalize it) as well as things that are tied to a particular problem (e.g. being able to identify the physics concepts that underlie the solution). All of the instructors conceived of the APPROACH TO SOLVING A PROBLEM as abilities that are tied to a particular problem. Four of these did so in a way that made it difficult to distinguish their conceptions of the APPROACH TO SOLVING A PROBLEM from their conceptions of PHYSICS CONCEPTS. Three instructors conceive of the APPROACH TO SOLVING A PROBLEM as general abilities that are not tied to a particular problem. Three instructors expect students to get anywhere between “some” and “a lot” of this type of appropriate knowledge during a year-long introductory calculus-based physics course. One instructor, however, does not expect students to get this type of appropriate knowledge during a year-long introductory calculus-based physics course.

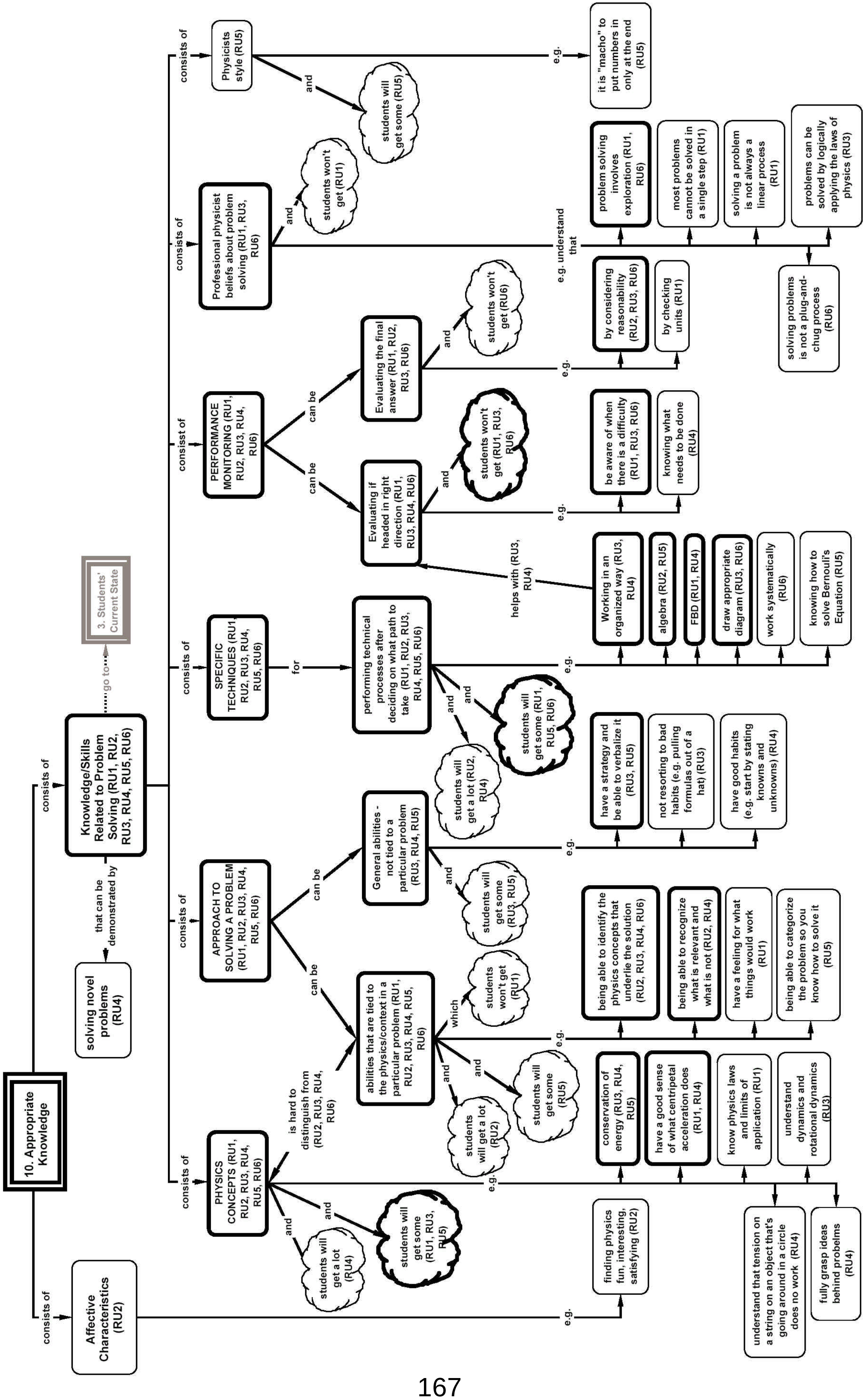
3. ***Appropriate knowledge includes being able to perform SPECIFIC TECHNIQUES.*** All instructors have this conception. SPECIFIC TECHNIQUES refers to an ability to perform technical processes after deciding on what path to take while solving a problem. For example, instructors said that solving a problem involves knowing how to do algebra and drawing free-body-diagrams. Instructors expect students to get anywhere between “some” and “a lot” of this type of appropriate knowledge during a year-long introductory calculus-based physics course.

4. ***Appropriate knowledge includes being able to do PERFORMANCE MONITORING.*** Five instructors have this conception. PERFORMANCE MONITORING refers to evaluating if headed in the right direction and evaluating the final answer while solving a problem. For example, RU1 commented that Student Solution C showed evidence of PERFORMANCE MONITORING because he was “aware of where the problem is” (RU1, statement #237) when he wrote “it can’t be that $v_f = v_b$ but I don’t know how to relate them. If $v_f = v_b$, then:…”. The instructors expect that being able to

do PERFORMANCE MONITORING is something that takes more time to develop and should not be expected of students after a single year-long class.

5. ***Appropriate knowledge consists of professional physicist beliefs about problem solving.*** Three instructors have this conception. Professional physicist beliefs about problem solving includes things such as understanding that problem solving involves exploration and that most problems cannot be solved in a single step. Only one instructor estimated student performance in this area and indicated that he did not expect students to develop these beliefs in a single year-long class.

Figure 4-25: Map 10 – Appropriate Knowledge



Map 14: Reflection on Teaching

This map (shown in Figure 4-26, p. 170) describes the things that instructors said during the interview that indicate how they reflect on their teaching performance. Note that this was not an explicit goal of the interview and only one question (Situation #6, Q8) was asked that specifically called for a reflection on teaching. Thus, the amount of information on this map is somewhat limited.

There are four qualitatively different ways that instructors reflect on their teaching: trying to learn about students, identifying difficulties based on past experience, considering the appropriateness of grading standards, and becoming aware of new ideas and/or knowledge from educational research. Three of the instructors have three of these conceptions. Three of the instructors have two of these conceptions.

