AN EMPIRICAL MODEL OF PHYSICS INSTRUCTORS' BELIEFS ABOUT THE PURPOSE, ACTIONS, AND CONTEXT OF DOING HOMEWORK

A THESIS

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Dedication

I dedicate this work to my mother, Mary Jo Pihlaja. Her dedication to my education throughout my life has been sacrificial and unwavering. Her support and empathy throughout this process has been life-giving, and she’s always been in my corner. Thanks, Mom. I love you.

Abstract

Over the past half century, researchers and curriculum developers studying physics education have created dozens of innovative curricula and educational tools, broadly referred to as research-based instructional strategies (RBIS), to fit almost any classroom situation. However, the rate of adoption of RBIS remains relatively low. A national survey of post-secondary physics instructors in 2012 showed that only half of physics instructors have ever implemented any RBIS in their classrooms, and many of them ceased to do so after implementation difficulties. Why aren't these effective strategies being implemented at larger rates? Part of removing barriers to RBIS adoption may be understanding what instructors believe about how students learn.

In order to answer a small portion of this question, I studied physics instructors' beliefs about homework. This study is taken up in two parts. First, I analyzed 25 interviews with physics instructors from various types of institutions in Minnesota. The intent of the interviews was to elicit instructors' beliefs about the role of problem solving in the student learning of introductory physics. I focused on portions of the interviews where instructors spoke about what students should do or learn while they are solving problems independent of instructor assistance (homework). Using analytical methods in line with grounded theory methodology, I performed cycles of vertical and horizontal analyses on these interviews to gain insight into actions, mindsets, contexts, and processes by which students learn physics through doing homework. Six themes regarding homework that emerged from this analysis were: 1) an obligated to do homework, 2) things students should do or not do while they do homework, 3) specific

processes students should perform while doing homework, 4) things students should think about or understand while they do homework, 5) mindsets that students should have while doing homework, and 6) working in the context of a group or alone.

The second part of the study was to use the themes from the interview analysis to create a survey, which was then sent to physics instructors in the state of Minnesota. I incorporated best practices of survey creation including question ordering, question posing, triangulation, and having both open-ended and fixed-choice responses. I estimate that between 37% and 64% of eligible postsecondary Minnesota physics instructors began the survey, with a completion rate of 88%.

Using both the interview analysis and the survey responses, I created an empirical model of physics instructors' beliefs about homework. There were four main results. First, there is agreement that the goals of doing homework are to learn problem solving and physics principles. Second, homework is seen as necessary for learning physics by a strong majority of instructors, but it is not seen as sufficient for learning. Third, there is a limited number of tasks or actions that instructors believe that students should do while they are solving problems to learn. Fourth, there is evidence that physics instructors fall onto a continuum of beliefs regarding how students should approach solving problems on their homework. On one end of this continuum, instructors believe students should follow an algorithmic process that includes the steps to solving any problem. On the other end of the continuum, instructors believe students should have a more open approach to solving problems where they consider all the tools and principles available to them in order to make decisions about how to solve a problem. These results can inform creators of curriculum and professional development experiences as they try to reach out and connect with instructors and perhaps change their beliefs and practice.

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1.1 Background

1.1.1 The Adoption Problem

Over the last 50-60 years, researchers have investigated the numerous difficulties students have in learning physics. Studies have been done in areas such as how students interpret physics concepts (Cummings et al., 1999; Etkina & Van Heuvelen, 2007; McDermott, Shaffer, & Rosenquist, 1996), effective practices in changing conceptions (Hewson, Beeth, & Thorley, 1998; Minstrell, 2001, Strike & Posner, 1992), and learning problem-solving (Heller & Hollabaugh, 1992; Heller, Keith, & Anderson, 1992) to name just a few. This research has led to the development of many instructional methods and curricula that have been shown to be effective at helping students improve their learning and success in physics, including cooperative problem solving (Heller & Hollabaugh, 1992; Heller, Keith, & Anderson, 1992), Physics By Inquiry (McDermott, Shaffer, & Rosenquist, 1996), Investigative Science Learning Environment (ISLE) (Etkina & Van Heuvelen, 2007), Studio Physics (Cummings et al., 1999), and Peer Instruction (Crouch & Mazur, 2001) among others. Each of these methods requires professional development for the instructor and potentially a different physical space or course structure than is typical for a traditional physics course. Additionally, the methods are likely to be different than what the instructor experienced in his or her education.

However, despite this plethora of curricula and tools to more effectively teach introductory physics, their adoption has been much less widespread than one would hope.

A survey by Henderson and Dancy (2012) studied what physics instructors have done with research-based instructional strategies (RBIS) and how they have implemented them. We can look at the results of the survey to see some of the reasons for the lack of widespread adoption, as well as speculate about others.

