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

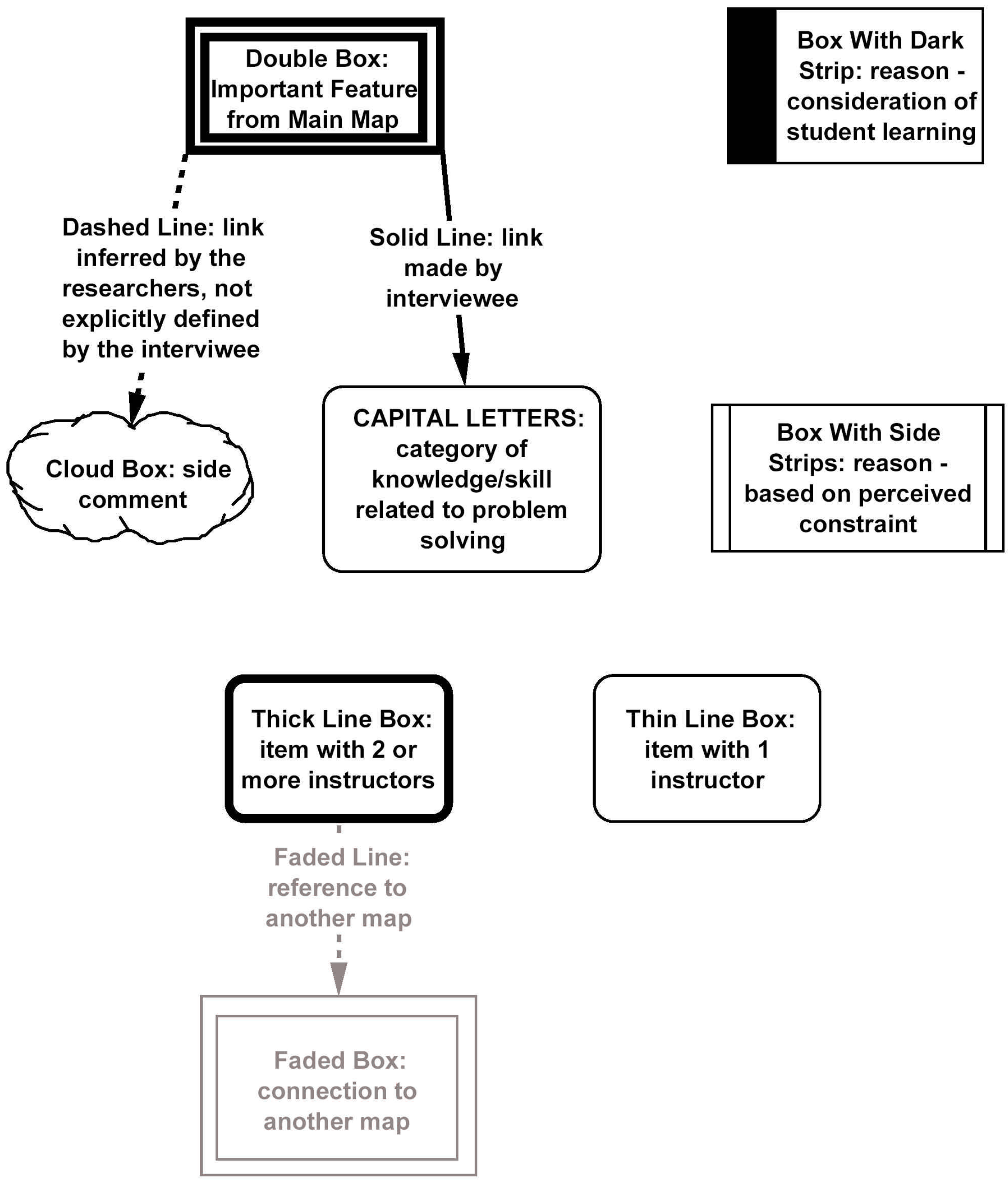
There are several different types of boxes and links that are used in the concept maps. These are designed to assist in the readability of the maps and also to differentiate between ideas and links that can be clearly attributed to the instructors and those that are imposed or inferred by the research 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.

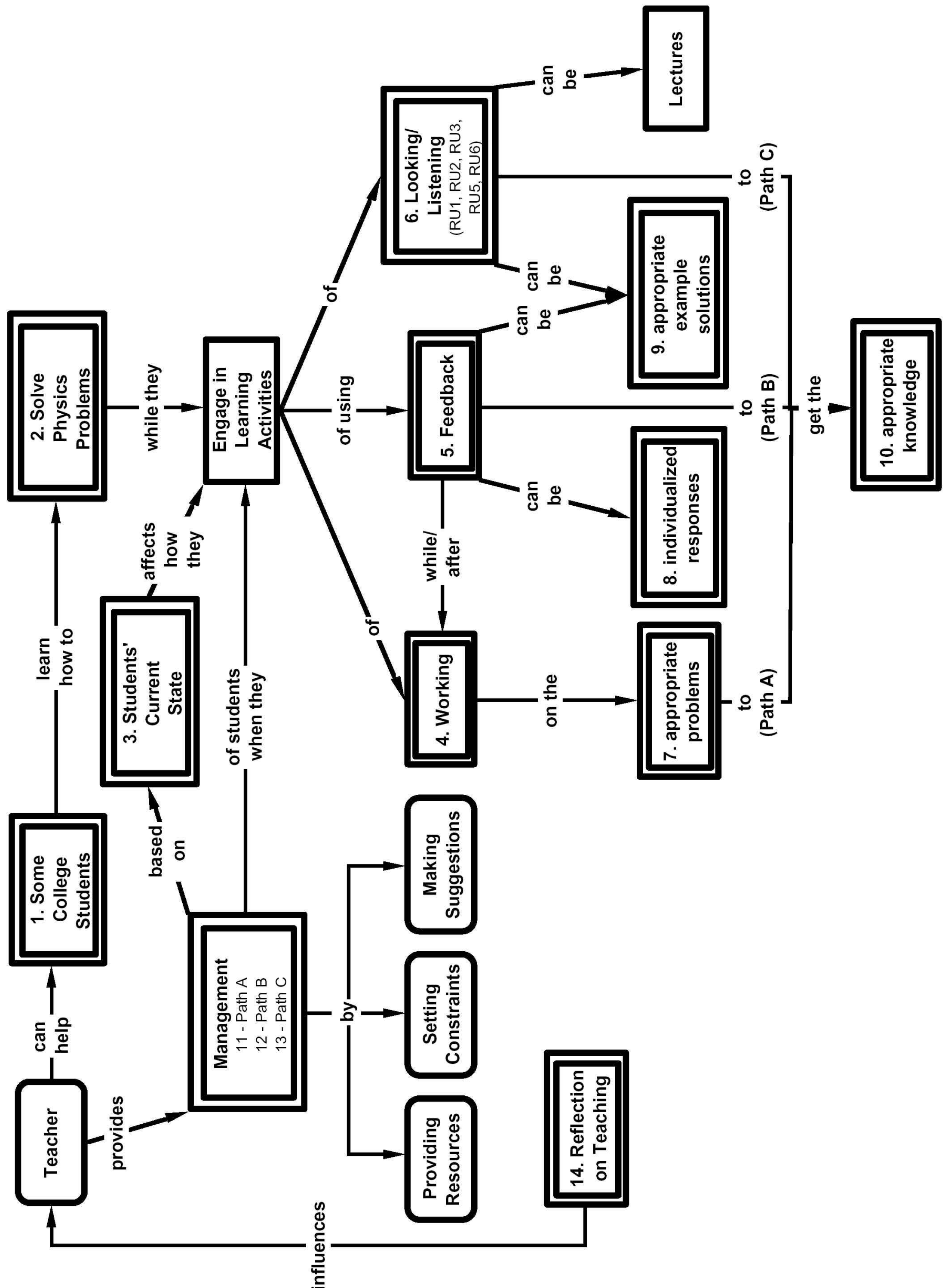
Instructors have three qualitatively different ways that they manage students' engagement in learning activities: Providing resources, setting constraints, and making suggestions. All instructors have all three conceptions.

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

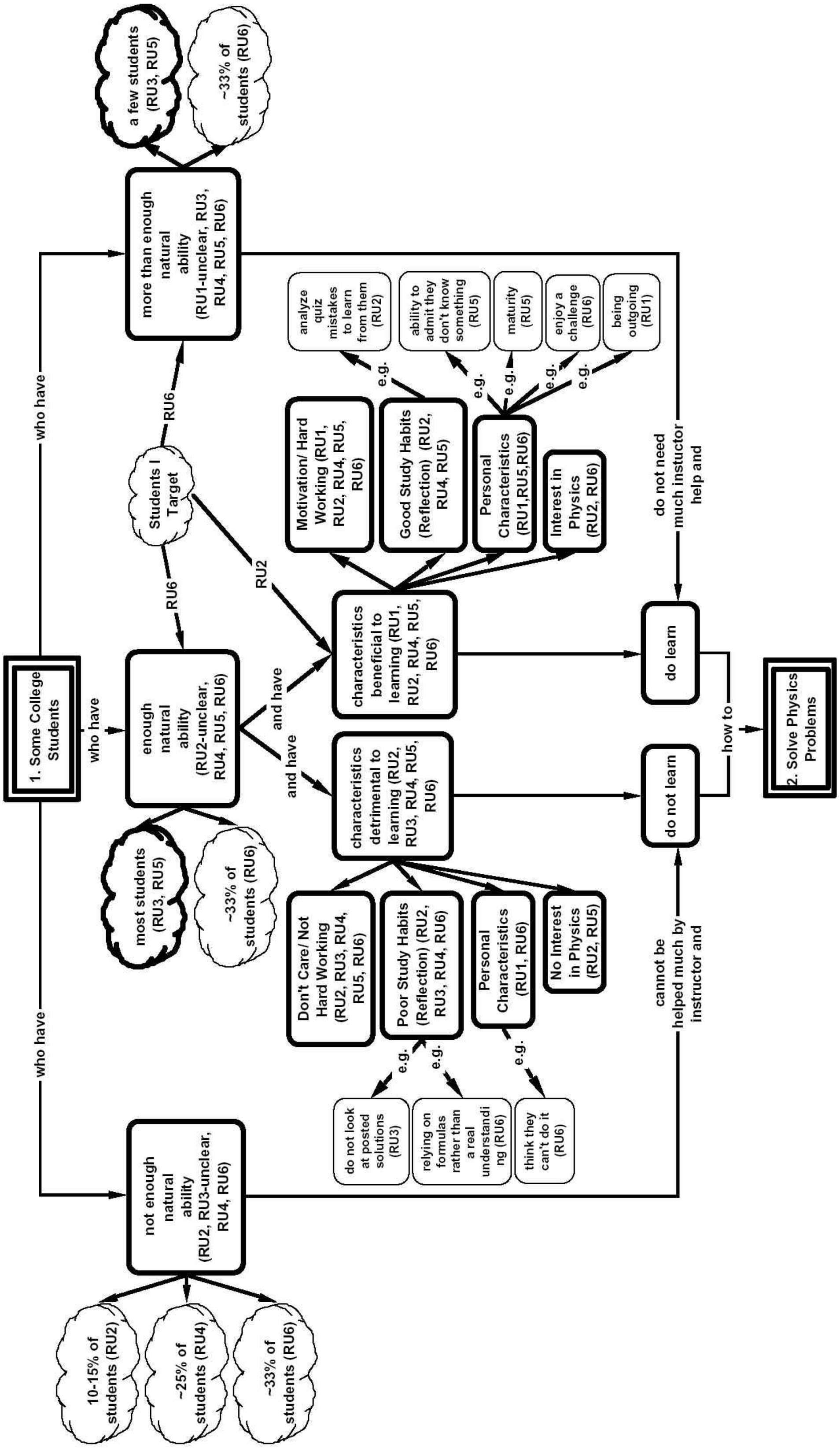
The map shows that there are two types of student characteristics that instructors use to describe whether a student will succeed or fail to learn how to solve physics problems. The first of these student characteristics is natural ability. Some students in the class do not have enough natural ability. 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.