1. ***Instructors reflect on their teaching by trying to learn about how students experience the course.*** Five instructors described ways that they try to learn about how students experience the course. For example, RU2 describes learning about students by having "a group of students with whom I meet four times during the semester because I can't make a poll of the whole class as to how things are going, and this group of students, they're meant to be representative of the class" (RU2, statement #147). RU4 describes learning about how students experience the course by "going around and snooping at the labs every once in a while to see how things are going" (RU4, statement#112).

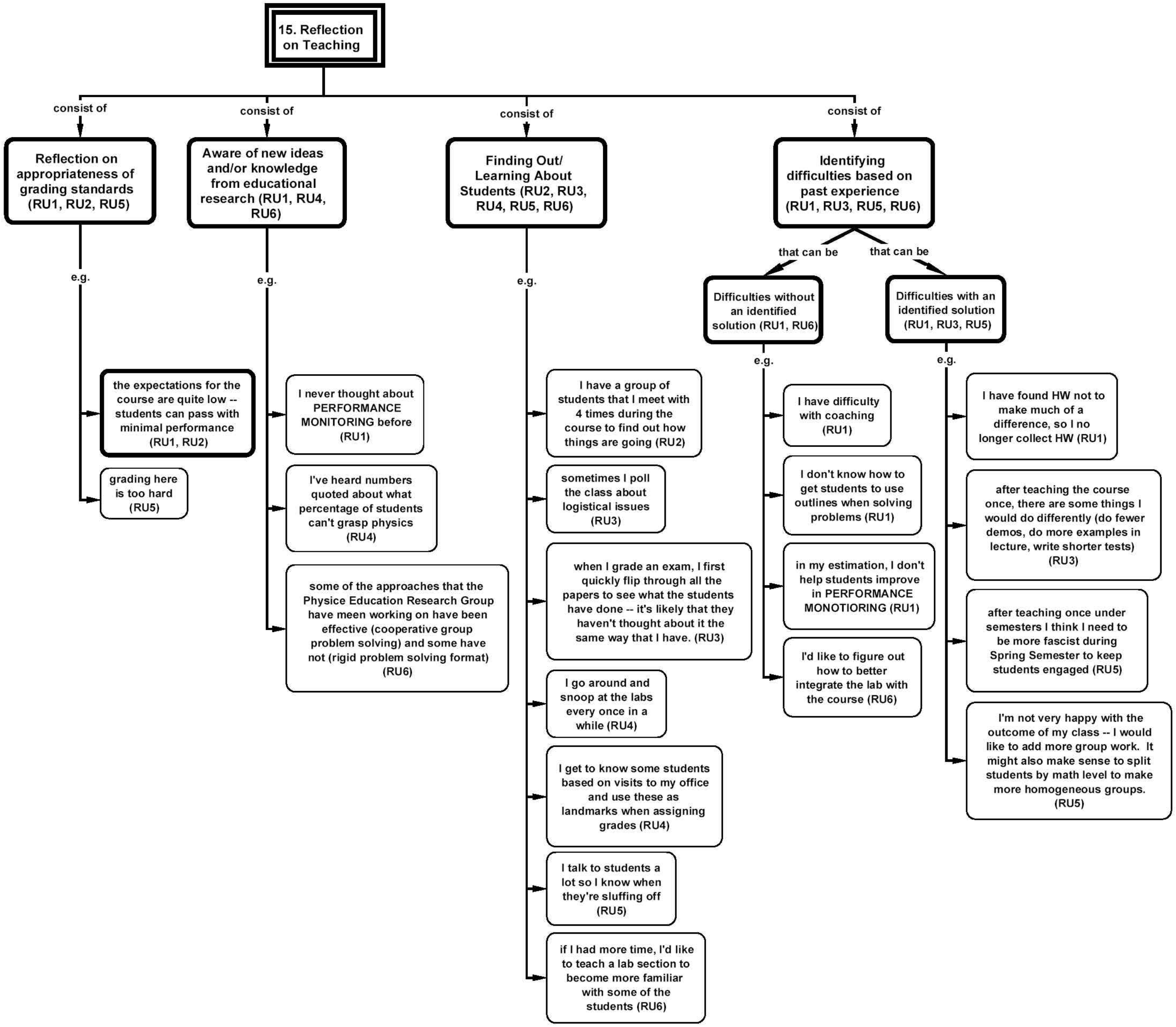
2. ***Instructors reflect on their teaching by identifying difficulties based on past experience.*** Four instructors described identifying difficulties based on past experience. Three of these instructors identified a difficulty and also identified a possible solution. For example, RU3 found that, when he taught the class, demos did not appear to be very helpful. Thus, in future classes, he thought that he would do fewer demonstrations and spend more time working example problem solutions. Although these instructors believe that they have found the cause of the problem, they do not describe any convincing evidence

to support their position. For example, it was not clear why RU3 believed that demonstrations were not very helpful.

Two of these instructors identified difficulties and did not identify a possible solution. One instructor, for example, expressed the conception that his class was not effective in helping students develop their knowledge/skill of PERFORMANCE MONITORING. He did not suggest any possible ways to change this situation.

3. ***Instructors reflect on their teaching by considering the appropriateness of grading standards.*** Three instructors discussed the appropriateness of the grading standards for their course. Two of the instructors thought that the grading standards were too low. They suggested that the expectations for the course were quite low and that students can pass with minimal performance. A third instructor, however, said that the grading standards were too high. This is an interesting difference of opinion given that these instructors teach the same population of students in the same introductory calculus-based physics courses. (The structure of the introductory calculus-based physics courses is described in Chapter 3, p. 71).
4. ***Instructors reflect on their teaching by becoming aware of new ideas and/or knowledge from educational research.*** Three instructors discussed using new ideas or ideas from educational research to reflect on their teaching. Two of the instructors mentioned ideas that they had become exposed to through educational research. Another instructor mentioned an idea that he became exposed to through his participation in the interview. He indicated that he had "never thought about PERFORMANCE MONITORING before" (RU1, statement #375).

Figure 4-26: Map 14 – Reflection on Teaching



Summary

In this chapter I have presented and described the viable explanatory model that was generated in this study to describe the conceptions that a small sample of university faculty have about the phenomena of the teaching and learning of problem solving in introductory calculus-based physics. Thus, a major conclusion of this study is that it is possible to generate such a model.

The model generated in this study can be best summarized by the Main Concept Map (see Figure 4-2, p. 109), however I will summarize it here in a table form that will allow the inclusion of more details about the general features of the map.

Table 4-1: Summary of instructors' conceptions of Some College Students, Solve Physics Problems, and Students' Current State.

Some College Students (Map 1)

Students' success in learning how to solve physics problems depends on their:

- Intelligence/natural ability (6 of 6)[*]
- Characteristics related to learning (6 of 6)
  Detrimental characteristics include: not caring/not working hard, poor study habits, and no interest in physics. Beneficial learning characteristics include: motivated/hard working, good study habits, and interest in physics.