About a quarter of physics instructors either do not know about or have not tried any RBIS. Another quarter have tried at least one, but discontinued use and often cited lack of support in implementation as one of the factors preventing adoption. For those who use some form of RBIS, some instructors may only adopt one or two strategies. While having half of instructors use RBIS seems like a good thing, in some cases where only parts of curricula or tools are being used, the instructional materials or methods are sometimes modified in such a way that they lose their effectiveness. Other hindrances to persisting in utilizing effective teaching strategies could be that instructors who implement one of these strategies are underwhelmed at the results or find themselves encountering more student resistance than expected. Instructors who are devoted to using these strategies are able to push through the difficulties, so we must look at whether the strategies conflict with or appear to conflict with the instructors' beliefs about how students learn physics. This could be a fundamental reason for lack of interest in adopting or adapting RBIS.

1.1.2 Beliefs about teaching and learning

Beliefs are a powerful construct that everyone develops to understand, interpret, and interact with the world around them (Brickhouse, 1990; Briscoe, 1991; Cooney, 1985; Deemer, 2004; Henderson, Dancy, & Niewiadomsha-Bugaj, 2012; Henderson, Yershalmi, Kuo, Heller, & Heller, 2007; Kagan, 1992; Mansour, 2009; Pajares, 1992;

Prawat, 1992; Tsai, 2002). These beliefs and/or their basis begin to develop as we encounter and make sense of the world and can be extremely hard to change, even when faced with internal inconsistencies and contrary evidence (Pajares, 1992). Because many of these beliefs are based on personal experiences and may not have an explicit or coherent structure, it can be very hard to determine what an individual's beliefs are.

In education, there is much research to show that beliefs about teaching influence teaching practice. With instructors who have more traditional beliefs about teaching, the correlation between beliefs and practice is more straight-forward (Charlesworth et al., 1993; Hashweh, 1996; Tsai, 2002). Teachers who say they believe that their role is to present information through a lecture while the students learn by listening attentively and taking notes are very likely to be doing exactly that. With instructors who hold more constructivist beliefs however, the relationship between belief and practice is more complicated (Hashweh, 1996; Prawat, 1992), perhaps because of the large range of instructional techniques that are consistent with constructivism. In this case, teachers' practices are determined not only by what they believe to be effective, but also by what they perceive to be their role, institutional constraints, etc. Such teachers may want to teach in a certain way but feel like it is not possible in their circumstances (Henderson & Dancy, 2007; Henderson et al., 2012). In any case, to understand the motivations for and possibly to influence what teachers do, it is important to know what teachers believe.

This may be particularly important because in the past few decades, the goals of science education have shifted from traditional notions of learning facts to an emphasis on learning processes such as non-routine problem solving. This shift is particularly noticeable in the National Science Standards from 1991, 1996 and 2012 (NRC, 1996; NRC, 2012; Rutherford & Ahlgren, 1991). Despite this, educational practices especially in physics teaching have been slow to change (Henderson, Dancy, & Niewiadomsha-Bugaj, 2012). Because the key to this inertia could be tied intimately to the beliefs teachers have about such process-focused learning and because the process of problem-solving is a central skill in all sciences, it is important to study instructors' beliefs about problem-solving.

1.2.3 Overview of Project

In physics, one significant effort to construct an empirical model of instructors' beliefs about problem solving was conducted by the Physics Education Group at the University of Minnesota (Henderson, et al., 2007; Yerushalmi et al., 2007) The researchers conducted 30 interviews lasting between 1.5 and 2.0 hours with the interview questions revolving around a set of familiar and diverse artifacts (e.g., homework problem statements as well as student and instructor problem solutions) to allow the instructors to talk about their practices, goals, and perceptions of students. Talking about learning and problem solving in multiple contexts enabled the investigators to triangulate an instructor's beliefs. This dataset still provides insight into current beliefs about instructors' beliefs for several reasons. First, physics teaching has an no significant changes in the last 20 years, and there is no reason to believe there has been sudden, widespread adoption of RBIS or a substantial difference in the new-faculty exposure to RBIS (Henderson, 2008; Henderson, Dancy, & Niewiadomska-Bugaj, 2012). Second, the physics instructor population tends to be very stable. Of the six interviewees used in the initial study of the interviews, 4 of the interviewees are still currently teaching classes.

The initial study analyzed a small number (6) of these interviews of instructors from a single educational institution and created an Initial Explanatory Model (IEM) for instructors' beliefs about problem-solving (Henderson et al., 2007) based on their statements. This model was represented using a concept map that included ten "principal categories" including Students who can improve, Appropriate knowledge, Solving physics problems, Typical students, Work, Use feedback, Look/listen, Appropriate problems, Individualized responses, and Appropriate example solutions (Henderson et al., 2007). For each of these principal categories, the researchers created a separate "child" concept map to express the range of instructors' ideas that fit under each of them.