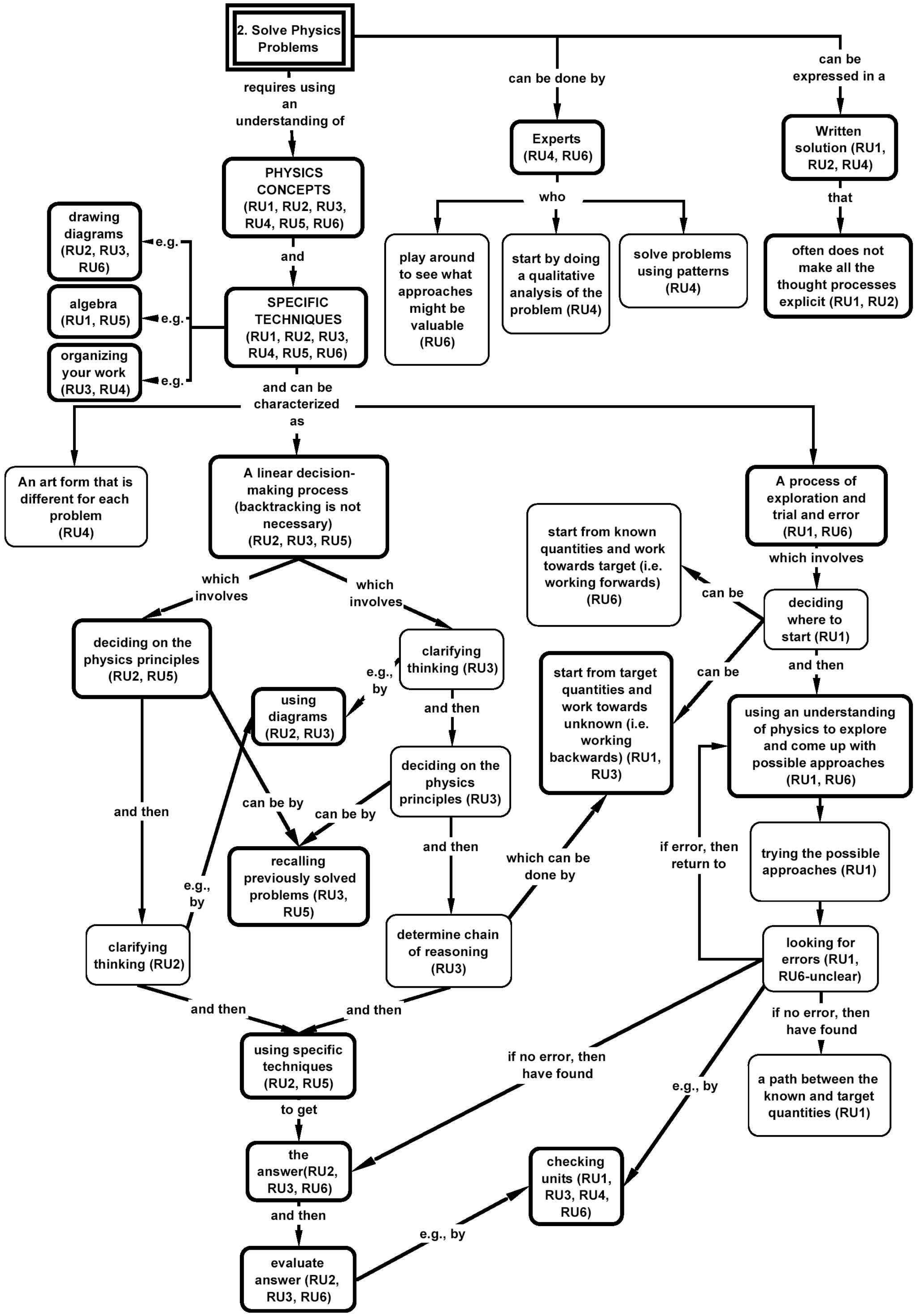
2. ***A process of exploration and trial and error.*** Two of the instructors saw problem solving as a process where an understanding of PHYSICS CONCEPTS is used to explore and come up with possible choices that are then tested. The conception is that making mistakes and having to backtrack is a natural 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.

<u>Knowledge/Skill Related to Problem Solving</u>

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

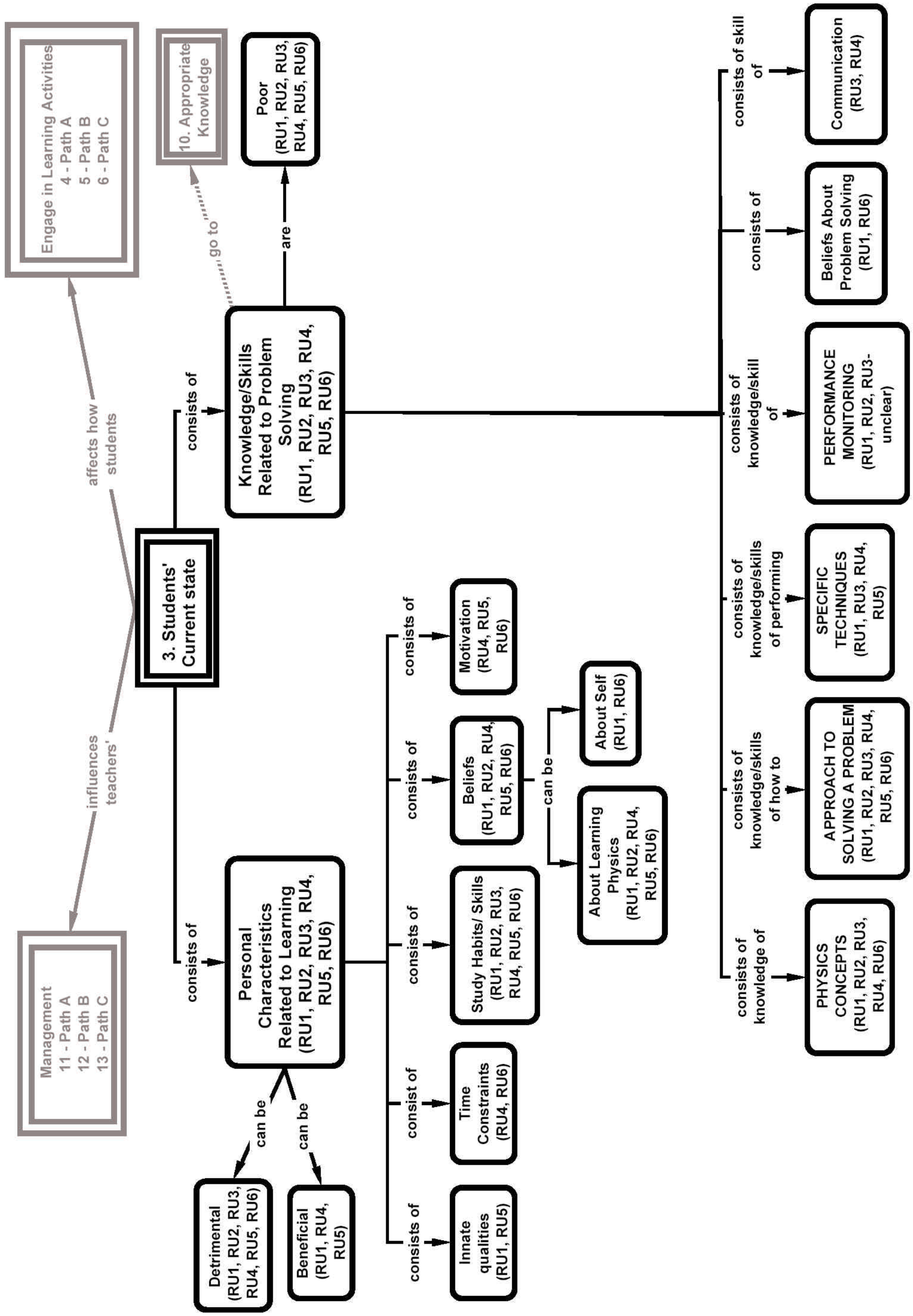


Figure 4-6: Map 3 (part 1) - Students' Current State

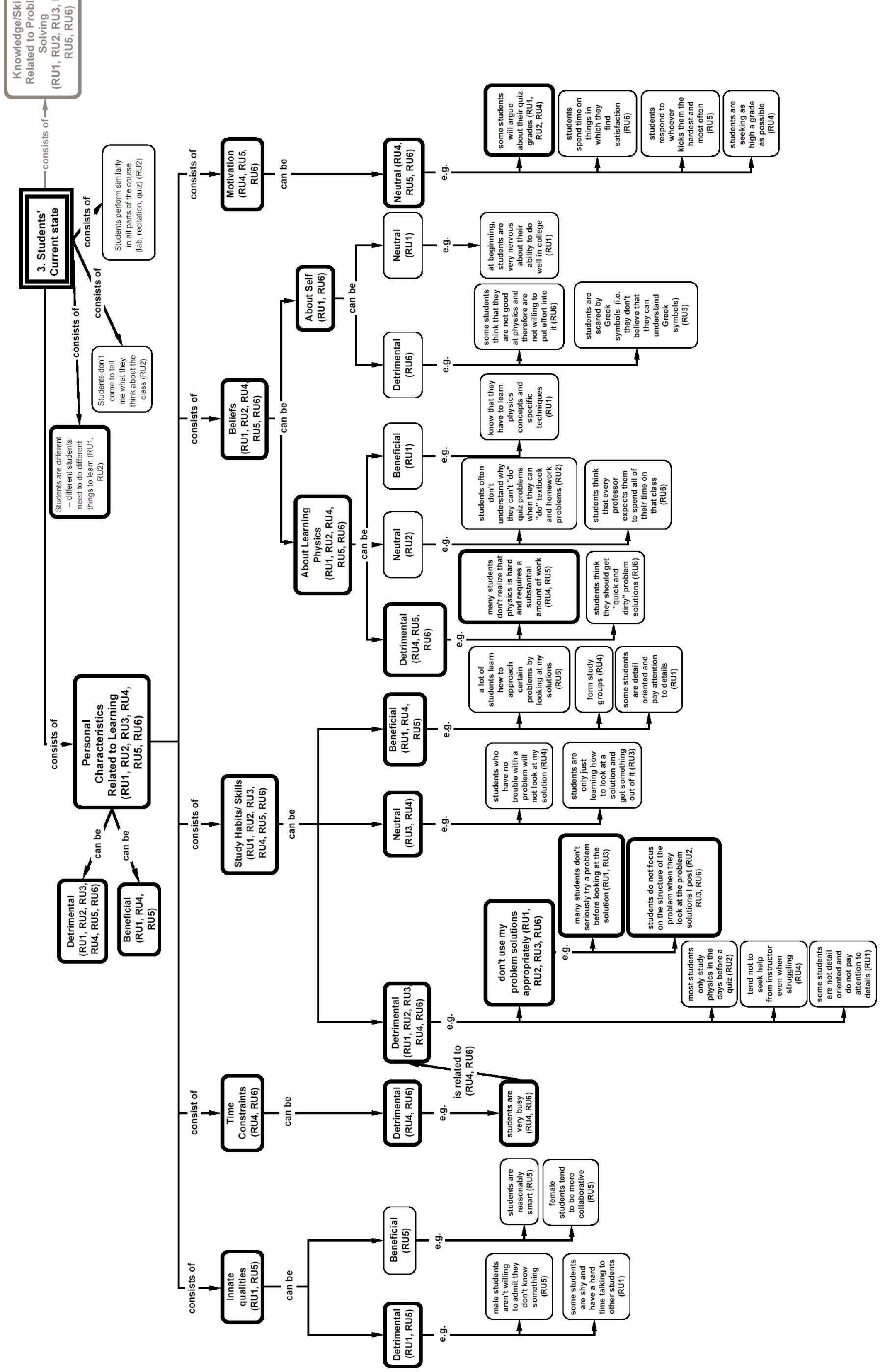
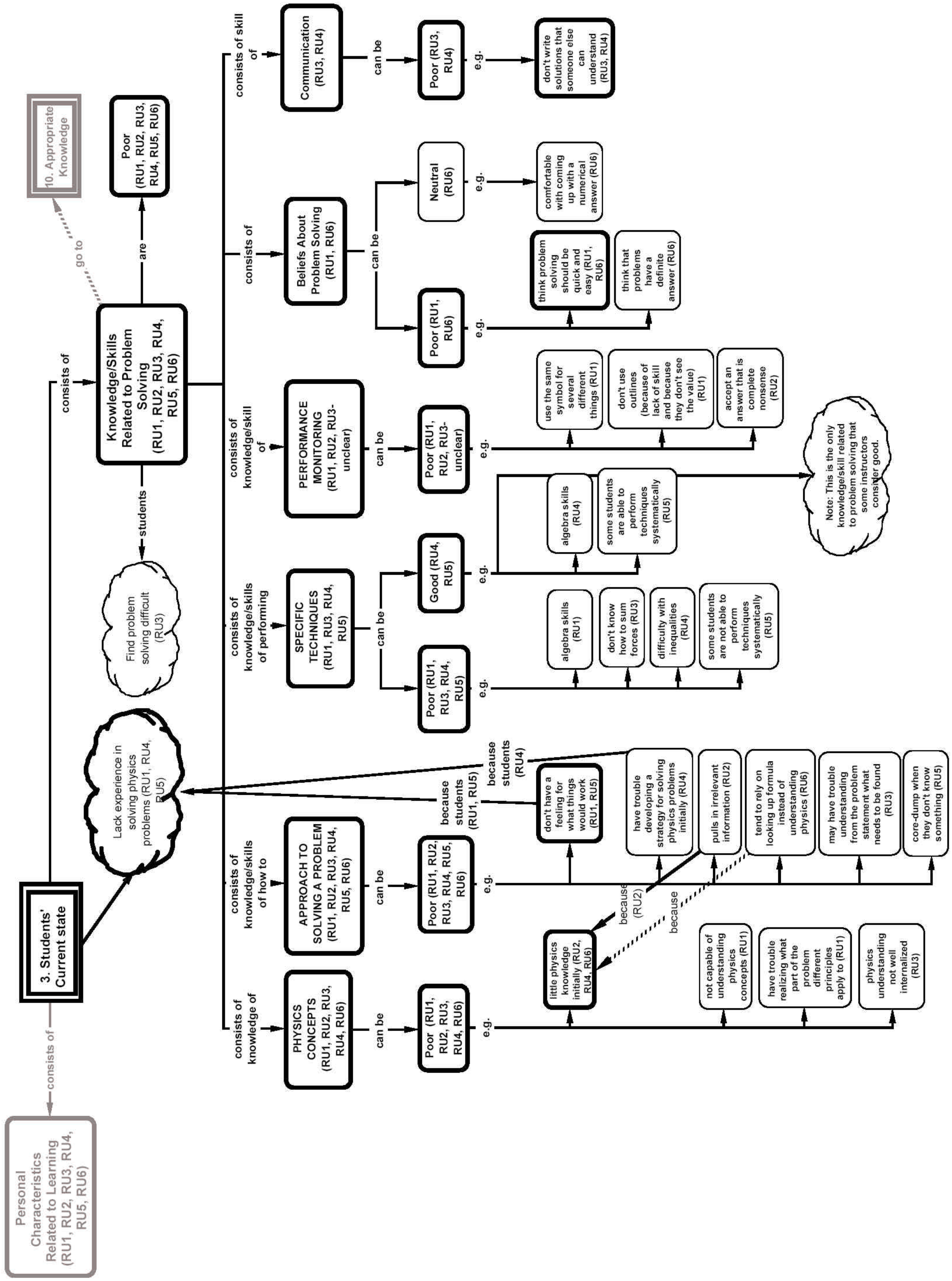


