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*	$P = \frac{\frac{1}{3} N m \overline{v^2}}{V}$ (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

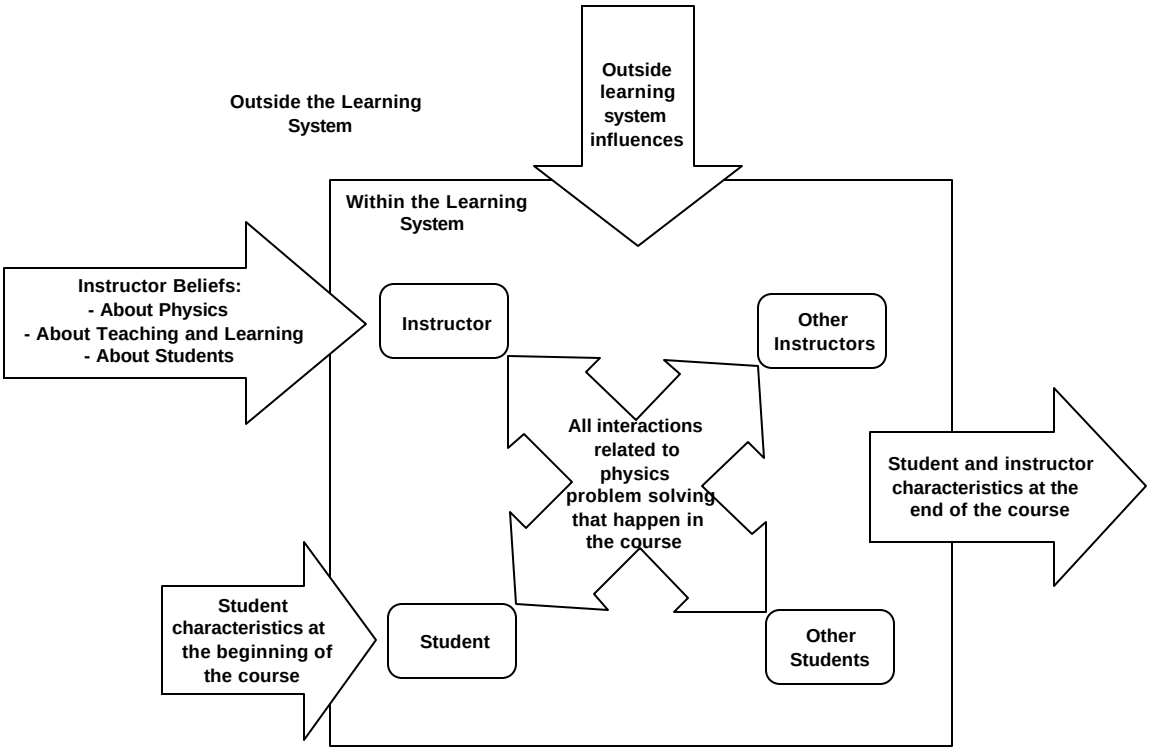
Although there are a wide variety of qualitative research methods used, most methods consist of at least three distinct parts (Miles & Huberman, 1994): a) breaking the text into some sorts of units; b) categorizing the units; c) looking at the categorized units in a way that increases understanding of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

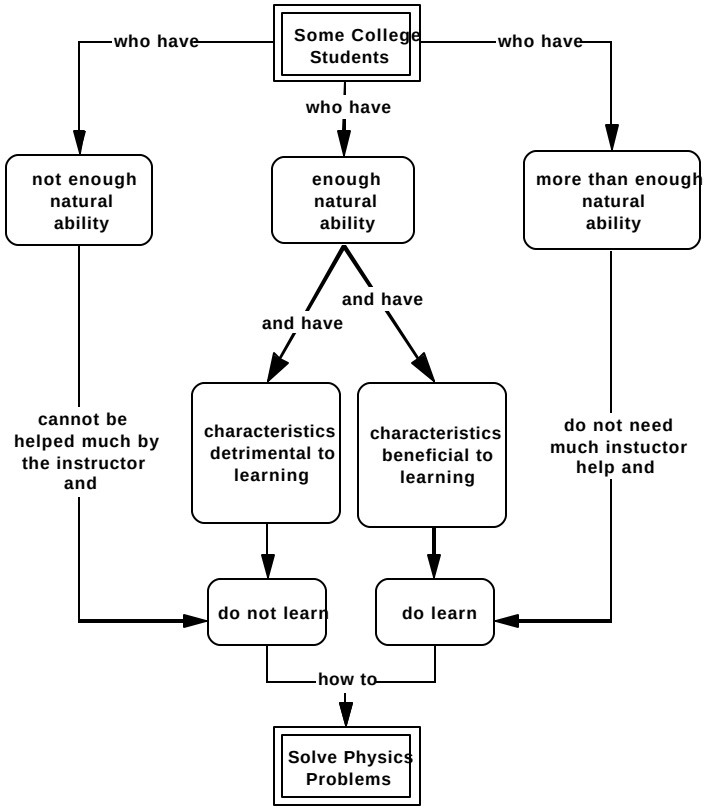
The final analysis method involved representing each instructor's conceptions in a series of concept maps and then combining these concept maps to form "composite" concept maps that represented the conceptions of the group of six instructors.