The next planned step of the project was to take each of those 10 principal categories and to test and elaborate on each one using the complete set of 30 interviews to create a Refined Explanatory Model (REM). This was done in one study soon after the establishment of the Initial Explanatory Model. Kuo's (2007) dissertation study took up the principal category of "Solving Physics Problems" and utilized the remaining interviews to develop a Refined Explanatory Model. This work will be described in greater detail in chapters 2 and 5. Once the complete dataset had been analyzed to include the full range of beliefs represented, the next step would be to create a written survey that would enable further testing of the model with a still larger population. Ultimately, the intent was to develop a comprehensive model of the beliefs of physics faculty about problem solving based on a large and diverse sample.

This study takes up the principal category of Work from the Initial Explanatory Model. In this context, Work refers to the activities that students do outside of class hours that involve practicing solving problems (aka homework). This principal category includes the specific activities or mindsets that students do or need in order for homework to be an effective part of their learning. I chose this principal category because of its centrality to the Initial Explanatory Model. There were no explicit questions in the interview to probe this principal category, but all the instructors spoke about specific things that students need to do or not do as they are solving problems as well as the instructors' goals in and the importance of giving homework. In this study, I expanded the idea of Work from what existed in the Initial Explanatory Model to a Refined Explanatory Model based on the full set of 30 interviews, created a survey that was sent to post-secondary physics instructors primarily in the state of Minnesota, analyzed the results of the survey, and propose a Refined Explanatory Model for Work.

1.2 Research Questions

In this study, I focused on the following three questions:

1) *What do physics instructors believe students should learn from solving problems outside of the formal classroom environment?*
2) *What do physics instructors believe students should do while solving problems outside of the formal classroom environment?*
3) *How do instructors believe working with others outside of the formal classroom environment affects a student's problem solving and learning?*

1.3 Overview of the study

This study was carried out in three main stages – Interview Analysis, Survey Creation, and Survey Analysis. Because of the diversity of data in this project, I employed both qualitative and quantitative analysis methods in the study. The research questions were all addressed at each stage of the study. Figure 1-1 shows the research process and how it relates to the previous research.