Figure 4-7: Map 3 (part 2) - Students' Current State



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.

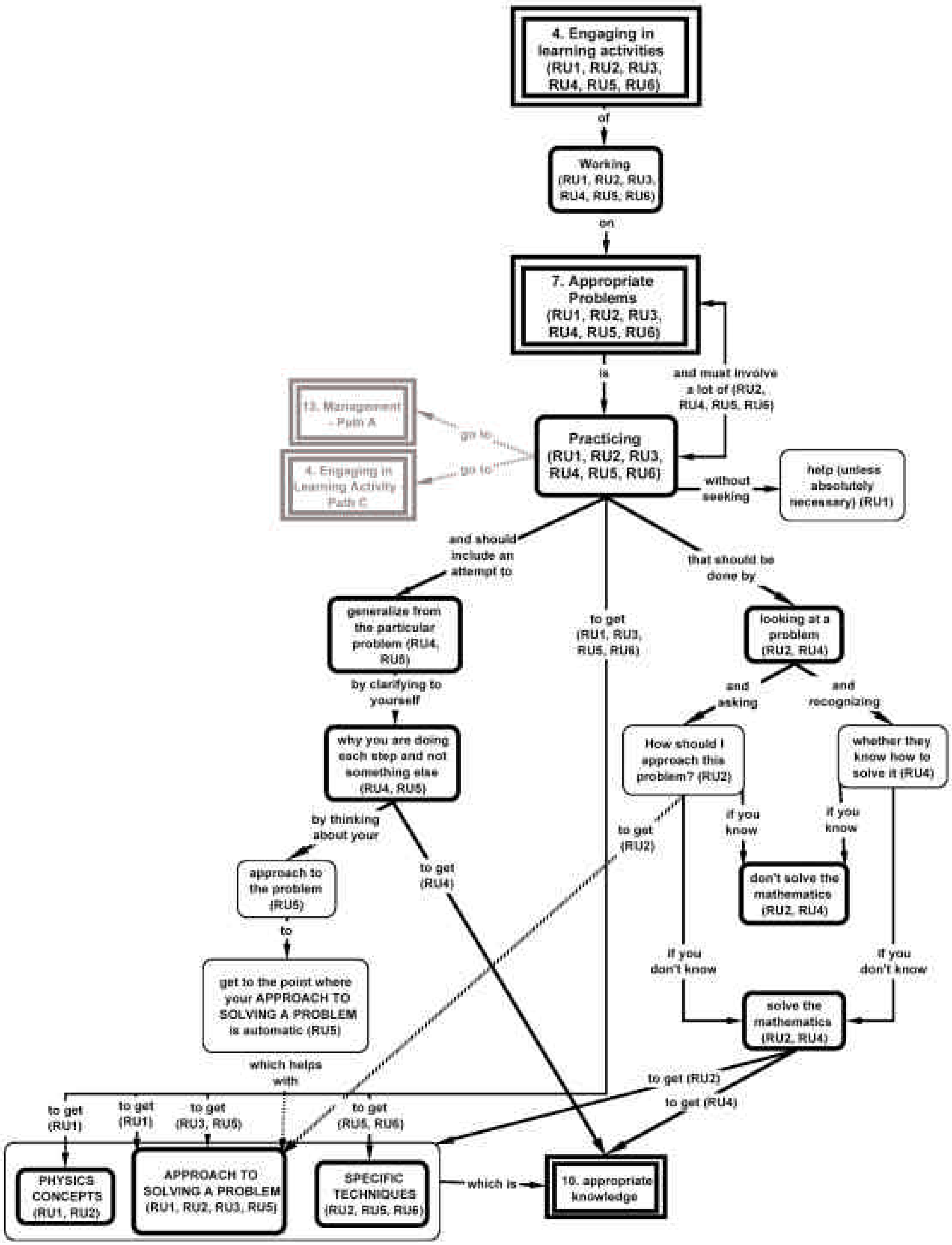
Map 4: Student Engagement in Learning Activities of Working (Path A)

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)



<u>Map 5: Student Engagement in Learning Activities of Using Feedback (Path B)</u>

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.

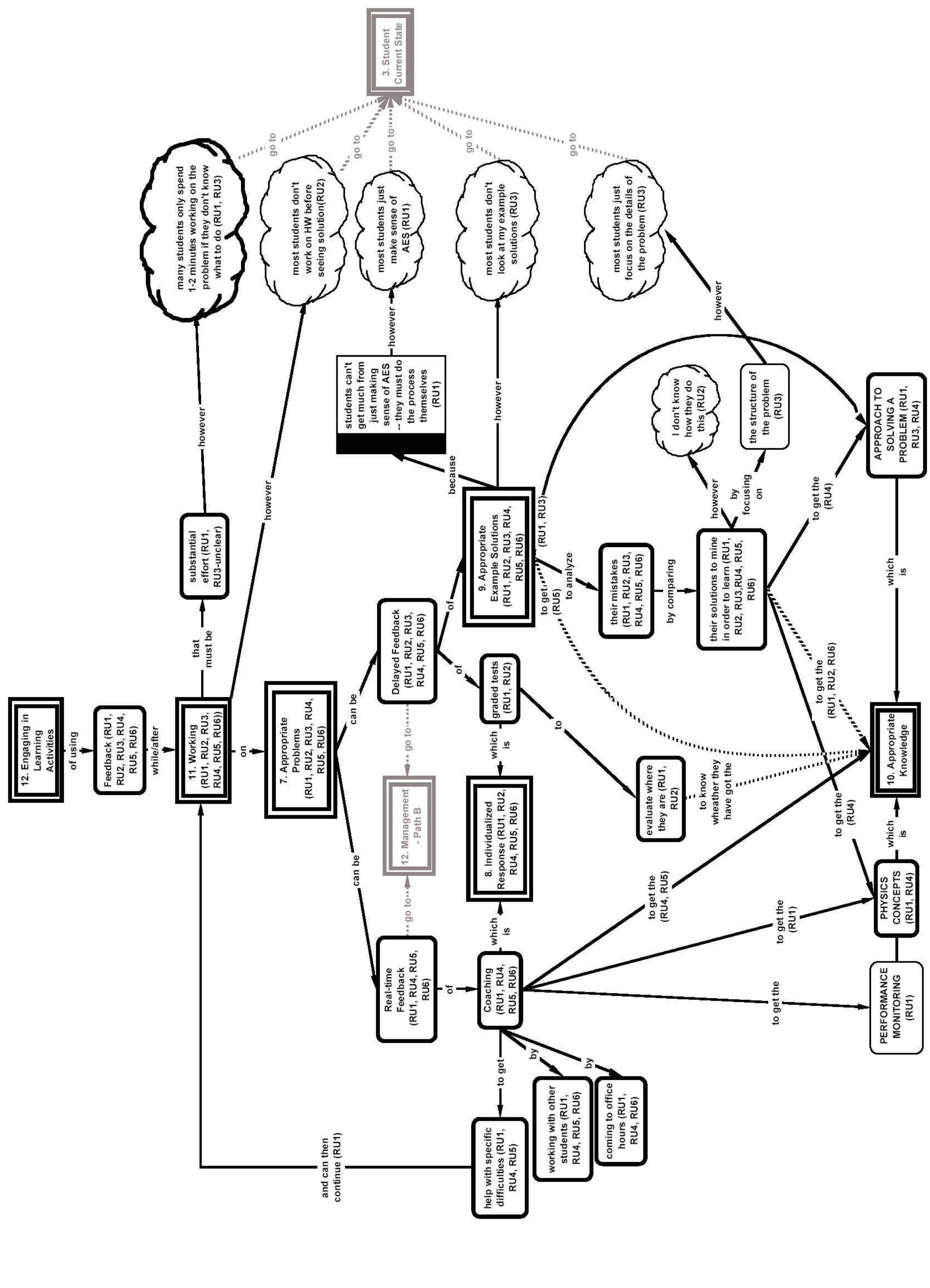
1. ***Students can learn how to solve physics problems by working on problems and then using delayed feedback.*** All of the instructors interviewed believed that students could learn how to solve physics problems by working on problems on their own (e.g. for homework or a test), and then looking at 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.

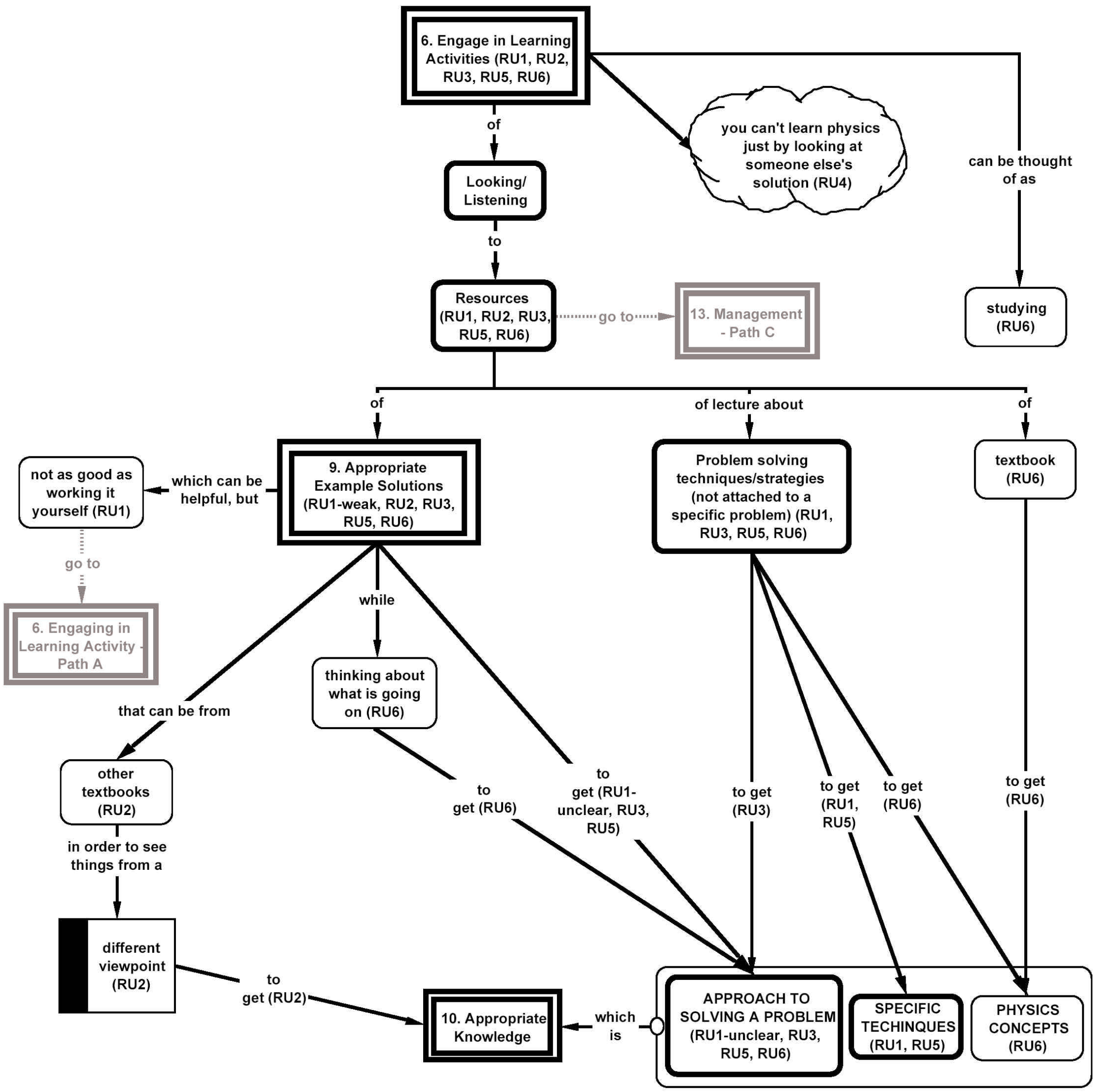
There are two qualitatively different ways that instructors think students can learn by looking/listening: looking/listening to appropriate example solutions, and looking/listening to lectures about problem solving techniques or strategies. Four of the instructors have both of these conceptions. One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