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".

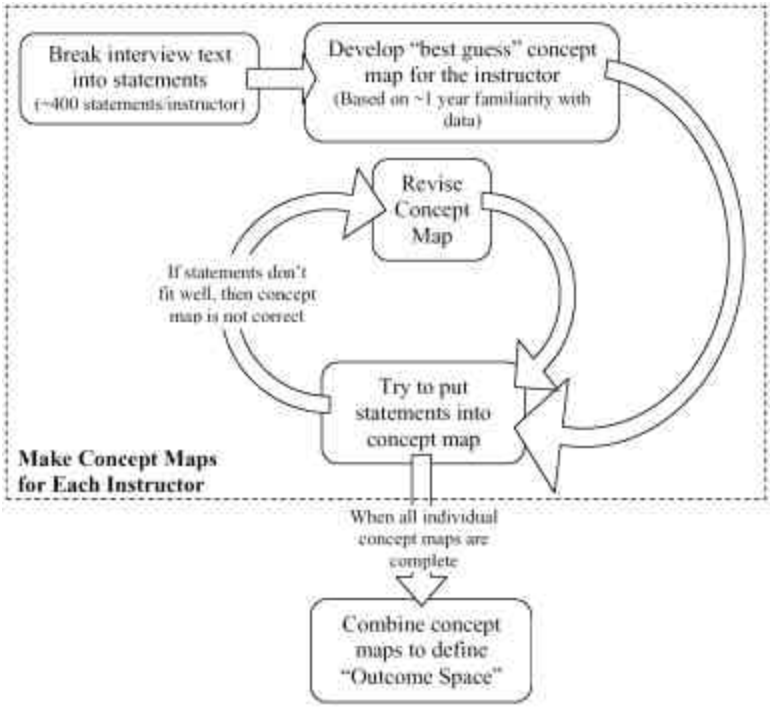


Concept maps have an advantage over prose writing in that a large number of interconnections can be represented rather compactly. Further, concept maps make very explicit connections between statements. Because the goal of this study is to generate an initial explanatory model, having explicit connections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



Procedure

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.

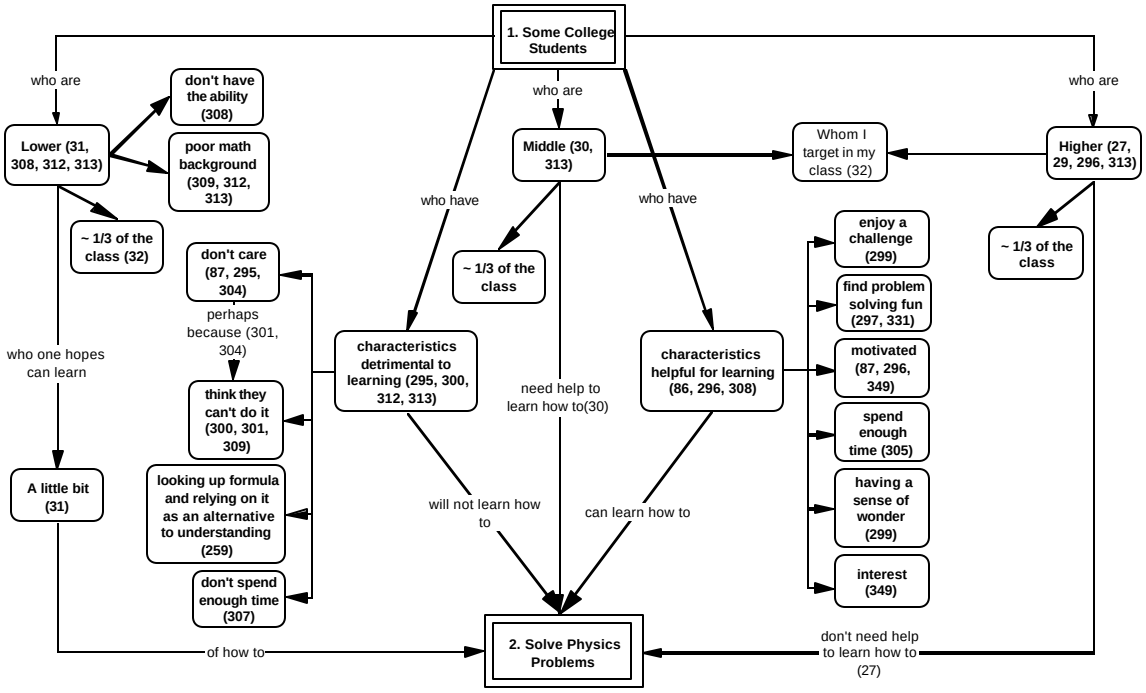
Table 3-3: Statements made from a piece of the interview transcript from RU6.