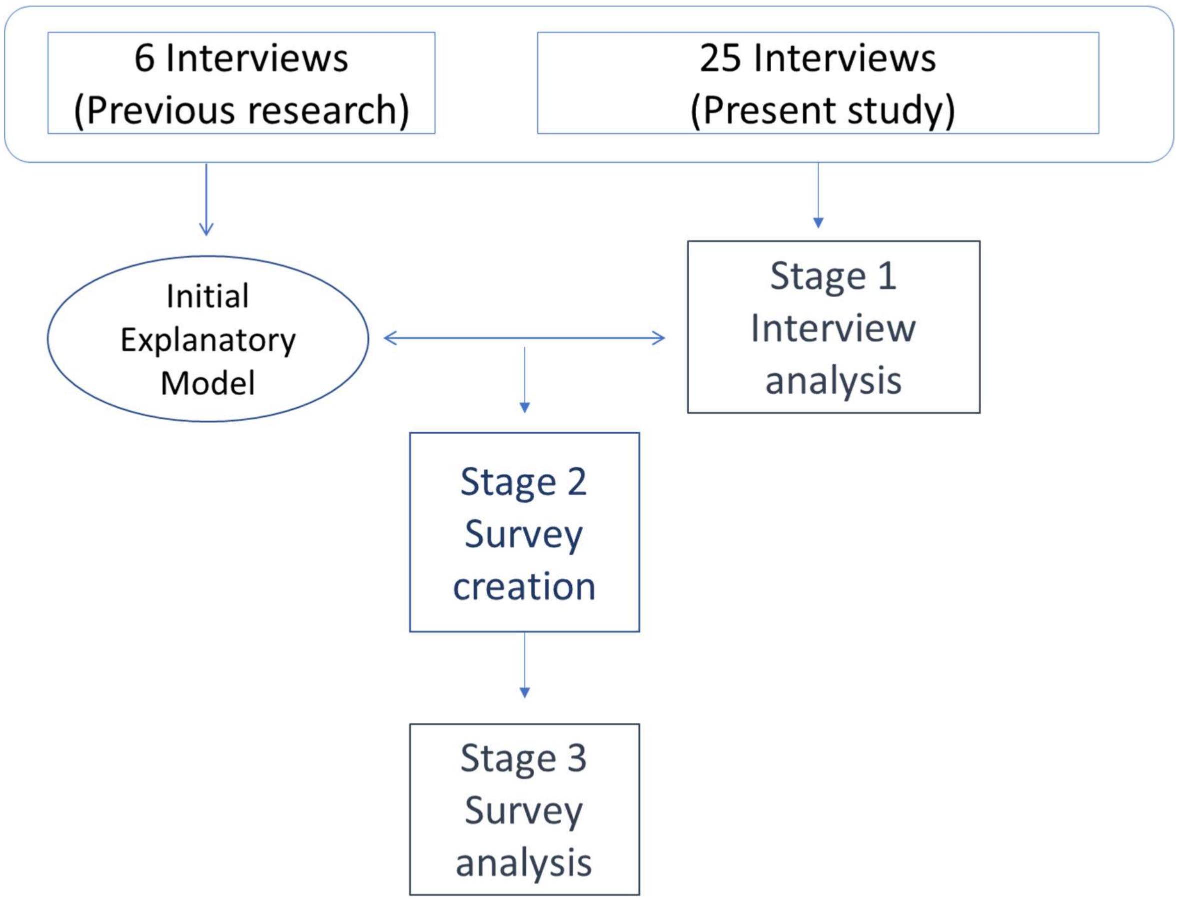


Figure 1-2: Diagram showing the relationships between the three stages of this work and its relation to previous work. There are 30 interviews total, but due to a record-keeping error, there is one common interview between the IEM study and this study.

1.3.1 Stage 1- Interview Analysis (Chapters 3, 4, and 5)

This first part of the work described in this dissertation was a detailed analysis of 25 interviews to elaborate on the principal category of Work. Twenty-four of these were not used in the initial study. (Due to a record keeping error, one of the original six was unintentionally analyzed for this study.) Because I focused on a previously identified idea, this is a convergent analysis. However, because this principal category was previously analyzed using only a limited dataset and was considered incomplete, this analysis is also exploratory in that it is meant to expand and expound on the ideas within the original principal category. I used qualitative methods in line with grounded theory methodology including coding, constant comparison and memo writing (Corbin and Strauss, 2008). These methods are useful for the textual analysis of the interviews because they provided a systematic approach to both finding new ideas and comparing ideas across interviews. Because of the number of interviews analyzed, I developed a cycle of analysis to look at the interviews in batches of 6 or 7 at a time. This provided a structure that was more efficient for identifying commonalities and new ideas than reading all the interviews in one chunk.

While the interviews were structured, they were not specifically focused on the Work principal category. The amount of time spent on different ideas by different instructors varied widely and was dependent on how the individual interviews progressed. The themes that emerged from my own interview analysis were compared to the Initial Explanatory Model. Because I did not use the Initial Explanatory Model exclusively to find the themes of the interviews, the comparison to the IEM was where I could test the themes that I found in the 25 interviews with the components of the principal category of Work found in the initial study. The main goal was to have a full representation of ideas held by physics instructors without regard to their institutions. The frameworks for what the goal of homework is, what instructors think students should do while doing homework, how instructors conceptualize the activities of homework, and what they think about group work were written described as themes from the interviews.

1.3.2 Stage 2- Survey Creation (Chapter 6)

I next constructed a survey to test the draft Refined Explanatory Model with a larger and more current population of instructors. The survey questions were related to themes that arose in the interview analysis, and the possible responses represented the range of ideas expressed by the instructors that were interviewed. At the same time, the survey was designed to allow respondents the freedom to introduce new ideas that had not been found in the interviews.

The construction of the survey also followed standard recommendations for survey research, including giving attention to the wording and ordering of the questions (Dillman et al., 2014). Multiple questions were used to probe respondents' ideas about Work and questions were posed in a variety of ways and in a variety of contexts in order to triangulate their beliefs so that a fuller picture of the themes from the interview analysis could be explored and tested. Because of the nature of studying beliefs, attention was also given to survey construction to minimize the potential of the respondents to give socially desirable responses based on perceived value judgements (Dillman, et. al., 2014).

Requests for participation in the survey were sent to every institution of higher learning in the state of Minnesota that offered introductory physics. The survey was available for a three-week period during late spring and early summer of 2018. A total of

84 respondents began the survey, although 9 did not meet the survey criteria and exited after the first question. Sixty-six of the respondents finished all of the questions in the content portion of the survey.

1.3.3 Stage 3- Survey Analysis (Chapter 7)

Because the survey included both closed- and open-ended questions, the survey analysis employed both quantitative and qualitative methods. I grouped the survey questions that related to each other to provide triangulated answers to the research questions. I used two main approaches to analyzing the data. First, where appropriate, I looked at the agreement of answers across the population of physics instructors giving attention to places where a majority of the instructors agreed in the responses. Second, I created groups of instructors based on their answer to a key question which attempted to distinguish instructors' frameworks of learning from problem solving. When looking at these aggregated groups, I selected certain questions to compare answers among the groups to see if there were significant differences among the groups. Finally, as a test of the validity of the survey, I ran a factor analysis to see if correlations in responses to the survey questions were consistent with the triangulation built into the survey.