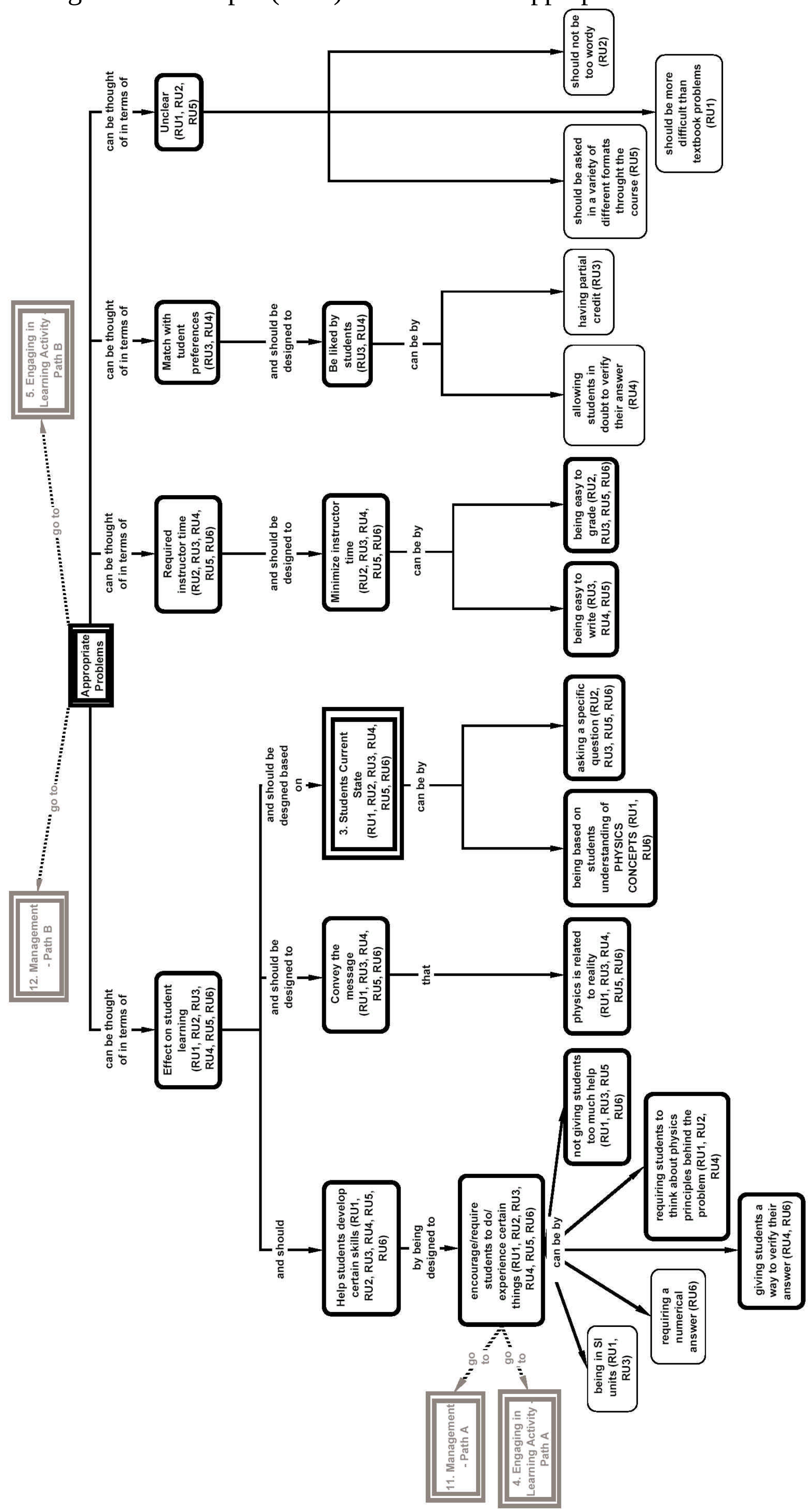


Figure 4-12: Map 7 (part 1) – Resource of Appropriate Problems

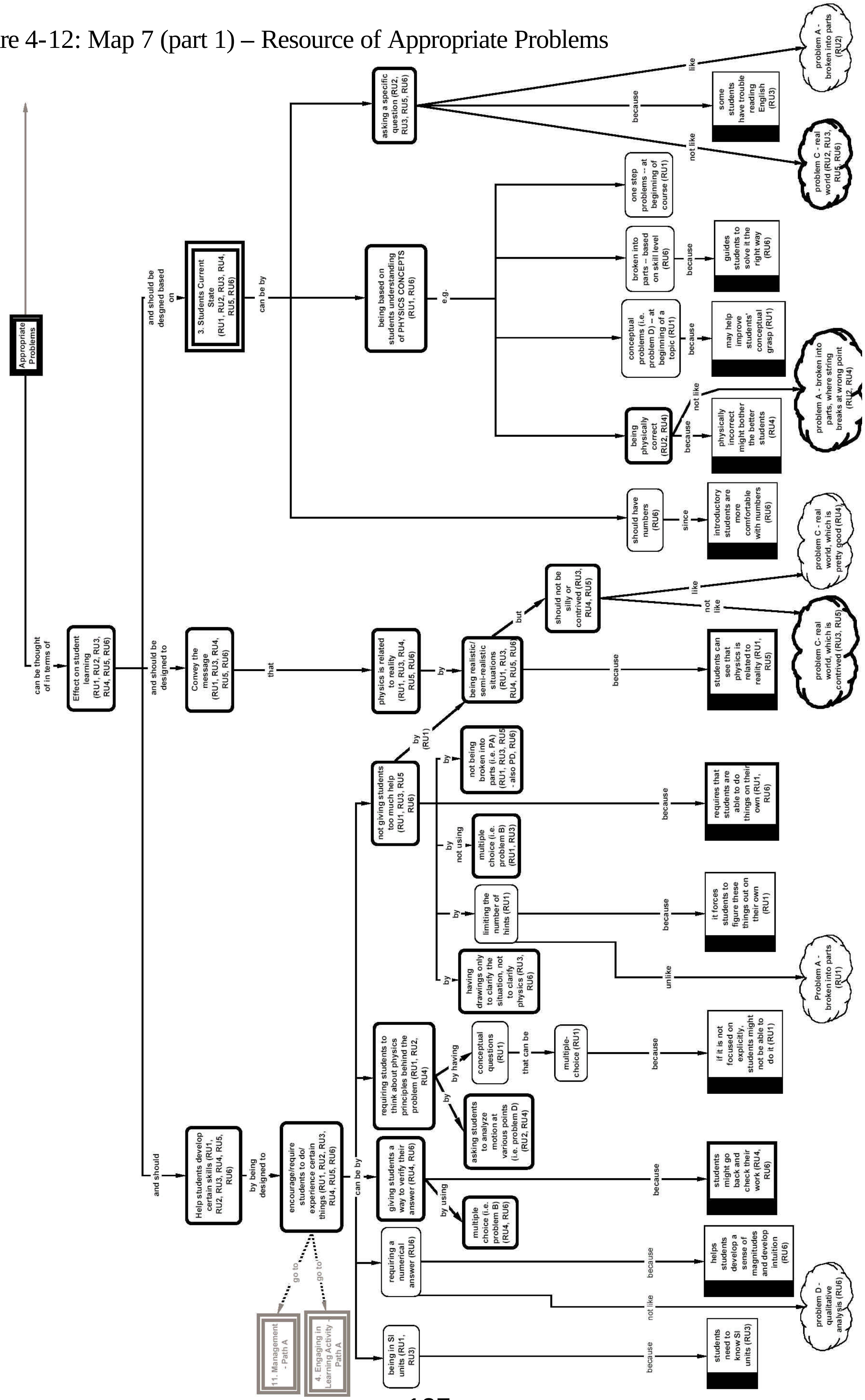
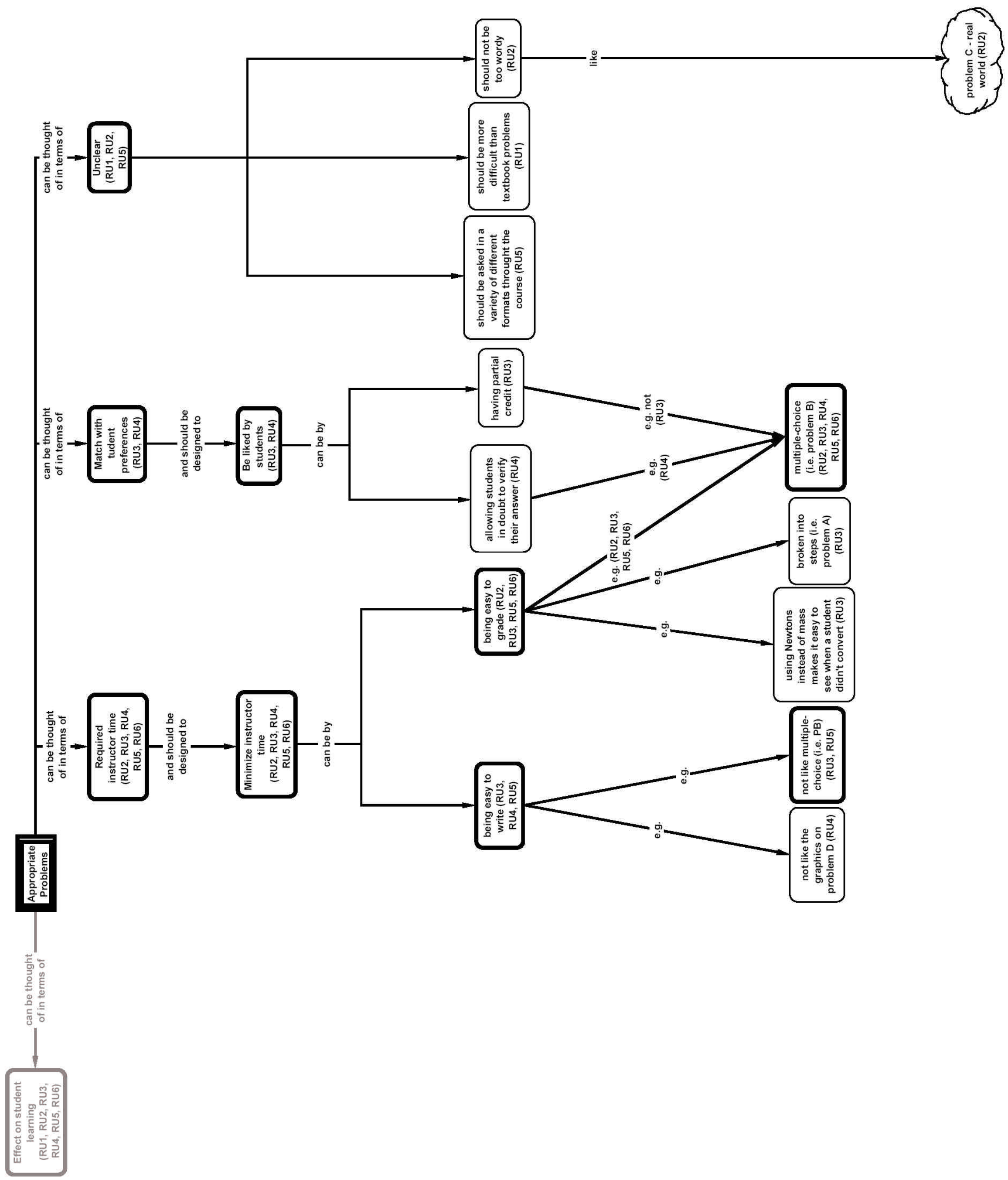