Solve Physics Problems (Map 2)

The problem solving process is:

- A linear decision-making process (3 of 6)
  Problem solving involves using an understanding of physics concepts and specific techniques to make decisions and decide what to do next. The correct decision is always made and there is no need to backtrack.
- A process of exploration and trial and error (2 of 6)
  Problem solving involves using an understanding of physics concepts to explore and come up with possible choices that are then tested. Making mistakes and backtracking is a natural and necessary part of problem solving.
- An art form that is different for each problem (1 of 6)
  Problem solving involves artfully crafting a unique solution for each problem.

Students' Current State (Map 3)

Students in introductory calculus-based physics have:

- A mixture of beneficial, detrimental, and neutral personal characteristics related to learning (6 of 6)
  Including: study habits/skills, beliefs about learning physics, and motivation.
- Poor knowledge/skills related to problem solving (6 of 6)
  Including: physics concepts, approach to solving a problem, specific techniques, performance monitoring, beliefs about problem solving, and communication.

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[*] Number of instructors with the conception

Table 4-2: Summary of instructors' conceptions of what students can/should do to learn how to solve physics problems.

Working on Problems (Map 4)	**Using Feedback (Map 5)**	**Looking/Listening (Map 6)**
Students can learn by working on appropriate problems (6 of 6)	Students can learn by using feedback while/after working on appropriate problems (6 of 6): • Using delayed feedback (6 of 6) • Using real-time feedback (4 of 6)	Students can learn by looking and/or listening to provided resources (5 of 6): • Looking at appropriate example solutions (5 of 6) • Listening to lectures (4 of 6)

Table 4-3: Summary of instructors' conceptions of resources that can be provided to help students learn.

		Three Perspectives		
Specific Resource		**Effect on Student Learning** (6 of 6)	**Required Instructor Time** (6 of 6)	**Match with Student Preferences** (5 of 6)
Appropriate Problems (Map 7)		• Should encourage/require students to do/experience certain things (6 of 6) • Should be based on students' current state (6 of 6) • Should be based on realistic situations (5 of 6)	• Should be easy to create and grade (5 of 6)	• Should be liked by students (2 of 6)
Appropriate Example Solutions (Map 9)		• Should convey information to students (6 of 6) • Should be based on students' current state (6 of 6)	• Should be easy to write or find (4 of 6)	• Should not be too long or complicated looking (4 of 6)
Individualized Responses (Map 8)	**Comments on Student Papers**	• Helpful for students (1 of 6)	• Labor intensive (2 of 6)	
	Grades on Student Papers	• Shapes student behavior (3 of 6) • Allows students to know where they are (2 of 6)		• Students expect it (1 of 6)
	Peer Coaching	• Similar results to instructor coaching (2 of 6)	• Requires less instructor time than instructor coaching (2 of 6)	• Less intimidating for students than instructor coaching (1 of 6)
	Instructor Coaching	• Helpful for students (2 of 6)	• Labor intensive (1 of 6)	• Students don't come for coaching (1 of 6)

Table 4-4: Summary of instructors' conceptions of management of student learning activities.

	Three Management Activities		
Learning Activities	**Setting Constraint**	**Making Suggestion**	**Providing Resource**
Working on Problems (Map 11)	• on problems that students work (6 of 6)		• of appropriate problems (6 of 6)
	• on situations in which students work problems (3 of 6)		
		• that students work on problems (3 of 6)	
Using Feedback (Map 12)	• that students work on problems by collecting solutions: - test (6 of 6) - in-class work (2 of 6) - graded HW (1 of 6)		• of grades on student solutions (6 of 6)
		• that students work on problems (e.g. non-graded homework) (4 of 6)	• of appropriate example solutions (6 of 6)
	• by arranging class time for small group work (4 of 6)		• of peer coaching (4 of 6)
		• that students come to office hours (3 of 6)	• of instructor coaching (4 of 6)
Looking/Listening (Map 13)			• of solving problems on the board during lecture to convey information (6 of 6)
			• of talking about problem solving techniques not attached to the solution of a particular problem (4 of 6)
			• of solving problems on the board during lecture to develop student interest (2 of 6)

Table 4-5: Summary of instructors' conceptions of Appropriate Knowledge and Reflection on Teaching.

Appropriate Knowledge (Map 10)

The knowledge/skill that good problem solvers use to solve problems consists of:

- Understanding PHYSICS CONCEPTS (6 of 6)
  Examples include: knowing conservation of energy, having a good sense of what centripetal acceleration does.
- Being able to develop an APPROACH TO SOLVING A PROBLEM (6 of 6)
  Examples include: having a strategy and being able to verbalize it, being able to identify the physics concepts that underlie the solution.
- Being able to perform SPECIFIC TECHNIQUES (6 of 6)
  Examples include: ability to do algebra, ability to draw free-body diagrams.
- Being able to do PERFORMANCE MONITORING (5 of 6)
  Examples include: evaluating if headed in the right direction, evaluating the final answer.
- Professional physicist beliefs about problem solving (3 of 6)
  Examples include: understanding that problem solving involves exploration, understanding that most problems cannot be solved in a single step.

Reflection on Teaching (Map 14)

Instructors reflect on their teaching by:

- Learning about how students experience the course (5 of 6)
  For example, by visiting the labs every once in a while.
- Identifying difficulties based on past experience (4 of 6)
  For example, by realizing that demos were not very helpful.
- Considering the appropriateness of grading standards (3 of 6)
  For examples, by thinking that grading standards are too low.
- Becoming aware of new ideas and/or knowledge from educational research (3 of 6)
  For examples, by listening to a speaker who states what percentage of students can’t grasp physics.

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.

Some College Students (Map 1)

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).

Learning Activities Cluster (Maps 4-6)

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

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[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).

The Role of PERFORMANCE MONITORING in Problem Solving

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.

Possible Reasons for the Instructional Paradox

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.

Knowledge About the Initial State of the Student

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.

Knowledge About the Desired Learner Outcomes

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?

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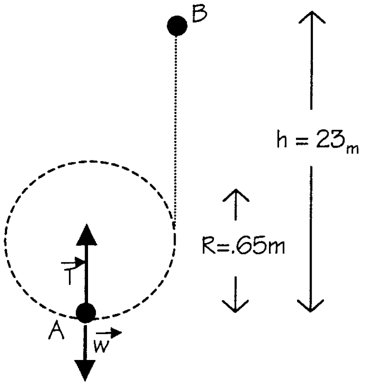
Appendix A

Interview Artifacts: Instructor Solutions

Instructor solution I



The tension does no work

Conservation of energy between point A and B

$$Mv_A^2/2 = mgh$$

$$V_A^2 = 2gh$$

At point A, Newton's 2nd Law gives us:

$$\vec{T} - \vec{w} = m\vec{a}$$

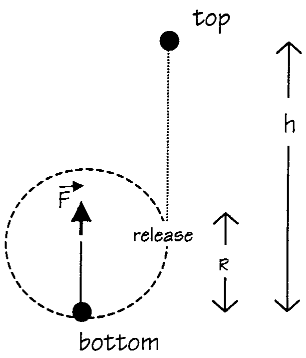
$$T - w = mv_A^2/R$$

$$T = 18_N + 2 \cdot 18_N \cdot 23_m/.65_m = \boxed{1292N}$$

Instructor solution II

Known
$w = 18N$ = weight of stone
$R = 0.65m$
$h = 23m$
$v_t = 0$ = velocity at top

Unknown
$v_r = ?$ = velocity at release
$v_b = ?$ = velocity at bottom
force my hand exerts = $F = ?$



Step 1) Find v_r needed to reach h

$E_i = E_f$

$E_{release} = E_{top}$

$PE_{release} + KE_{release} = PE_{top} + KE_{top}$

$\cancel{m}gR + \cancel{m}v_r^2/2 = \cancel{m}gh + \overset{0}{\cancel{mv_t^2/2}}$

$v_r^2 = 2g(h - R)$

Conservation of energy for the stone earth system, since no external forces.