1.4 Implications

1.4.1 Theoretical

This study is an extension of work started to explore post-secondary physics instructors' beliefs about the connection between student learning and their problem solving. It is distinct from similar research like expert and novice problem-solving because the focus is shifted to the instructors' beliefs about the teaching and learning of problem-solving in physics and not the employment of the skill. Initial results have shown that there is a difference in instructors' approaches to teaching problem solving in some or many cases, and this study expands that picture to give insight into what ways instructors believe students should be taught to solve problems.

1.4.2 Practical

Results of this line of research can help curriculum developers package their materials in a way that feels natural and usable to instructors. Instructors cite factors such as time, space, lack of support, and lack of student interest, among others as reasons for non-adoption of RBIS. However, some instructors work to implement RBIS despite such issues. Perhaps an underlying reason for why some instructors are willing to devote more time and effort than others is the extent to which the perceived goals and methods of a RBIS is consistent with or in conflict with an instructor's beliefs. If an instructor believes that the goals and methods of a curriculum or educational tool is consistent with his or her beliefs about how students learn physics, that person may be more likely to work to adopt the tool or use it in a way that maintains its effectiveness, or to expend more time and effort to overcome setbacks in implementation (Henderson & Dancy, 2007).

Results from this study can also be helpful to those designing professional development experiences. If one wants to connect with instructors and help them change their teaching practice, it is useful to know what their beliefs about how students learn might be. That way, one can avoid unnecessary conflicts with those beliefs and focus on speaking to the parts of their beliefs that are in line with the proposed practice.

Finally, having an empirically-based model for beliefs will be helpful in self-understanding and communication. Where there are differences of ideas, it would be helpful to have a coherent model that represents those differences in an authentic way to the person who holds them and to those who have different ideas. Being able to name and describe the different ways of conceptualizing problem solving is the first step to have a productive discussion about it. It is also beneficial to identify areas of overlap and commonality of values so that there can be a mutual understanding of goals.

Chapter 2: Literature Review

In the research literature, the idea of "beliefs" that teachers hold has gone by many different names (e.g., beliefs, constructs, concepts, values, attitudes, etc.) and conversely, the word "beliefs" itself has been used differently in different research studies (Kagan, 1992; Parajes, 1992; Prawat, 1992). Furthermore, the protocols used in investigations might well influence and be influenced by the meaning of the term intended by researchers and/or how the term is understood by the participants in the studies. Of practical importance is whether the differences between studies are large enough to make comparisons between studies meaningful. Pajares (1992) has stated that the fundamental notion behind all these terms is the same. Kane and coworkers (2002), however, have questioned the validity of that statement. For the purposes of this literature review, we adopt the point of view of Pajares.

2.1 Beliefs about teaching and learning

2.1.1 Nature of beliefs

In general, teachers have developed a complex set of beliefs about themselves, their students, their teaching goals, what they can accomplish given their perceived constraints (institutional, students, and personal), what they consider to be practical, what they see as successful teaching, and a host of other teaching related ideas (Briscoe, 1991; Cooney, 1985; Deemer, 2004; Henderson & Dancy, 2007; Henderson, Dancy, & Niewiadomska-Bugaj, 2012; Kagan, 1992; Mansour, 2009; Pajares, 1992; Prawat, 1992; Tsai, 2002).

The hierarchy and interconnectedness of an instructor's beliefs are important to consider globally (Parajes, 1992; Tsai, 2002). All beliefs are not considered to be equal and the relationships between the beliefs are necessary to consider because adjusting one belief will have implications for other beliefs. How important or tightly connected one's beliefs are varies from person to person and interactions between beliefs can be difficult to anticipate. A person's beliefs are generally prioritized, with some being dominant or taking precedence over others, and the strength of these beliefs may either be due to how they are organized or to how fundamental they are to each person (Parajas, 1992; Tsai, 2002). Tsai found that high school physics and chemistry teachers in Taiwan had connected, interdependent beliefs about the teaching, the learning, and the nature of science (2002). In that study, teachers' views of these three concepts were categorized as traditional, process, or constructivist. Tsai found that a teacher was very likely to have similarly categorized views of at least two of the concepts and that many of the teachers held connected and interdependent beliefs of all three concepts. This result shows that addressing the beliefs of teachers may require attention to a broad construct.