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)

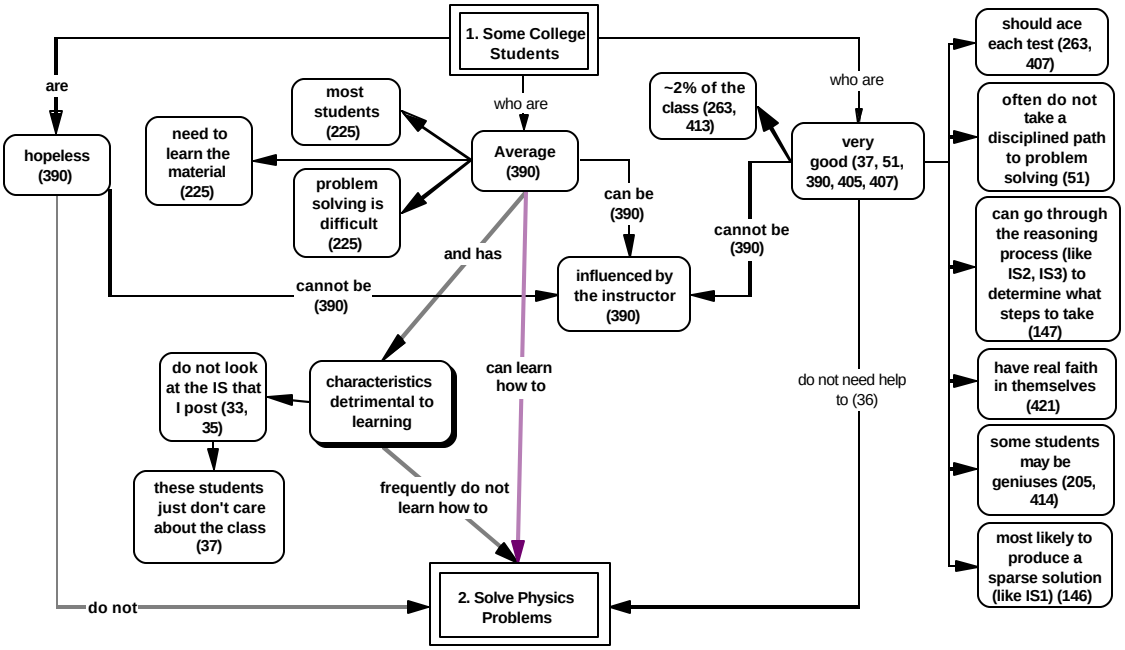


Figure 3-8: RU4 Individual Map 1 (Some College Students)