Note: you could also choose other systems.

KE of earth estimated to be 0

You could also use kinematics to find v_r.

Step 2) Find v_b needed to have v_r at release

$E_{bottom} = E_{release}$

$PE_{bottom} + KE_{bottom} = PE_{release} + KE_{release}$

$mg0 + \cancel{m}v_b^2/2 = \cancel{m}gR + \cancel{m}v_r^2/2$

Using v_r from above:

$V_b = [2gh]^{1/2}$

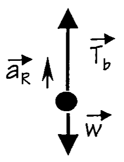
Conservation of energy for the stone earth system. Since $T \perp v$ in circular path, T does no work.

Step 3) Find T_b, tension at bottom, needed for stone to have v_b at bottom

$\sum \vec{F} = m\vec{a}$

$\sum F_R = ma_R$

$T_b - w = m\, v_b^2/R$



Free body diagram

To relate the forces to velocity we can look at the radial component, and use $a_R = v^2/R$.

Using v_b from above:

$T_b - w = 2\, mgh/R$

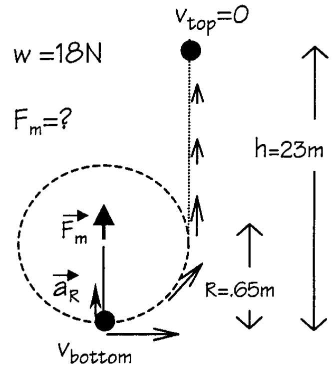
$T_b = w + 2\, w\, h/R = 18 + 2\; 18\; 23/.65 = \boxed{1292N}$

T_b equals F, the force my hand exerts, for a massless string

Instructor solution III

<u>Approach:</u>

I need to find F_m, force exerted by me. I know the path, h (height at top) and v_t (velocity at top)



A) For a massless string $F_m = T_b$ (T_b-Tension at bottom)

B) I can relate T_b to v_b (velocity at bottom) using the radial component of $\sum \vec{F}=m\vec{a}$, and radial acceleration $a_R=v^2/R$, since stone is in circular path

C) I can relate v_b to v_t using either i) energy ii) Dynamics and kinematics

ii) Messy since forces/accelerations change through the circular path

i) I can apply work-energy theorm for stone. Path has 2 parts:

first - circular, earth and rope interact with stone,

second - vertical, earth interacts with stone

In both parts the only force that does work is weight, since in first part hand is not moving $\Rightarrow \vec{T}\perp\vec{v} \Rightarrow \vec{T}$ does no work.

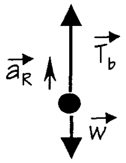
<u>Execution:</u>

B) Relate T_b to v_b

$$\sum \vec{F}= m\vec{a}$$

$$\sum F_R= ma_R$$

$$T_b- w = m\, v_b^2/R$$



C) Relate v_b to v_t

Work = ΔKE

For constant force

$$\vec{F} \cdot \vec{d} = KE_f - KE_i$$

$$F_y d_y = KE_{top} - KE_{bottom}$$

Substituting C) into B)

$$T_b - w = 2\, w\, h/R$$

$$F_m = T_b = w + 2\, w\, h/R$$

$$= 18 + 2\; 18\; 23/.65$$

$$= \boxed{1292\text{N}}$$

N=N m/m
units O.K.

Large compared to weight, but stone needs to travel up large distance

Check limits: $T_b\uparrow$ as R $\downarrow$, for smaller circle I'll need bigger force, reasonable

Appendix B

Interview Artifacts: Student Solutions

Student Solution A

$$\frac{V^2}{R} = a = \frac{F}{m} \qquad \frac{2\pi R}{T} = V$$

$$a = \frac{\left(\frac{2\pi R}{t}\right)^2}{R} = \frac{4\pi^2 R}{T^2}$$

$$V = \sqrt{Ra}$$

$$y = y_0 + vt + \frac{at^2}{2}$$

$$= 0.65 + \sqrt{Ra}\,t + \frac{at^2}{2}$$

$$\cancelto{0}{V^2} - V_0^2 = -2g\Delta y$$

$$V_0 = \sqrt{2g\Delta y} = \sqrt{Ra}$$

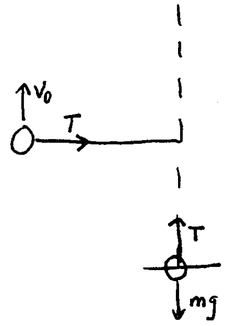
$$\frac{2g\Delta y}{R} = a = \frac{F}{m}$$

uses $V_{release}$ instead of V_{bottom}

Does not sum forces

$$F = \frac{2mg\Delta y}{R} = \frac{2\cdot 18\cdot(23-0.65)}{0.65} = 1237.846\,N$$

Student Solution B



This is a centripetal force problem $\Rightarrow F = m\frac{v^2}{R}$

Free fall:

$$\overset{= 0 \text{ at max. height}}{V_y} = V_0 - gt$$

$$gt = \frac{V_0}{g}$$

$$t = \frac{V_0}{g}$$

$$\Delta y = y_0 + V_0 t - \tfrac{1}{2} g t^2$$

$$\Delta y = y_0 + V_0\left(\frac{V_0}{g}\right) - \frac{1}{2} g \left(\frac{V_0}{g}\right)^2$$

$$\Delta y = y_0 + \frac{V_0^2}{g} - \frac{1}{2}\frac{V_0^2}{g}$$

$$\Delta y = \frac{(y_0 - 1/2)\, V_0^2}{g}$$

$\boxed{\text{uses } \Delta y \text{ instead of } y}$

$\boxed{\text{makes math error}}$

$$\frac{\Delta y g}{(y_0 - \frac{1}{2})} = V_0^2$$

$$T = F = ma = \frac{m V_0^2}{R}$$

$$= \frac{mg\Delta y}{(y_0 - 1/2) R}$$

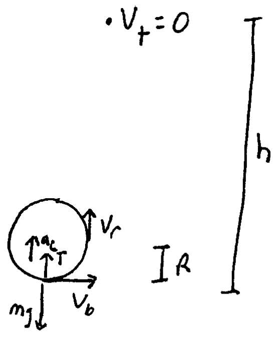
$$= \frac{18 \cdot 22.65}{(.65 - 1/2)(.65)} = 4182\,\text{N}$$