Beliefs are often developed over long periods of time and are grounded in personal experience (Brickhouse, 1990; Cooney, 1985). As such, these beliefs are resistant to change and tend to self-perpetuate (Pajares, 1992). Consistent with the research on conceptual change, if instructors feel that their belief set is useful for explaining observations in their context, then they will not be motivated to change their beliefs. For example, Brickhouse found that beliefs can be represented as a metaphor of the role of the teacher and the interactions among the persons in the classroom such as the teacher, individual students, and students as a group (1990). The conceptualization of teaching using a role metaphor such as teacher as coach, teacher as guide, or teacher as expert can be a way to identify deeply held notions about how the teacher perceives herself and her goals (Brickhouse, 1990). If an individual teacher feels her analogy works to provide a framework for her role and actions, she could be resistant, consciously or not, to incorporating new ideas that do not fit that framework.

2.1.2 Studying beliefs

Studying the beliefs of teachers is difficult because simply asking someone what they believe is generally ineffective. For example, a person might not have thought deeply about his or her beliefs and therefore be unable to give a coherent statement (Deemer, 2004; Kagan, 1992). Alternatively, a person might report what she thinks she believes, but this may be inconsistent with behavioral evidence. Furthermore, a person might say what she would *like* to believe, rather than what she *actually* believes (Parajes, 1992). Finally, some instructors might have elevated their personal beliefs to the status of knowledge and be unwilling to or incapable of discussing them as beliefs (Parajes, 1992).

In addition, one cannot necessarily determine teachers' beliefs from their practice. Even though teachers' beliefs about students and teaching may be congruent, their beliefs about themselves and their environment may also substantially influence their teaching practice (Kagan, 1992). For instance, a teacher may believe that students learn best when they are engaged in inquiry. This teacher might also be competent in implementing inquiry-type instruction and believe that it is effective. However, that same teacher may choose not to use an inquiry-type curriculum for several reasons: she might believe that her students are unable to work in that environment or that she doesn't have enough time in a school year to cover the material required. She could also believe that she, personally, is not capable of implementing the teaching method effectively or that she would not receive the support she needs to navigate challenges in introducing it.

Best practices regarding studying beliefs include avoiding asking direct questions regarding beliefs, and instead asking questions concerning actual practice and the reasons behind those practices, as well as triangulating beliefs with artifacts in interviews (Henderson et al., 2007; Kagan, 1992; Kane et al., 2002). Consequently, the methodology chosen for a study on beliefs is very important (Henderson et al., 2007; Kagan, 1992; Kane, Sandretto, & Heath, 2002). Studies correlating teaching practice and beliefs inherently have small sample sizes because of the enormous amount of work required to study a single participant (Brickhouse, 1990; Briscoe, 1991; Cooney, 1985; Goertzen, Scherr, & Elby, 2010b; Tsai, 2002). Conversely, larger studies relying on surveys of teachers are usually unable to provide evidence linking belief and practice explicitly (Henderson et al., 2012).

2.1.3 Correlation between belief and practice

Although the connection between teachers' beliefs and practice is not necessarily straight-forward, studies of teachers' beliefs show that, in general, they do correlate with practice (Brickhouse, 1990; Briscoe, 1991; Goertzen et al., 2009, 2010a, 2010b; Hashweh, 1996; Kagan, 1992; Pajares, 1992; Prawat, 1992). Teachers who have more traditional beliefs about teaching and learning tend to have the most congruence with practice (Charlesworth et al., 1993; Hashweh, 1996; Tsai, 2002). Teachers who hold more constructivist beliefs have a wider variance between the belief and observed practice (Hashweh, 1996; Prawat, 1992), perhaps because of the wider range of "constructivist" teaching styles.

While the connection between beliefs and practice may be complex, what is important is that the teachers do connect their beliefs with their practice; there is no evidence that teachers will willingly or consistently violate their beliefs in their practice (Goertzen et al., 2009, 2010a). Specific connections between belief and practice can usually only be pinpointed when the teachers themselves are asked to explain their specific teaching behaviors (Goertzen et al., 2009; Kane et al., 2002). In one study of a teacher's beliefs versus practice, it was through reflection that the teacher realized the conflicts between his stated beliefs and practice (Briscoe, 1991).

2.1.4 Changing beliefs/practice

Much of the literature on teachers' beliefs emerges from studies on how research-based instructional strategies (RBIS) are or are not being incorporated into classroom practice (Briscoe, 1991; Errington, 2004; Goertzen et al., 2009, 2010a, 2010b; Henderson, 2008; Henderson & Dancy, 2007; Mansour, 2009).