Figure 4-13: Map 7 (part 2) – Resource of Appropriate Problems



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

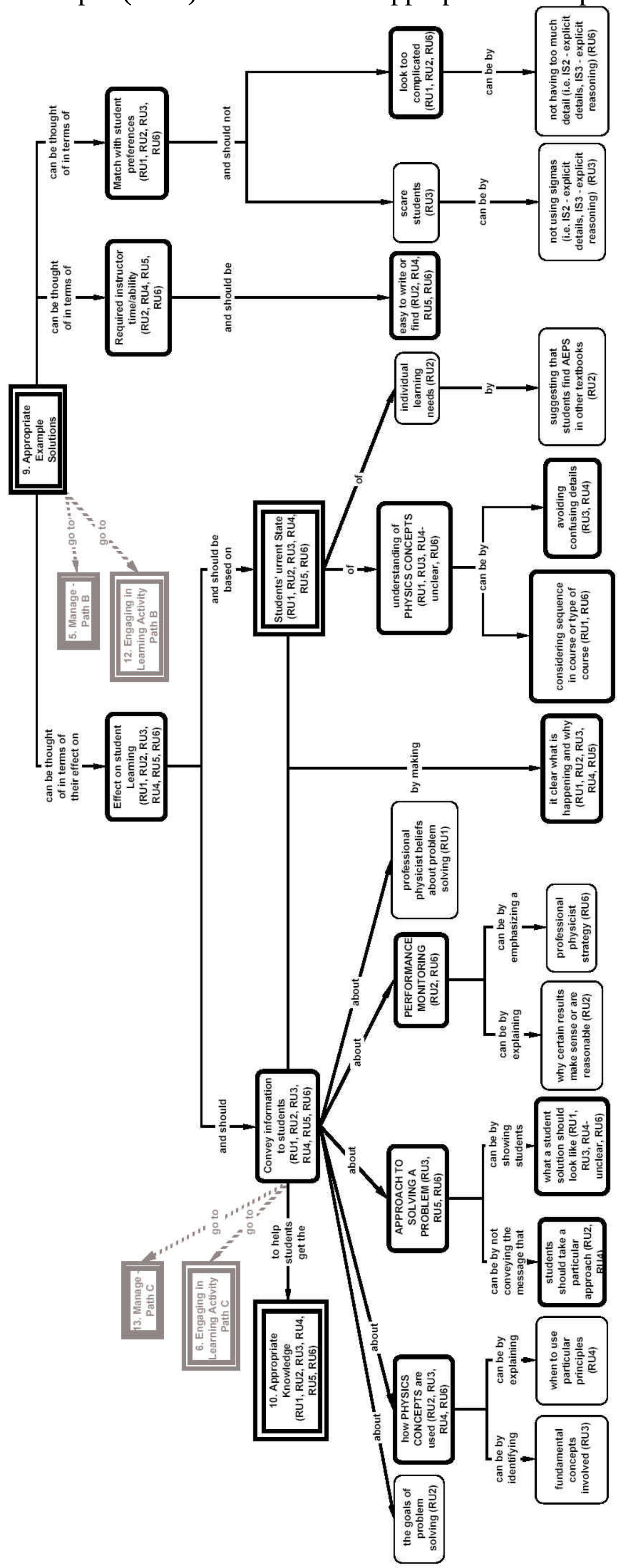


Figure 4-15: Map 9 (part 1) – Resource of Appropriate Example Solutions

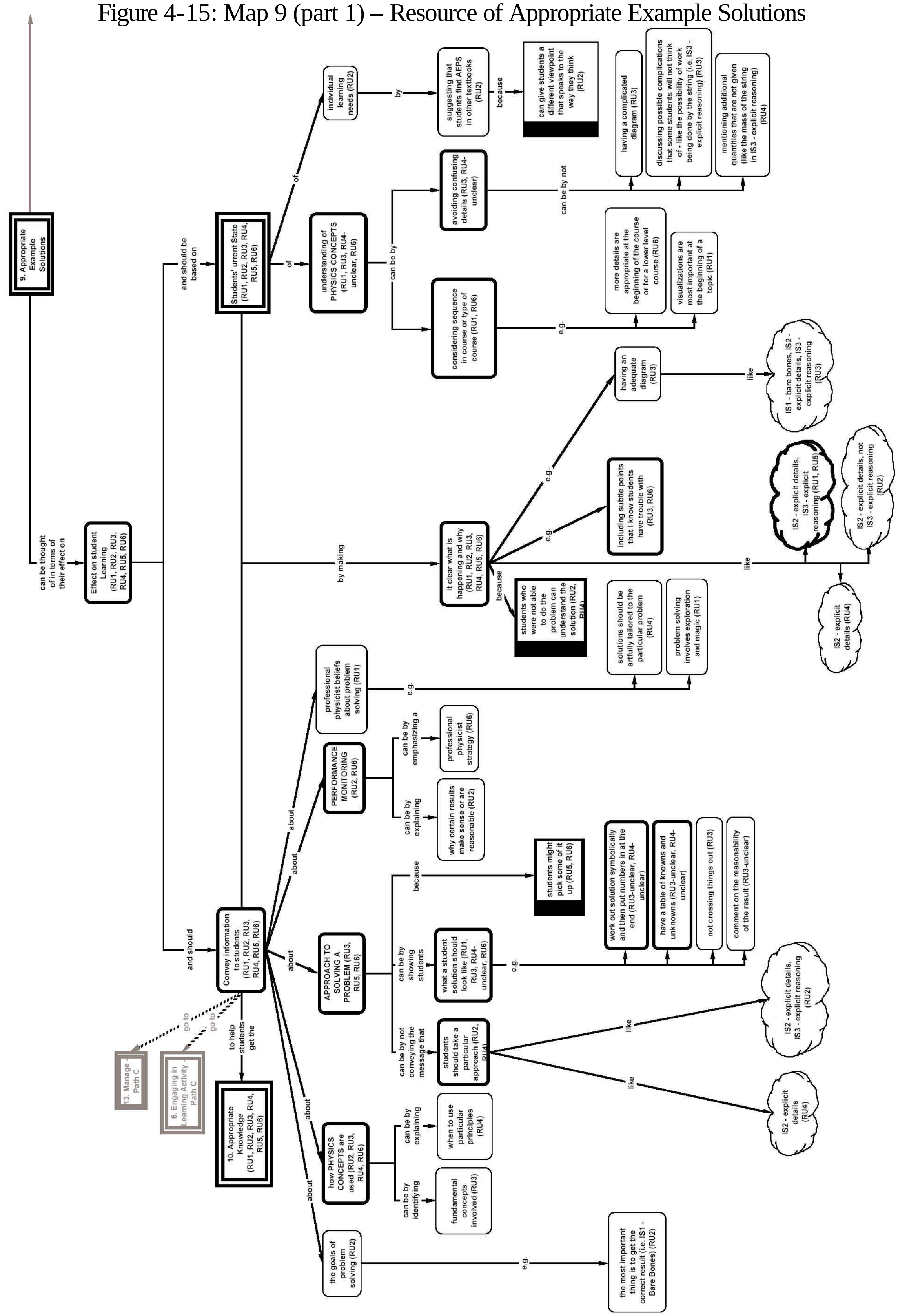
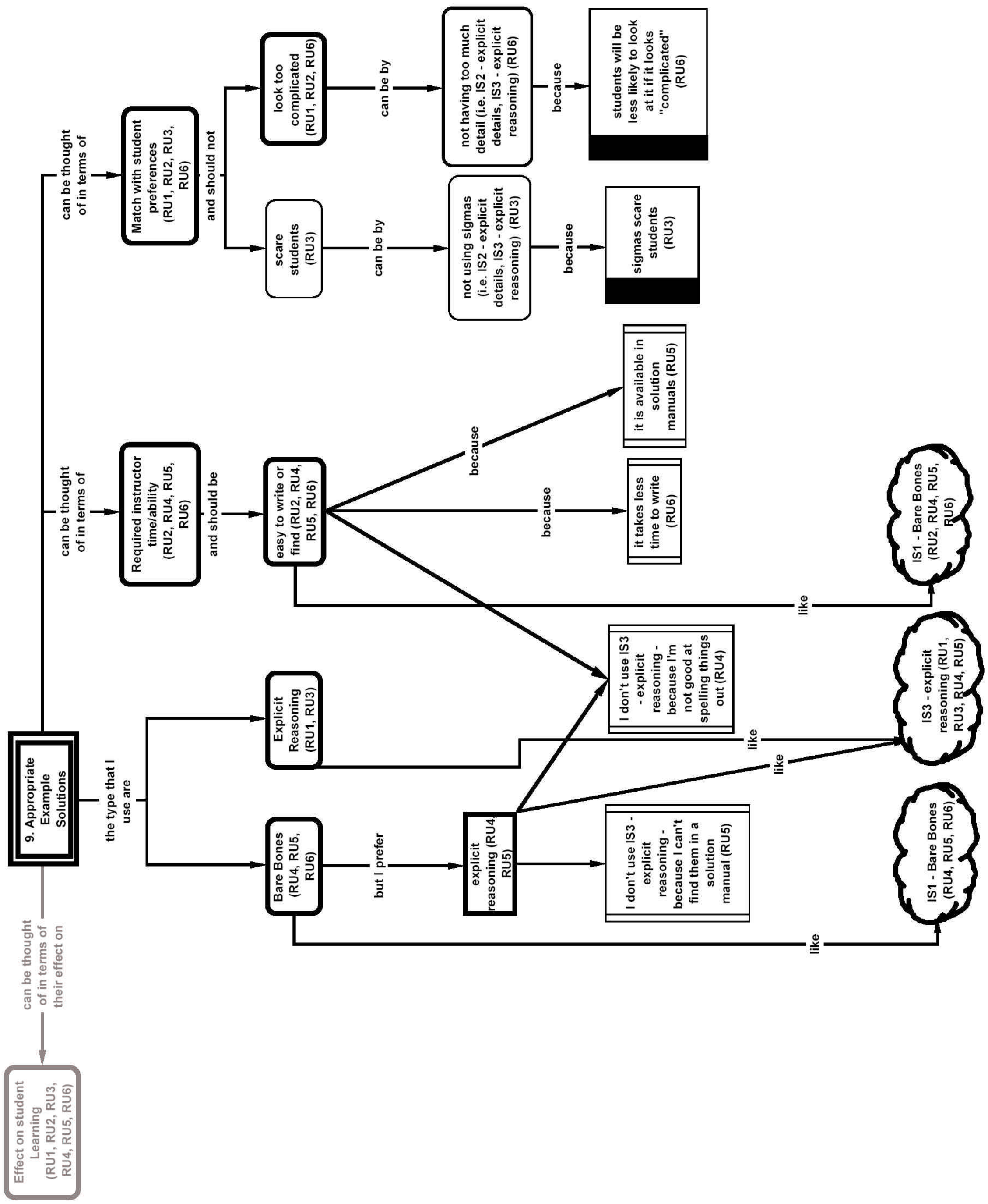