Force Exerted by me

$\boxed{\text{Does not sum Forces}}$

$\boxed{\text{uses } V_{release} \text{ instead of } V_{bottom}}$

Student Solution C



$V_t = 0$
$V_r = ?$
$V_b = ?$
$T = ?$
$mg = 18N$
$h = 23m$
$R = 0.65m$

Find velocity to reach height (free Fall)

$$V^2 - V_0^2 = 2a(y-y_0)$$

~~$0 - V_0^2 = 2(-g)(h)$~~

$$0 - V_r^2 = 2(-g)(h-R)$$

$$V_r = \sqrt{2g(h-R)}$$

$$= \sqrt{2\cdot 9.8\,m/s^2 \cdot (23-0.65)m} \qquad \sqrt{m/s^2 \cdot m} = m/s$$

$$= 20.9\,m/s$$

It can't be that $V_r = V_b$ but I don't know how to relate them. If $V_r = V_b$, then:

uses Vrelease instead of Vbottom

Find Force

$$\Sigma \bar{F} = m\bar{a}$$

$$T - mg = ma_c$$

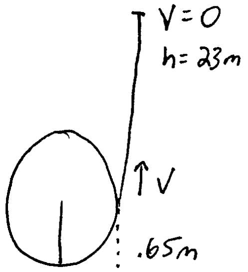
$$N + \frac{N}{m/s^2}\cdot\frac{m^2/s^2}{m} = N$$

$$T = mg + \frac{mV_r^2}{R} = 18N + \frac{\frac{18N}{9.8\,m/s^2}(20.9\,m/s^2)^2}{0.65m}$$

Force exerted by me $= 1256N$

Looks large, but stone needs to go up far

Student Solution D



Energy conservation between top and release

$$\frac{1}{2}mv^2 = mg\Delta h$$

$$v^2 = 2gh$$

$$V = \sqrt{2(-9.8)23}$$

$$V = 21.2$$

uses h instead of h-R

makes sign error

changes sign

Between release and bottom $T \perp v$ so no work done

∴ Energy is conserved and velocity is the same

$$\Sigma \bar{F} = m\bar{a}$$

$$T - mg = \frac{mv^2}{R}$$

$$T = 18 + \frac{\frac{18}{9.8} \cdot 21.2^2}{.65}$$

$$= 1292N$$

uses $V_{release}$ instead of V_{bottom}

Student Solution E

$$V^2 = 2gh$$

$$F - mg = \frac{m2gh}{R}$$

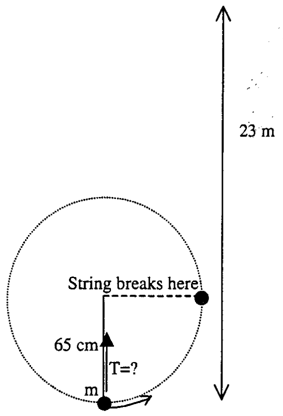
$$F = 18 + \frac{2 \cdot 18 \cdot 23}{.65} = 1292\ N$$

Appendix C

Interview Artifacts: Problems

Problem A

A 1.8 kg mass is attached to a frictionless pivot point and is moving in a circle at the end of a 65 cm string. The string breaks when the mass is moving directly upward and the mass rises to a maximum height of 23.0 m. What is the tension in the string one-quarter turn before the string breaks? Assume that air resistance can be neglected.



A) What velocity, v_1, must the stone have when released in order to rise to 23 meters above the lowest point in the circle?

B) What velocity, v_0, must the stone have when it is at its lowest point in order to have a velocity v_1 when released?

C) What force will you have to exert on the string at its lowest point in order for the stone to have a velocity v_0?

Problem B

You are whirling a stone tied to the end of a string around in a vertical circle having a radius of 65 cm. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a maximum height of 23 meters above the lowest point in the circle. In order to do this, what force will you have to exert on the string when the stone passes through its lowest point one-quarter turn before release? Assume that by the time that you have gotten the stone going and it makes its final turn around the circle, you are holding the end of the string at a fixed position. Assume also that air resistance can be neglected. The stone weighs 18 N.

A) 1292 N
B) 1258 N
C) 1248 N
D) 1210 N
E) None of the Above

Note: The choices are based on common student problems.

Problem C

You are working at a construction site and need to get a 3 lb. bag of nails to your co-worker standing on the top of the building (60 ft. from the ground). You don't want to climb all the way up and then back down again, so you try to throw the bag of nails up. Unfortunately, you're not strong enough to throw the bag of nails all the way up so you try another method. You tie the bag of nails to the end of a 2 ft. string and whirl the string around in a vertical circle. You try this, and after a little while of moving your hand back and forth to get the bag going in a circle you notice that you no longer have to move your hand to keep the bag moving in a circle. You think that if you release the bag of nails when the string is horizontal to the ground that the bag will go up to your co-worker. As you whirl the bag of nails around, however, you begin to worry that the string might break, so you stop and attempt to decide before continuing. According to the string manufacturer, the string is designed to hold up to 100 lbs. You know from experience that the string is most likely to break when the bag of nails is at its lowest point.

Problem D

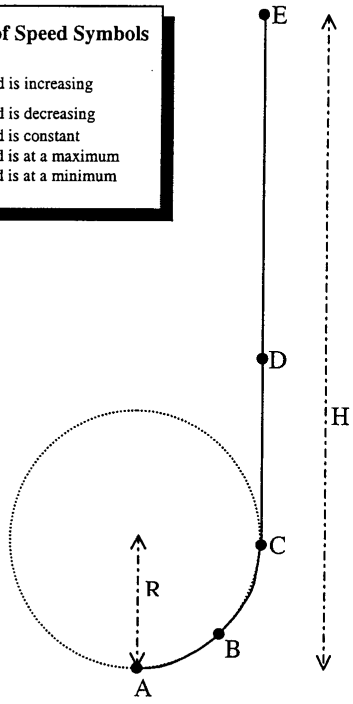
You are whirling a stone tied to the end of a string around in a vertical circle of radius R. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a maximum height, H, above the lowest point in the circle. In order to do this, what force will you have to exert on the string when the stone passes through its lowest point one-quarter turn before release? Assume that by the time that you have gotten the stone going and it makes its final turn around the circle, you are holding the end of the string at a fixed position. Assume also that air resistance can be neglected.

A) For each point labeled in the diagram, circle the symbol(s) that describe how the speed of the stone is changing.

Point	Change in Speed
A	↑ ↓ = max min
B	↑ ↓ = max min
C	↑ ↓ = max min
D	↑ ↓ = max min
E	↑ ↓ = max min

Change of Speed Symbols

↑	Speed is increasing
↓	Speed is decreasing
=	Speed is constant
max	Speed is at a maximum
min	Speed is at a minimum



B) At each point on the diagram, draw and label a vector representing the acceleration of the stone.