If one wants to change a teacher's beliefs, there is much in the conceptual change literature that is relevant. One of the central pillars of conceptual change is to first identify the previously concepts or knowledge held by the learner. This serves two purposes. The first is to be able to provide appropriate instruction to the learners based on their mental state (Minstrell, 2001). The second is that learners need to be aware of their own knowledge before they are ready either to add to it or modify it (Hewson, Beeth, & Thorley, 1998; Strike & Posner, 1992). In the case of misconceptions, effective instruction depends on how deeply held the misconception is and how willing the learners are to change their way of thinking. Several types or rounds of instruction may be needed to stimulate a change in thinking. Even if a previously held idea is shown to be inconsistent with data or scientific theory, learners will not change their thinking unless a workable theory is available to replace it (Strike & Posner, 1985).

Despite the substantial literature on conceptual change, however, presentations of research-based or reform teaching strategies and curricula are rarely responsive to their audiences (Goertzen et al., 2010b). This approach directly contradicts two of the core tenets of RBIS, which are that presentations should be audience-centered, and that the audience is expected to be intellectually active during the presentation (Redish, 2003). Without a reliable model of instructors' beliefs, these presentations at workshops, seminars, talks, and conferences will not be as efficient as they could be in communicating better teaching strategies with teachers of all kinds. Of course, there are constraints on how presentations are canonically delivered which can be very appropriate for other types of information like research presentations but cannot be expected to be effective when addressing issues of changing how one teaches.

Institutional factors can also hinder teachers from changing their teaching practices (Henderson & Dancy, 2007, Henderson et al., 2012). One reason teachers have given for not implementing RBIS is because their teaching environments do not allow such methods. A second reason is that while they may believe that a particular RBIS provides better and more effective instruction than they are currently providing, they feel that a lack of institutional support and student resistance to non-traditional teaching methods makes it impractical to use (Henderson & Dancy, 2007; Henderson et al., 2012). Finally, instructors who do not believe a teaching method is effective might find it lacking because they tried it without learning all the implementation details and thus used it incorrectly, or because they customized it in ways that were more suitable to them, but which destroyed the intervention's effectiveness (Dancy & Henderson, 2010).

2.1.5 K-12 teachers versus postsecondary teachers

There is overlap in the research regarding teachers' beliefs in K-12 and postsecondary settings such as beliefs correlating with practice (Goertzen, Scherr, & Elby, 2010a), beliefs are based on personal experience and can be resistant to change (Henderson, Dancy, & Niewiadomska-Bugaj, 2012), and teachers do not persist in methods that they see as failing (Goertzen, Scherr, & Elby, 2009; Henderson, Dancy, & Niewiadomska-Bugaj, M., 2012;). Kane et al. argues that the research on teaching beliefs has not been incorporated into research on teaching beliefs at the post-secondary level where it would be applicable (2002). However, it is important to note how the two types of teachers differ, since the general population of K-12 teachers and postsecondary instructors of physics are dissimilar enough that research results cannot be considered automatically transferrable. One difference between the two groups of teachers is that a majority of postsecondary physics instructors do not have any pedagogical training (Kane et al., 2002). At the postsecondary level, a degree in relevant subject area or in some cases, a good performance in the physics class in which a person is teaching or assisting is considered sufficient preparation to teach a class. Such instructors tend to teach how they were taught unless they themselves seek out alternatives. A second difference between K-12 teachers and postsecondary instructors is the population that they teach. Adult education is structured in a very different way than adolescent education in that students are expected to be motivated, as well as mature enough to process information appropriately.

2.2 Physics specific research

The body of research that deals with postsecondary physics instructors' beliefs about instruction is small. Furthermore, because such research is time and labor-intensive, sample sizes of studies tend to be low. However, the findings published in this literature are consistent with the general findings of the studies of teachers' beliefs discussed already, and in addition, highlights physics-specific issues.

2.2.1 Teaching Assistants' (TAs') beliefs about physics instruction

Although virtually all postsecondary physics instructors were previously graduate students, the fact that only a small fraction of physics graduate teaching assistants (TAs) become postsecondary instructors means that the two groups are not equivalent. However, there are enough similarities between the two groups to make research on TAs of interest. Furthermore, because very few postsecondary physics instructors receive additional education regarding teaching between their graduate work and the beginning of their faculty positions (Henderson, 2008), advanced TAs and beginning physics instructors have essentially the same amount of pedagogical training.

There are few studies that connect TAs' expressed beliefs about teaching and their observed practice. One comprehensive study of this type was conducted by Goertzen, Scherr, and Elby (2009; 2010a; 2010b). The RBIS used in this context was Tutorials in Physics developed by the University of Washington (McDermott & Shaffer, 1998). These tutorials are worksheets consisting of carefully sequenced questions that help students elaborate their knowledge of physics concepts, paying attention to well-documented student difficulties and connecting students' "common sense" thinking to physics phenomena. TAs received special professional development before using the tutorials in recitation sections, which included learning about the tutorials, the research basis behind the pedagogical method, and methods for effective implementation. The researchers then recorded the recitation sessions run by the TAs, analyzed their teaching behaviors, and had the TAs watch episodes of their own teaching while explaining their decisions. This allowed the researchers to look at the correlations between the TAs' stated beliefs and their practice.