Figure 4-16: Map 9 (part 2) – Resource of Appropriate Example Solutions



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

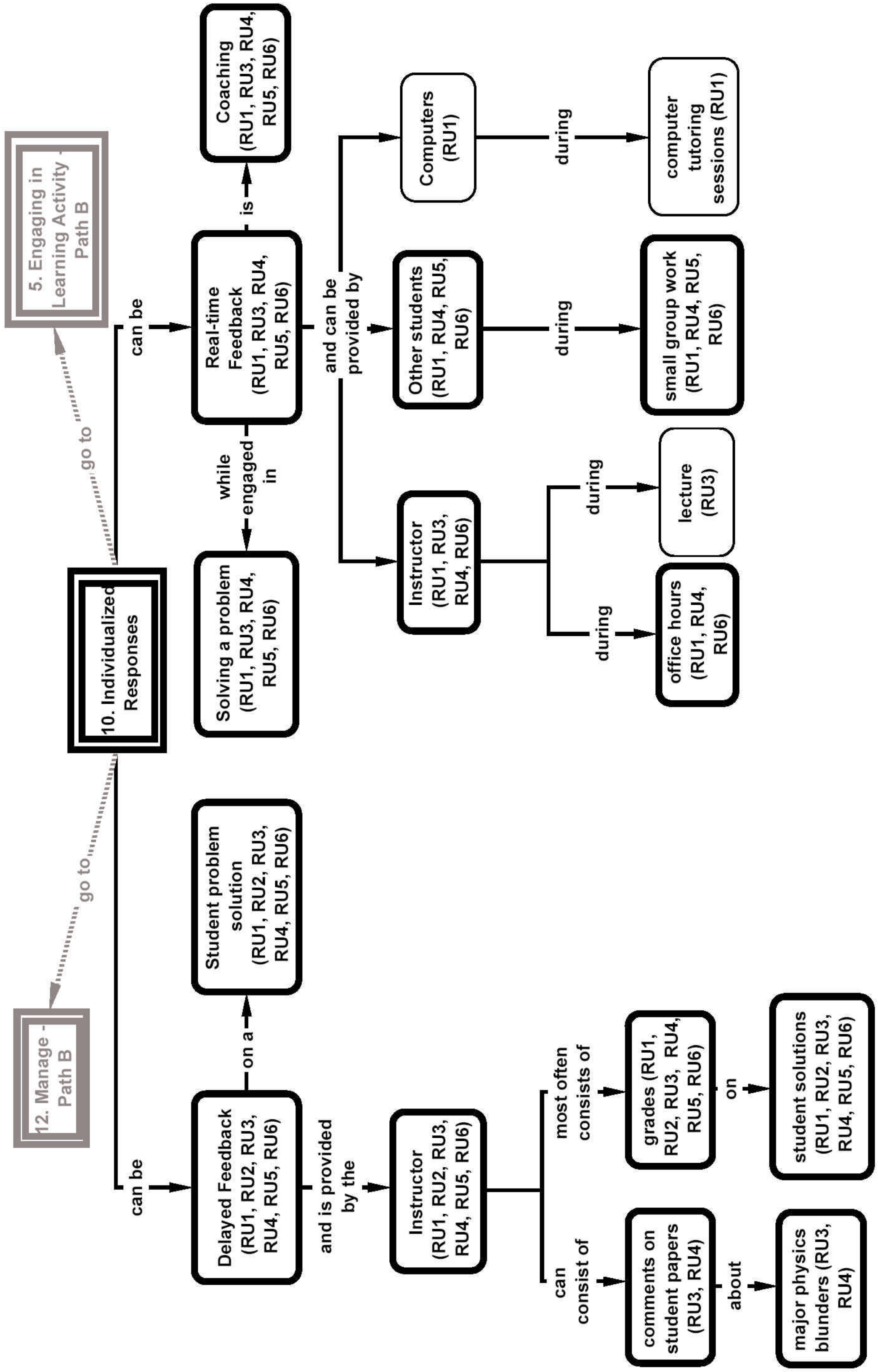


Figure 4-18: Map 8 (part 1) – Resource of Individualized Responses

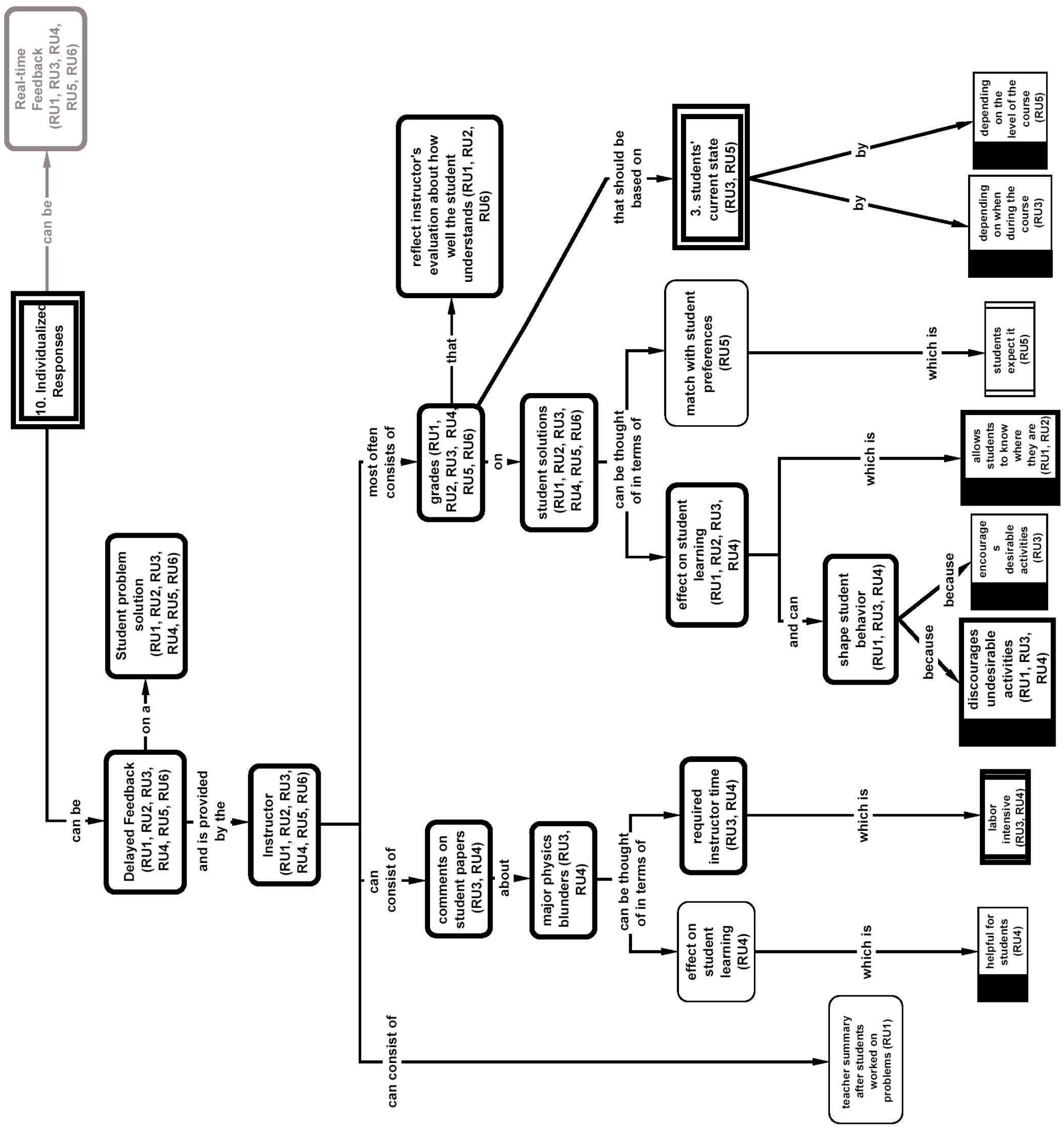
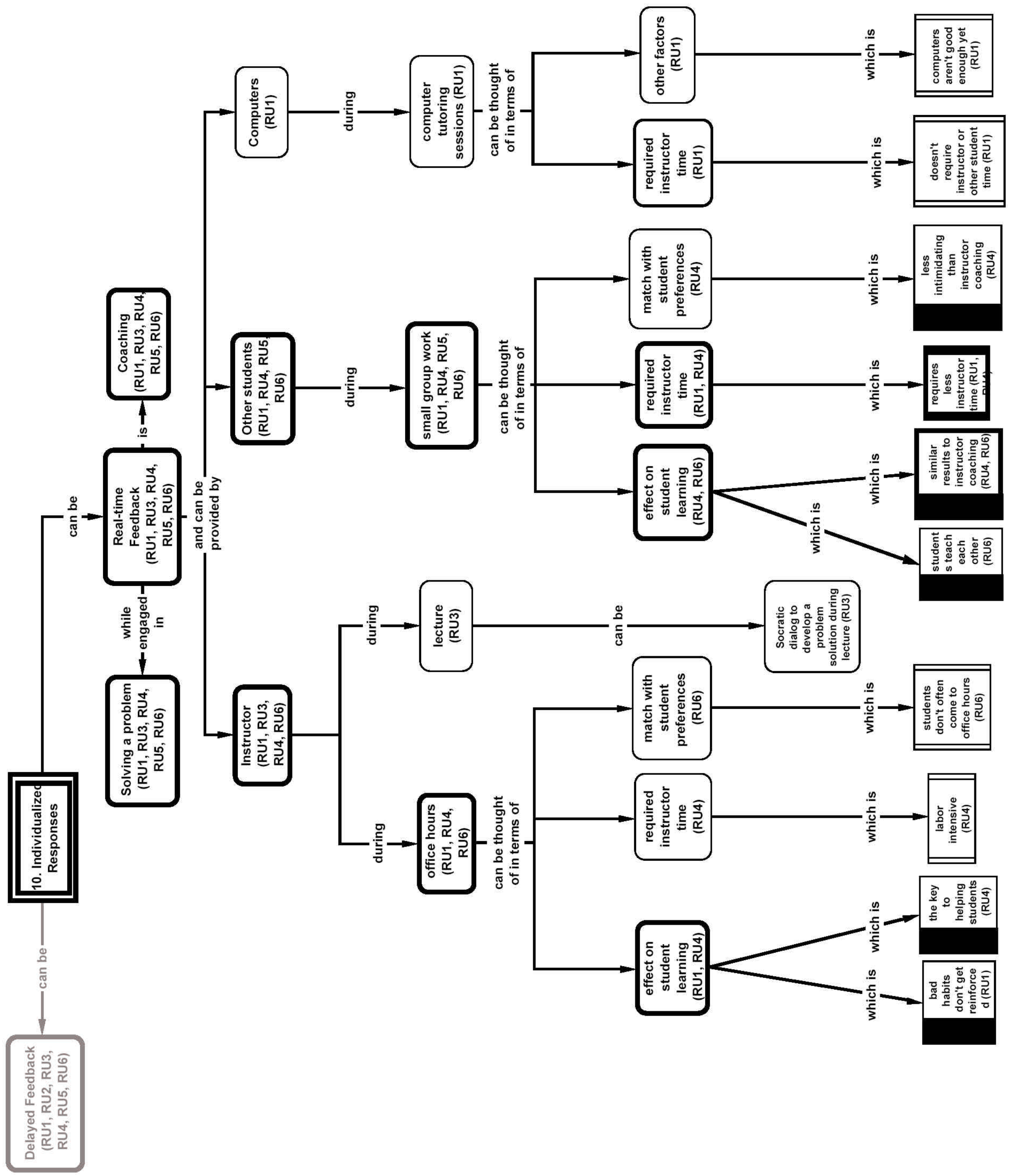


Figure 4-19: Map 8 (part 2) – Resource of Individualized Responses



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***

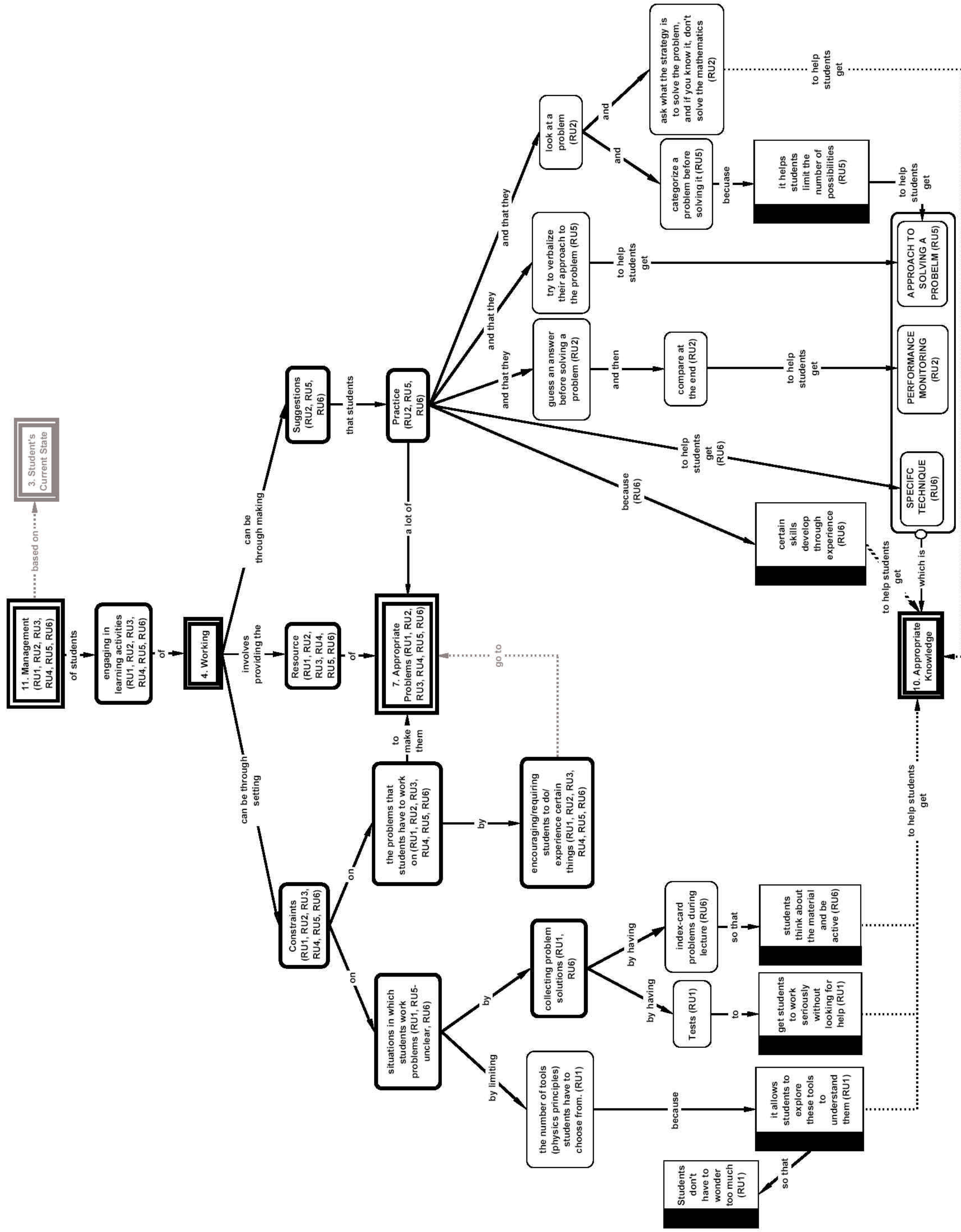
have to work. All of the instructors described designing appropriate problems that encourage or require students to do certain things that will help them learn while working on the problem. These are described in more detail on Map 7: Appropriate Problems.