C) At each point, draw and label vectors to represent all of the forces acting on the stone.

Appendix D

Interview Protocol

Introduction

"This interview is divided into 4 situations, the first focuses on solutions that instructors give students, the second on solutions students give instructors, the third on possible ways of posing problems, and the final situation will be a combination of the things we've talked about in the first three situations. Throughout the interview we will refer back to the "homework problem" that you solved."

"Please think about your experience teaching introductory calculus-based physics as you answer the interview questions. I'll start with examples of solved problems."

Situation #1 (Example Problem Solutions)

Q1: "In what situations are students provided with examples of solved problems in your class. For example, during lecture, after homework or a test, etc."

Probing question, if necessary: "How does this work? Do you hand out the solutions, or is there something else that happens?"

"What is your purpose in providing solved examples in these different situations?"

Q2: "How would you like your students to use the solved examples you give them in these different situations? Why?"

"What do you think most of them actually do?"

Q3: **"**Here are several instructor solutions for the problem you solved that were designed to be posted or distributed for students to see. They are based on actual instructor solutions."

"Take a look at each of these instructor solutions and describe how they are similar or different to your solutions. Please explain your reasons for writing solutions the way you do."

"I want to look now from a slightly different Perspective: Some instructors' solutions represent aspects/components of what instructors consider important in problem solving. This may include things that a student needs to know or be able to do, or explicit representation of thought processes he has to go through while solving a problem. Now, I'd like to have you consider how these things are represented in the worked examples."

Q4: “Looking at the instructor solutions, what aspects/components that you consider important in problem solving are represented in these instructor solutions, and what aspects are not represented?”

Write each thing on an individual index card (Label card IS and solution #).

Situation #2 (Student Solutions)

Q1: “This situation will deal with written student solutions. We will first focus on grading of student solutions. I imagine you grade students on the final exam and quizzes. What is your purpose in grading the students?

“What would you like your students to do with the graded solutions you return to them?”

Probing question, if necessary: “Why?”

“What do you think most of them actually do?”

“Are there other situations besides the final exam and quizzes in which your students are graded? Do you have the same purposes for these situations?”

Q2: “Here are student solutions to the problem that we have been looking at. These solutions are based on actual student solutions from an introductory calculus-based physics class at the University of Minnesota. To save time, we have indicated errors in each solution in the boxes on the page.”

“Please put the solutions in order of the grade they would receive for this solution on a quiz if they were in your class. Then I’ll ask you to grade them and explain your grading. Assume the students were told by you about how they will be graded.

Probing question, if necessary: “What are the features you considered when assigning this grade?”

Record the grades and ranking.

Probing question, if necessary: “Please explain what these numbers mean – what is your grading scale?”

“Would you grade them differently if they were graded in the other situations (other than a quiz)? How?”

Q3: "Now I would like to use these student solutions to expand the discussion of aspects or components of problem solving that we started in the 1st situation. Here I'd like to focus on what students actually think or do while solving a problem."

"Imagine you gave this problem to your students for homework near the end of your course and you got the following solutions. I know that it is not possible to infer with certainty from a written solution what a student went through while he was solving the problem. However, in this situation I will ask you to do just that."

"Try to put yourself in the students' shoes: go through the solution from beginning to end, following what you think was on the students mind when he did what he did, and speculate about things that are suggested by these solutions".

"What other aspects/components of problem solving that we havn't already talked about are suggested by these solutions. By aspects/components of problem solving we mean thought processes that the student might have gone through, things he might have known or done."

Write each thing on a card, in a positive manner (Label card SS and solution letter).

Probing question, if necessary (make sure this is answered for all student solutions):
"What is your overall impression of each of these students approaches? What are the most important differences between them?"

"Are there other things that you have noticed in the way students solve problems that we haven't talked about already?"

Write each thing on a card, in a positive manner (Label card SS).

Situation #3 (Problems)

Q1: "In the first two situations we dealt with one problem and talked a lot about what sorts of things a student might need to know or be able to do to solve it. In this situation, we will expand our view somewhat by looking at other ways of asking problems around the same physical situation. There are four new problems."

"Please describe how these problems are similar or different to problems you give to your students. Please explain why you use the problems that you use."

Probing question, if necessary: "Do the problems you give students look different in different situations (lecture, homework, test, Beginning or end of course…)? How and Why?"

Q2: "Different ways of asking problems require different things from students. We would like to use these problems to capture aspects of problem solving that we might not have talked about yet."

"Comparing these problems to the problem that we have been using so far (the Homework Problem), are there things a student needs to know or be able to do when solving these problems that are not required in solving the homework problem? Do you see any things that the homework problem requires that you haven't yet mentioned?"

Write each thing on a card (Label card P and problem letter).

Situation #4 (Grand finale)

Q1: "Now I would like to combine the things that we've talked about in the last 3 situations. I've written each of the things you thought students might go through when solving a problem on an individual card. I would like to have us talk about these in more detail, but to make it simpler I would first like you to categorize them."

"Please put these cards into categories of your choosing?"

Probing question, if necessary: "Tell me about each category … Why do these go together? How would you name this category?"

Write each category on a big index card, clip it on top of the cards in the category. Write the name of each category on recording sheet.

Q2: "For students who had troubles with each of these categories at the beginning of the course, what do you think they could do to overcome them?"

Q3: "For a student who had trouble with each of these categories, what could you do to help him/her overcome it?"

Probing questions, if necessary: "In particular what type of solved examples or problems could you give? What would you ask students to do with them? How would you grade to help this type of student?"

Q4: "I would like to focus on how hard it is for students to improve in the things in each of these categories if they had trouble with them in the beginning of the course? Please put the cards in order from easiest to hardest for students to improve. Please explain your ordering."

Write ordering on recording sheet.

Q5: "Which of these things is it reasonable to expect most students to be able to do by the end of the introductory calculus-based physics course? Why?"

Q6: "Next, I'd like to find out where your students are regarding the things you mentioned. Think about a typical calculus based physics course at your school. For each category check the appropriate box that represents roughly what portion of the class can do these sorts of things at the beginning of the course and what portion of your class can do them at the end of the course?"

Allow Interviewee to fill in appropriate section on recording sheet.

Q7: "I want you to focus on two kinds of students: those who improved things they had trouble with at the beginning, and those who did not. What makes these 2 kinds of students different?"

Probing questions, if necessary: "What things did each kind of student do during class? What qualities did each kind of student bring to class?"

Q8: "Looking down the list of changes of your students during the course, are you happy with your course outcomes? What would need to be different in order for you to be happier?"

Probing questions, if necessary: "How should your institution treat the Introductory physics course? What can you as an instructor do? Should students be required to bring certain qualities to class?"