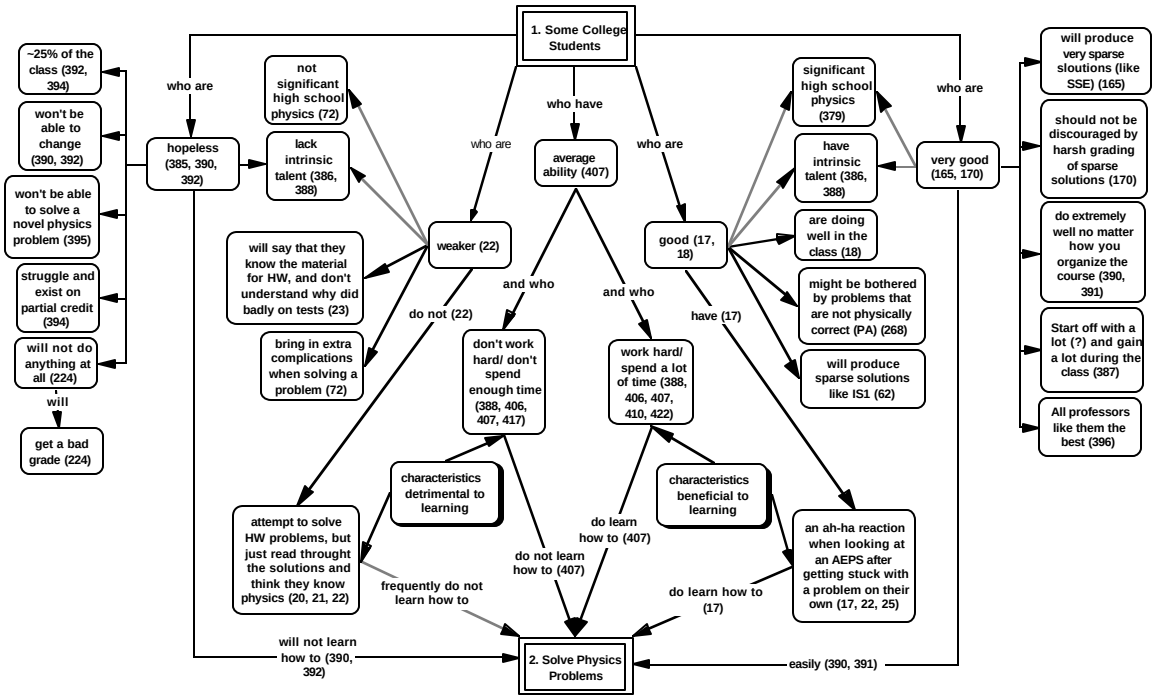
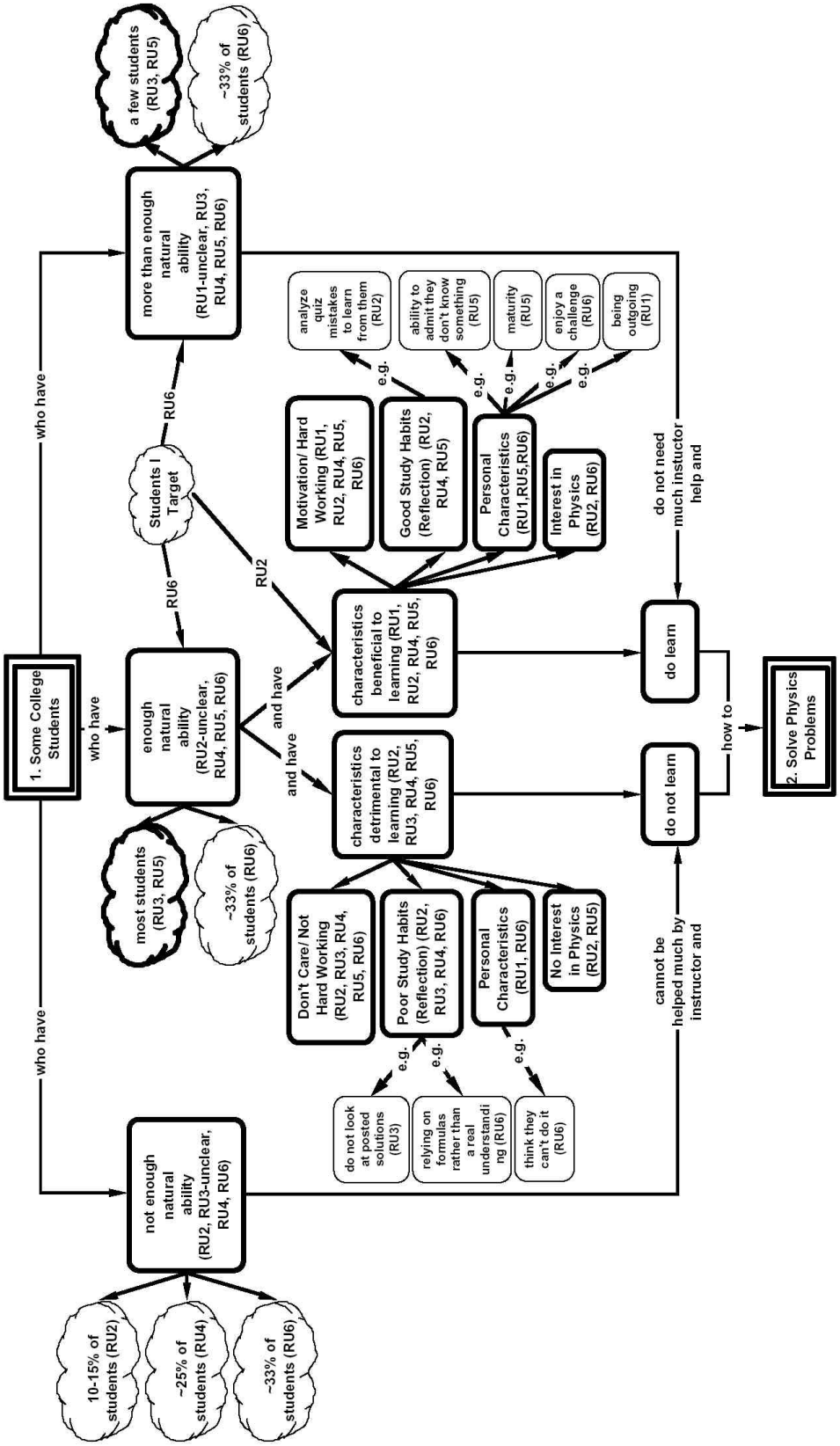


Figure 3-9: Composite Map 1 (Some College Students)



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.