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)

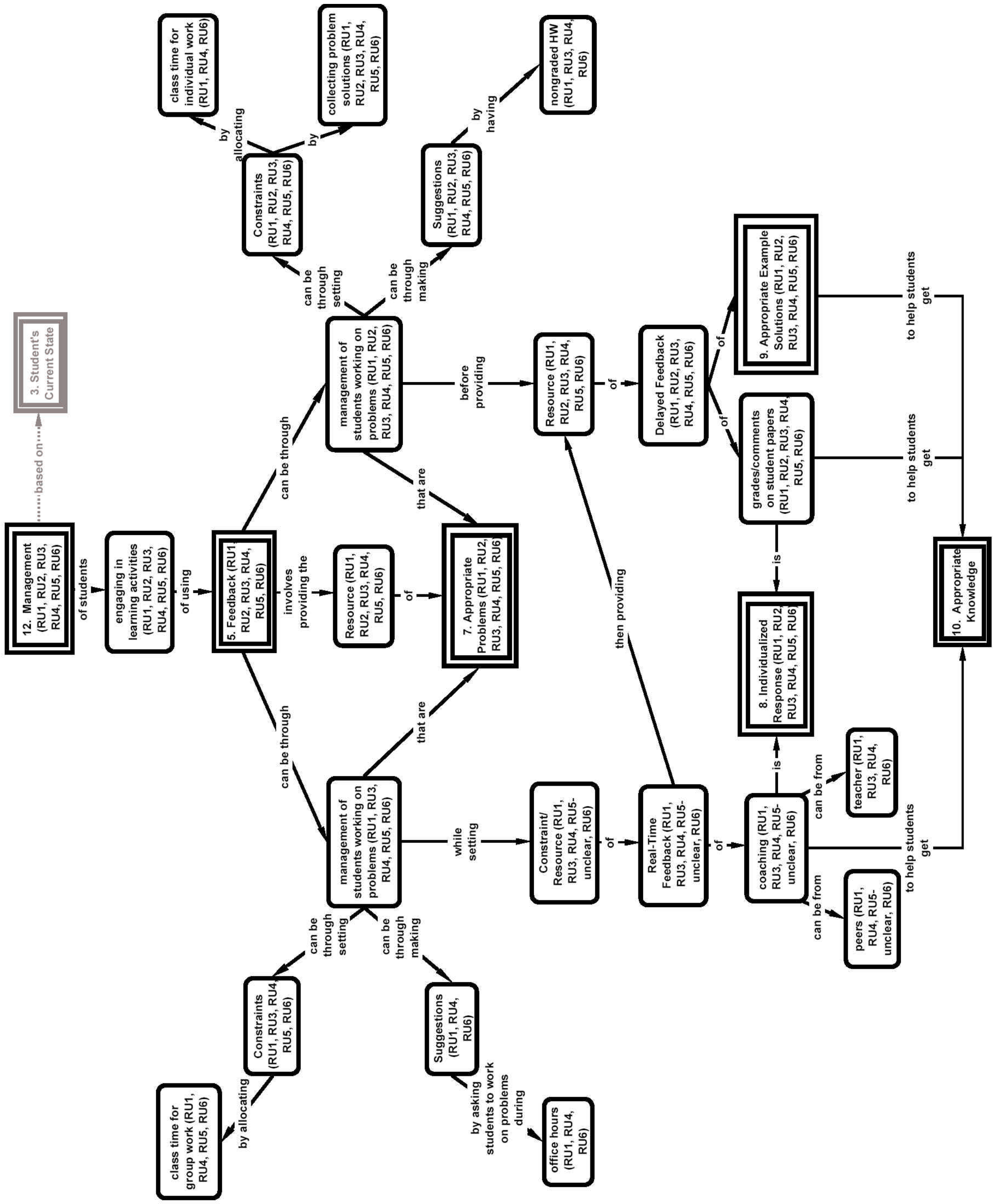


Figure 4-22: Map 12 (part 1) – Management of Students' Engagement in Learning Activities of Using Feedback (Path B)

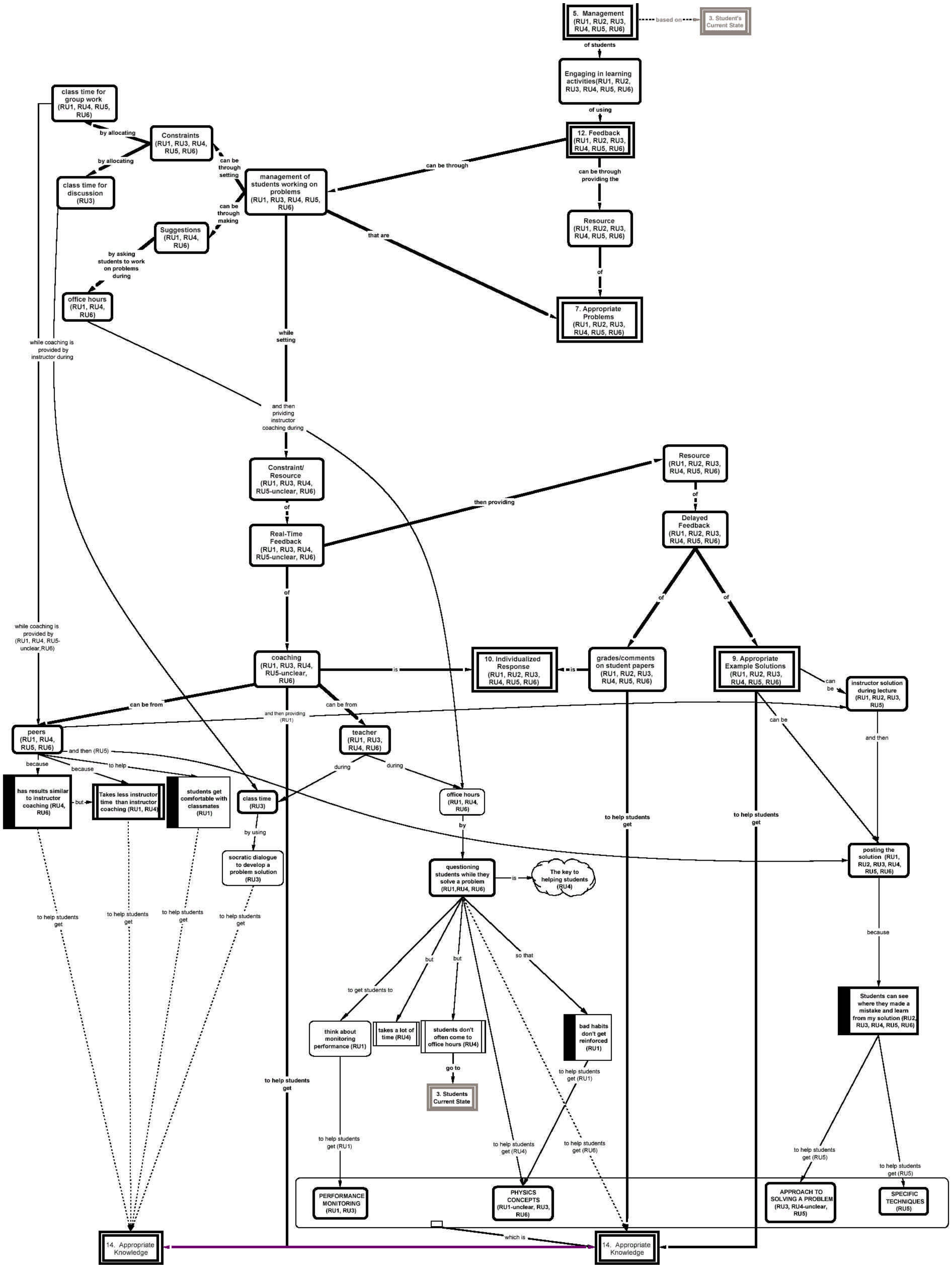
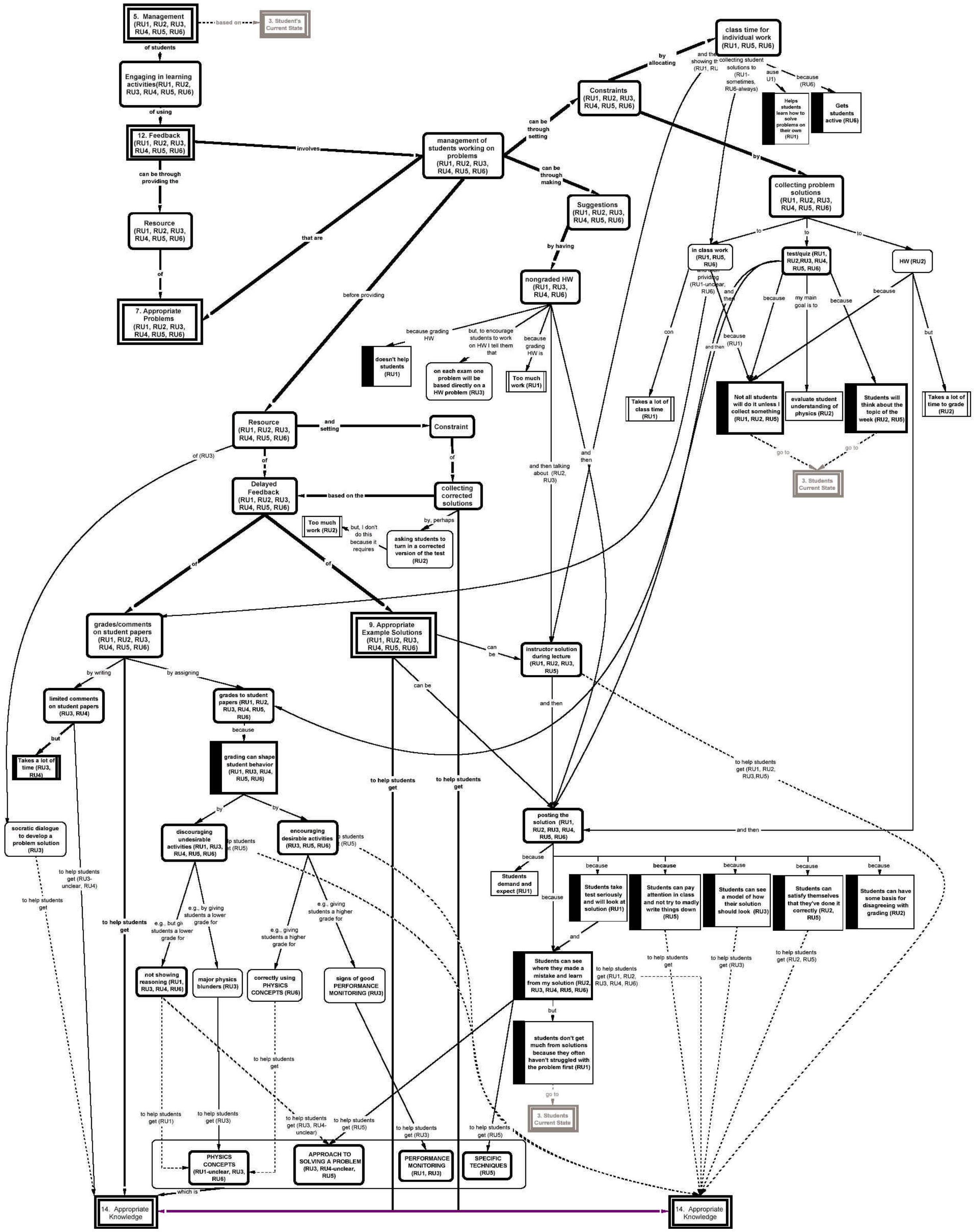


Figure 4-23: Map 12 (part 2) – Management of Students' Engagement in Learning Activities of Using Feedback (Path B)



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).