Probing questions, if the instructor indicates that he is interested in changing something about himself or his teaching (if necessary): "What could help you in doing things differently? What could help you to find out how you could do things differently?"

Recording Sheet (For Situation #4)

Categories of things	Difficulty of Improvement (1 for hardest)	Beginning				End				Satisfaction	
		0 - 25%	25 - 50%	50 - 75%	75 - 100%	0 - 25%	25 - 50%	50 - 75%	75 - 100%	Yes	What needs to change?
1.	○										
2.	○										
3.	○										
4.	○										
5.	○										
6.	○										
7.	○										
8.	○										
9.	○										

Appendix E

Packed Mailed to Interviewee Prior to Interview

Cover Letter

Homework Problem

Background Questionnaire

Physics Education Research Group
April XX, 2000

Dr. Research Participant
Department of Physics
Whatever University
123 Street Address
City, State, ZIP

Dear Dr. Participant;

Thank you for agreeing to participate in our NSF-sponsored study "Problem Solving in Introductory Physics". Your interview is scheduled for Tuesday, April XX, 2000 at 1:00 PM. We will meet you at your office. The interview will be videotaped and take approximately 1½ hours to complete.

Enclosed is a background questionnaire that we would like you to complete – it should take about 5 minutes. Also enclosed is an introductory physics problem labeled "Homework Problem". Many parts of the interview will be based around this problem and its solution so we'd like you to solve it before coming to the interview.

We appreciate your participation in this project and hope that you will find the interview thought provoking.

Please contact us if you have any questions.

Sincerely;

Charles Henderson
612-625-9323
hend0007@tc.umn.edu

Edit Yerushalmi
612-624-7578
Idit@physics.umn.edu

Homework Problem

You are whirling a stone tied to the end of a string around in a vertical circle having a radius of 65 cm. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a maximum height of 23 meters above the lowest point in the circle. In order to do this, what force will you have to exert on the string when the stone passes through its lowest point one-quarter turn before release? Assume that by the time that you have gotten the stone going and it makes its final turn around the circle, you are holding the end of the string at a fixed position. Assume also that air resistance can be neglected. The stone weighs 18 N.

The correct answer is 1292 N

BACKGROUND INFORMATION

Your answers to the following questions will help us understand the interview results.

Name ____

Where do you teach? ____

Sex: ☐ Male
☐ Female

How many years have you taught physics at the college level? _______

	Introductory Calculus-Based Physics	Introductory Algebra-Based Physics	Introductory Honors Physics
Is this class offered at your school?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
How many times have you taught this course?			
What was the last year that you taught this course?			

COURSE INFORMATION:

Please answer the following questions as they apply to the introductory calculus-based course at your school when you are the course instructor.

How many students are in a typical introductory calculus-based course: ___________

What is the gender distribution of a typical introductory calculus-based course:

_____% Male

_____% Female

Lecture / Whole Class Meetings

Who is in charge: ☐ I am
☐ Someone else
(Another Professor, Staff Member, Teaching Assistant, etc.)

Contact hours/week: __________

Special Session

What type(s) of special sessions do you have?
☐ No Special Session
☐ Recitation / Discussion Session
☐ Tutorial Session
☐ Problem-Solving Session
☐ Other: ________________

Who is in charge? ☐ I am
☐ Someone else
(Another Professor, Staff Member, Teaching Assistant, etc.)

Contact hours/week: __________

Please check the appropriate box to indicate ***how often*** *the following activities occur in each portion of your introductory calculus-based physics course. Each activity is broken down into two categories – one involving problem solving and the* ***other*** *involving other types of activities.*

A = HARDLY EVER B = NOT VERY OFTEN C = SOMETIMES D = QUITE OFTEN E = ALMOST ALWAYS

	Lecture					**Special Session**				
	A	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
Instructor solves example problem	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other Instructor presentation (e.g. lecture, demo)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Whole-class discussion leading to a problem solution	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other whole-class discussion (e.g. exploring new concept)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Student presents problem solution	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other student presentation (e.g. project report)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Students work in small groups to solve a problem	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other student small group work (e.g. discussing new concept)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Students work alone to solve a problem	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other individual student work (e.g. read textbook)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Laboratory

Who is in charge? ☐ I am
☐ Someone else (Another Professor, Staff Member, Teaching Assistant, etc.)

Contact hours/week: __________

Please check the appropriate box to indicate ***the importance*** *of the following goals in the* ***Laboratory*** *portion of your introductory calculus-based physics course.*

A = UNIMPORTANT
B = SLIGHTLY IMPORTANT
C = SOMEWHAT IMPORTANT
D = IMPORTANT
E = VERY IMPORTANT

	A	**B**	**C**	**D**	**E**
The purpose(s)/goal(s) of ***our lab*** *is for students to:*					
Verify physical principles	☐	☐	☐	☐	☐
Learn to use experimental tools	☐	☐	☐	☐	☐
Build conceptual knowledge	☐	☐	☐	☐	☐
Develop scientific reasoning skills	☐	☐	☐	☐	☐
Improve problem solving skills	☐	☐	☐	☐	☐
Other: ____________________	☐	☐	☐	☐	☐

Office Hours

Contact hours/week: __________

Grading

Who is in charge? ☐ I am
☐ Someone else (Another professor, Staff Member, Teaching Assistant, etc.)

How much time do **you** spend grading (hours/week)? __________

Goals for the Introductory Physics Course:

Many different goals could be addressed through a calculus-based introductory physics course. Please rate each of the following possible goals in relation to its importance.

A = UNIMPORTANT	C = SOMEWHAT IMPORTANT	E = VERY IMPORTANT
B = SLIGHTLY IMPORTANT	D = IMPORTANT	

	A	B	C	D	E
Know the basic principles behind all physics (e.g. forces, conservation of energy,...).	☐	☐	☐	☐	☐
Know the range of applicability of the principles of physics (e.g. conservation of energy applied to fluid flow, heat transfer, plasmas,...).	☐	☐	☐	☐	☐
Be familiar with a wide range of physics topics (e.g. specific heat, AC circuits, rotational motion, geometric optics,...).	☐	☐	☐	☐	☐
Solve problems using general quantitative problem solving skills within the context of physics.	☐	☐	☐	☐	☐
Solve problems using general qualitative logical reasoning within the context of physics.	☐	☐	☐	☐	☐
Formulate and carry out experiments.	☐	☐	☐	☐	☐
Analyze data from physical measurements.	☐	☐	☐	☐	☐
Use modern measurement tools for physical measurements (e.g. oscilloscopes, computer data acquisition, timing techniques,...).	☐	☐	☐	☐	☐
Program computers to solve problems within the context of physics.	☐	☐	☐	☐	☐
Overcome misconceptions about the behavior of the physical world.	☐	☐	☐	☐	☐
Understand and appreciate "modern physics" (e.g. solid state, quantum optics, cosmology, quantum mechanics, nuclei, particles,...).	☐	☐	☐	☐	☐
Understand and appreciate the historical development and intellectual organization of physics.	☐	☐	☐	☐	☐
Express, verbally and in writing, logical, qualitative thought in the context of physics	☐	☐	☐	☐	☐
Learn to work in teams to solve problems within the context of physics.	☐	☐	☐	☐	☐
Use with confidence the physics topics covered.	☐	☐	☐	☐	☐
Apply the physics topics covered to new situations not explicitly taught by the course.	☐	☐	☐	☐	☐
Other Goal: ______________________________	☐	☐	☐	☐	☐

Please place a star (*) next to the two goals listed above that you consider to be most important.

Appendix F

Consent Form

CONSENT FORM
Problem Solving in Introductory Physics

You are invited to be in a research study of physics problem solving. We have selected you because you have taught introductory calculus-based physics in the Twin Cities area in the last five years. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by: Pat Heller, Ken Heller, Charles Henderson, and Idit Yerushalmi from the University of Minnesota.

Background Information:

We are conducting a study, funded by the National Science Foundation, to determine what physics faculty value in the learning and teaching of problem solving. We will use this information to improve the design of curricular materials.

Procedures:

If you agree to be in this study, you will be asked to complete four tasks that are based on physics problems and solutions taken from introductory calculus-based physics courses. The entire interview should take approximately 1½ hours. The interview will be videotaped, however the video will be focused on the activity you are performing. Your face or other identifying features will not be videotaped.

Risks and Benefits of Being in the Study:

There are no risks to participation in this study.

We hope that you will find the interview questions interesting and that they allow you to think about aspects of physics instruction that you might not frequently have the time to consider.

Confidentiality:

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify you. Research records will be kept in a locked file; only researchers will have access to the records. The videotapes will only be accessible by the researchers. They will be kept for three years after the completion of the study and then destroyed.

Voluntary Nature of the Study:

Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Contacts and Questions:

The researchers conducting this study are Pat Heller, Ken Heller, Charles Henderson, and Idit Yerushalmi. You may ask any questions you have now. If you have questions later, you may contact them at Physics Building, room #161; Phone: (612) 625-9323.

If you have any questions or concerns regarding the study and would like to talk to someone other than the researcher(s), contact Research Subjects' Advocate line, D528 Mayo, 420 Delaware Street S.E., Minneapolis, Minnesota 55455; telephone (612) 625-1650.

You will be given a copy of this form to keep for your records.

Statement of Consent:

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature ____ Date ________________

Signature of Investigator ___________________________ Date ________________

Appendix G

Note Cards and Categorization for Each Instructor

	RU1	RU2	RU3	RU4	RU5	RU6
APPROACH TO SOLVING A PROBLEM	**Overall Approach/Philosphy** - Need to know where relations come from - Need to know how to break problem into steps. - Understand there is not logical path to understanding when to use a relation - Important to explore yourself what you can do with physics ideas. - Translating English statements to physics/math equations.	**Strategy** - Thinks velocity is same at release and bottom. - Looking at formulas at constant acceleration. - Understands that kinematics/kinetic energy can be used. - It must be free fall. - Realizes energy conservation is a key to the problem. - Assembling steps. - Sees it is a centripetal force problem. - Sees that he needs to find velocity. - Physics principles. - Constant acceleration in a gravitational field. - Puts ideas together: centripetal force, constant acceleration in a gravitational field. - Analyze each step. -What are the principles?	**Strategic Things** - Need to decide on steps. - Identify physics in a problem situation. - Need to follow some strategy. - Technical Processes. - Draw a diagram - Organize solution well. - Reasoning process. - Identify physical concepts.	**Organizing work** (so you know what needs to be done and someone else can understand.) - Develop a strategy to arrange principles - Leave quantities in symbolic form until the end. - Puts garbage (irrelevant information) on the paper. - Messy style. - Manipulating equations. - Have a strategy. - Summarize knowns and unknowns at beginning. **Distressing Things** -Pull formulas out of hat.	**General Approach** - Divide problem into parts. - Realize that problem involves dynamics. - Categorize problems (i.e. PE, elastic collision, etc.) - Organize decision-making on a tree structure. - Figure out what the problem is. - Think about problem in a logical way.	**Hope Students Don't** - Use formula from book. - Searching for formulas.
PHYSICS CONCEPTS	**General Understanding of Physics Laws** - Realize part of motion is not constant acceleration - Use energy conservation correctly - know how to use small tools (e.g. F-ma) - Come up with relation and then justify it - Force has to do with centripetal acceleration.		**Important Physics Concepts** - Identify role of rotational dynamics and conservation of energy. - Converting between units. - Understand dynamics. - Needs to know conservation of energy. - Identify conservation of energy.	**Big Principles** - Have good insight. - Centripetal acceleration. - Conservation of energy. - Fully grasp idea of conservation of energy. - Have a grasp of qualitative features of problem. - Know that tension in string in a circular path does no work. - Use all important principles.	**Decide on Principles** - Decide what principles to use (i.e. A potential energy problem, then a force problem).	**Understand Physics** - Realize energy is involved. - See relationship between T⊥v and energy conservation. - Do force balance correctly. - See energy conservation
PERFORMANCE MONITORING	**Big Picture Technique** - Need to evaluate if right direction - Be aware of where the problem is - Need sense of direction	**Perspective** (The ability of a solver to have a feeling for what the answer should be and a tendency to try to connect a problem solution with reality.) - Translate back to see if meaningful.	**Signs of Maturity** - Have faith in answer. - Recognize when something is missing. - Comment on result.		X	**Hope Students Do** - Intuition - Realize that final result is large. - Have a doubt when unsure. - Play around to see what approaches might be valuable.

SPECIFIC TECHNIQUES	**Technique** - Distinguish velocity between different points (don't use same *v* everywhere) - Need to define variables - Good algebra skills - Draw force diagrams for various situations - Check units	**Implementation** - Comes Up With Expression For Velocity. - Expression For Tension. - To Get The Result. - Substitutes Get Answer. - Combine To Mathematical Form. - He Knows He Finds Velocity At The Wrong Point. - Diagram To Clarify. - Characteristics Of The Motion. - Adds *Mg*. - V^2/R - Using conservation of energy.	**X**	**X**	**Techniques** - Match PE to KE - Use correct points for energy conservation - Do algebra correctly. - Get sign of mg right in ΣF=ma. - Write a table for horizontal vs. vertical motion (in kinematics.)	**Procedural** - Draw vector diagrams - Make sure units OK. - Draw pictures. - Systematic. - Check units. - Read and understand problem.
MISCELLANEOUS	**Details** - Need mental picture - Using correct height					
		Gratuitous Remarks - $T \perp v$, so no work is done.				
				Specific to problem at hand - Understand reference for height - Remember that the weight force is there. - Use free fall and kinematics.		
				Multiple Choice (Things that relate to multiple-choice questions) - If answer is off, go back and find difficulty. - Have confidence in answer.		
					Style (culture of physics) - Don't put numbers in until the end.	