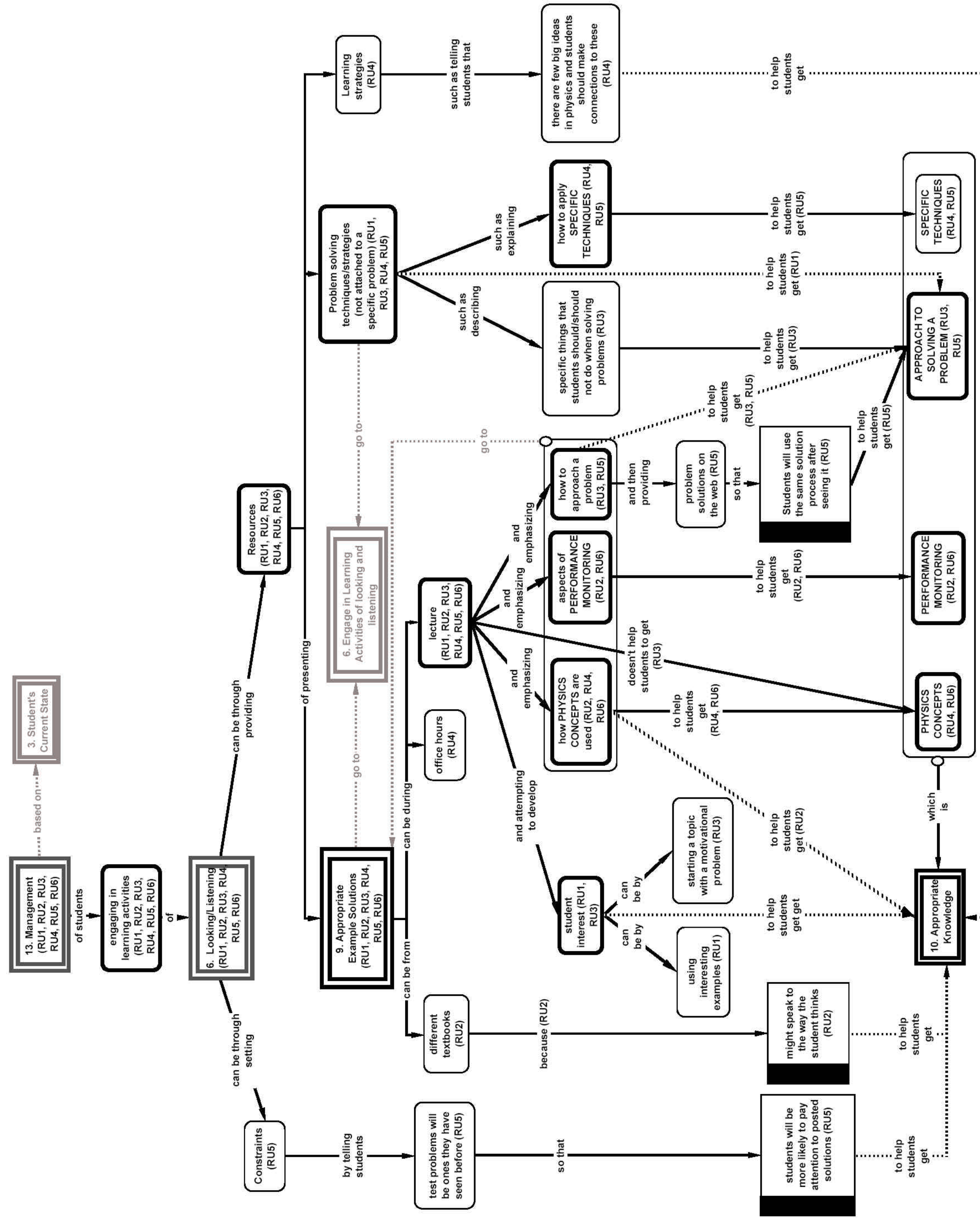
There are three qualitatively different ways that instructors conceive of their management of students' engagement in learning activities of looking/listening: solving problems on the board during lecture, talking about problem solving techniques/strategies, and solving interesting problems on the board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

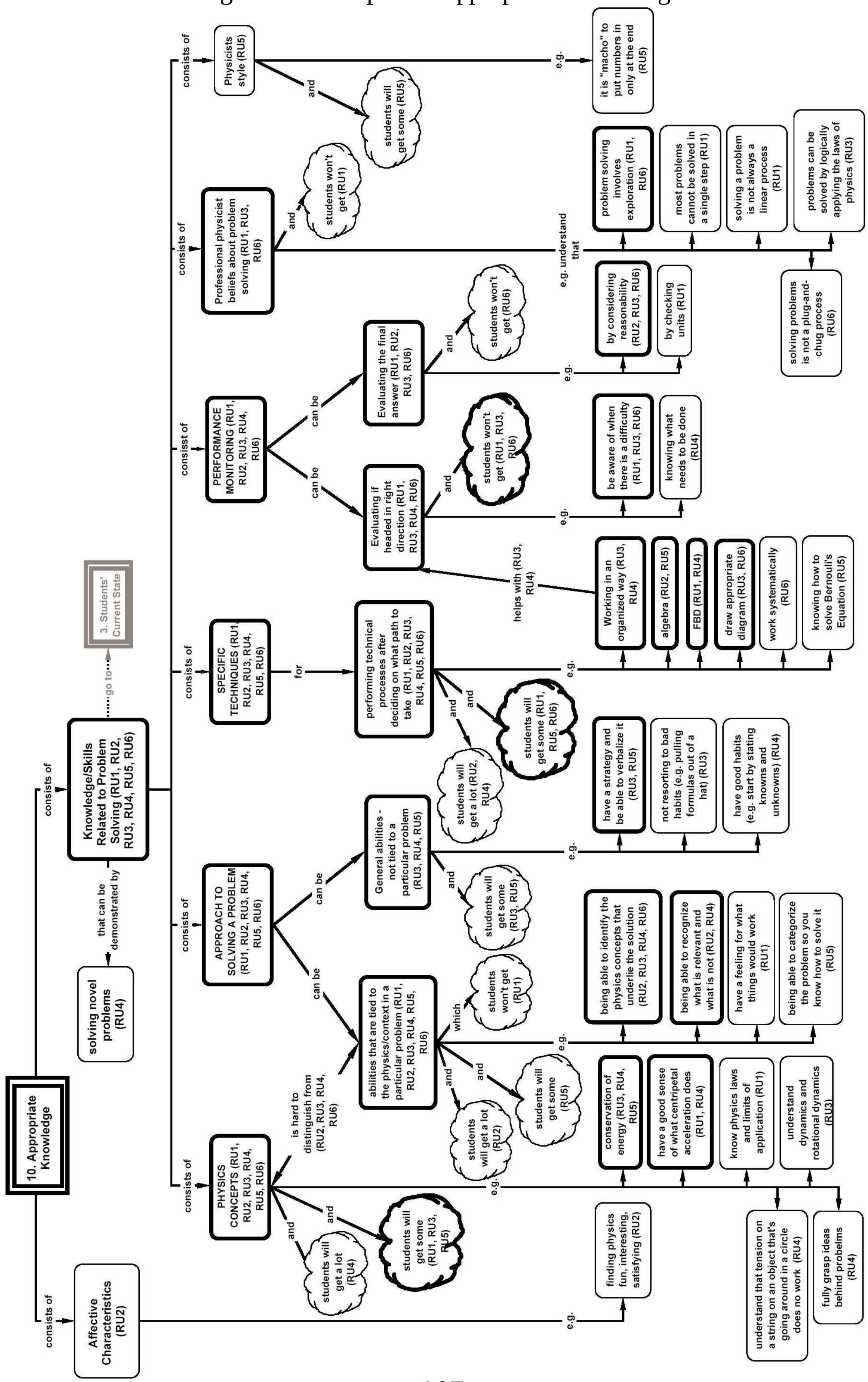
3. ***Appropriate knowledge includes being able to perform SPECIFIC TECHNIQUES.*** All instructors have this conception. SPECIFIC TECHNIQUES refers to an ability to perform technical processes after deciding on what path to take while solving a problem. For example, instructors said that solving a problem 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

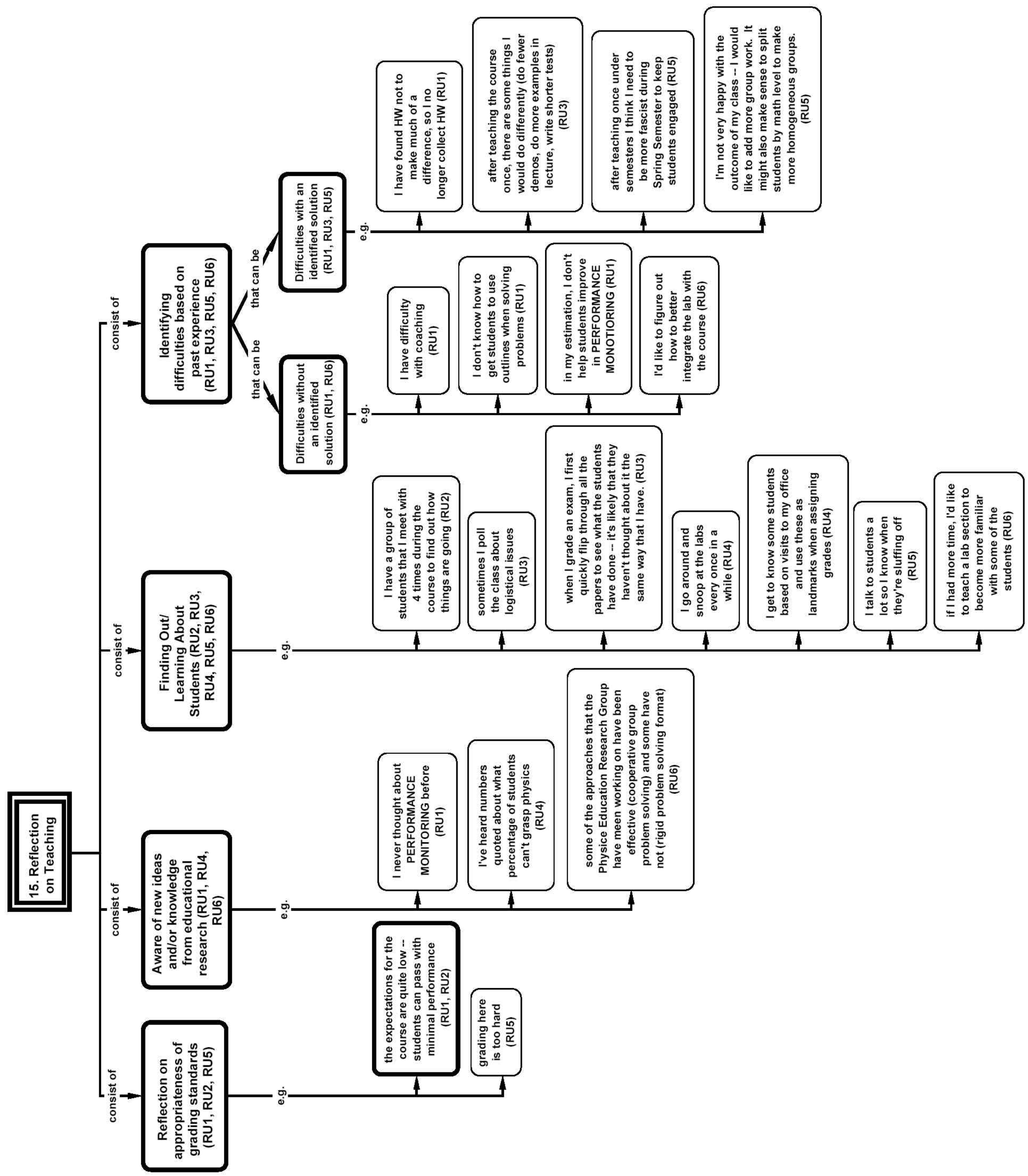
to support their position. For example, it was not clear why RU3 believed that demonstrations were not very helpful.

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.

* 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.

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

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

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

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.