This research was congruent with the wider literature on teacher beliefs in finding that, while belief and practice are correlated, the exact relationship is complex and involves a wide variety of factors. The researchers analyzed the teaching behaviors of three TAs whose teaching was categorized as "focusing on indicators" such as correct answers, regardless of how the students presented the answer or what they said during their explanations (i.e. the right answer with an uncertain or incorrect justification). However, when the TAs explained their reasoning during the interaction, they all had different reasons for what they did, but the reasons were not based on the design of the tutorials (Goertzen et al., 2010b). The TAs were using their own understanding of good or appropriate teaching without taking into account the way the curriculum was structured. Another finding was that if a TA did not "buy in" to the curriculum, they changed it to fit their own teaching beliefs (Goertzen et al., 2009). In this context, "buy in" was defined as being positively disposed towards a variety of pedagogical methods, seeing conceptual understanding as important, and being willing to help students construct their understanding.

In several of the teaching episodes, one TA discounted the curriculum to the students and subverted it by giving his own explanations. This TA indicated that he valued presenting a logical progression of the solution to the problem rather than having students construct their own understanding using "common sense" thinking from everyday life. This approach degraded the effectiveness of the curriculum since it was inconsistent with that of the designers.

Lastly, the researchers found that all the TAs involved in the study had potentially useful ideas about students and learning (Goertzen et al., 2010a). The TAs based their decisions on what they thought was most helpful for student learning, rather than any dislike of the curriculum.

Although this study was done specifically to improve the trainings for TAs at the researchers' department, it has wider implications for understanding physics instructors' beliefs and the adoption of RBISs. The training received by TAs in the study did not take into account the beliefs and state of knowledge of the TAs. If the training were to first have the TAs talk or write about their understanding and experience of teaching, there would at least be a basis for comparing the pedagogical method being presented and the TAs' previous ideas. The dissonance might be addressed in this case instead of ignoring it altogether. The researchers also speculated that the "buy in" of the curriculum was greatly affected by the institutional buy in. If the faculty are not highly supportive of an RBIS or view it as unimportant or ineffective, then the TAs will likely not value it or be committed to correct implementation. The overall implication is that knowing what instructors believe is important to their willingness to use RBIS.

2.2.2 Faculty beliefs about problem solving

To examine beliefs of physics instructors about problem solving, the Physics Education Research group at the University of Minnesota conducted 30 extensive, artifact-based interviews with physics faculty from a wide range of types of institutions (Henderson et al., 2007; Yerushalmi et al., 2007). The artifacts consisted of problem statements and instructor and student problem solutions. The interview protocol prompted the faculty to talk about what they liked or disliked about the various artifacts, and in so doing, talk about their own practice or whatever they were thinking during the interview. The artifacts were constructed to represent a wide variety of options within each category. For example, student solutions included one that had a correct answer, but very few details to show the student's reasoning, and one that displayed a great deal of the reasoning process and that also had two cancelling math errors that led to the right answer, as well as a few others with varying levels of detail and/or errors. All the artifacts, as well as a description of the interview protocol, are discussed in Chapter 3. Three major results have come from these interviews. The first was an empirical model of physics instructors' beliefs about problem solving, the second was a categorization of instructors' conceptualizations of problem-solving processes, and the third concerned instructors' beliefs about grading.

2.2.2a Result 1: Empirical model

The main purpose of the interviews was to develop an initial explanatory model (IEM) of physics instructors' beliefs about the learning and teaching of problem solving. All thirty interviews were collected around the same time; however, only six of the interviews (all with physics faculty at the University of Minnesota) were used to establish analytical protocols as well as to construct the IEM because they were thought likely to have similar beliefs (Henderson et al., 2007). The other twenty-four interviews would then be used to test, refine, and expand the model. As stated in the paper,

> "The purpose of our research is to begin the process of building a model to describe the beliefs of physics faculty that influence their choice of curricular materials and pedagogy when they teach introductory physics. It is anticipated that this model can be used to formulate a set of testable hypotheses that will lead to an elaborated and corrected model with features that can be applied to curriculum and professional development."
> (Yerushalmi et al. 2007, pg. 020109-1)

This preliminary model is taken to be the basis for further research and generation of questions, not as a model that is to be tested and either confirmed or refuted. There is no claim that it provides a full picture out the beliefs of instructors, rather it is to be used as a starting point and a guide for how the concepts might fit together. The IEM from the six interviews was represented by a series of concept maps. The top level concept map is shown in Figure 2-1.

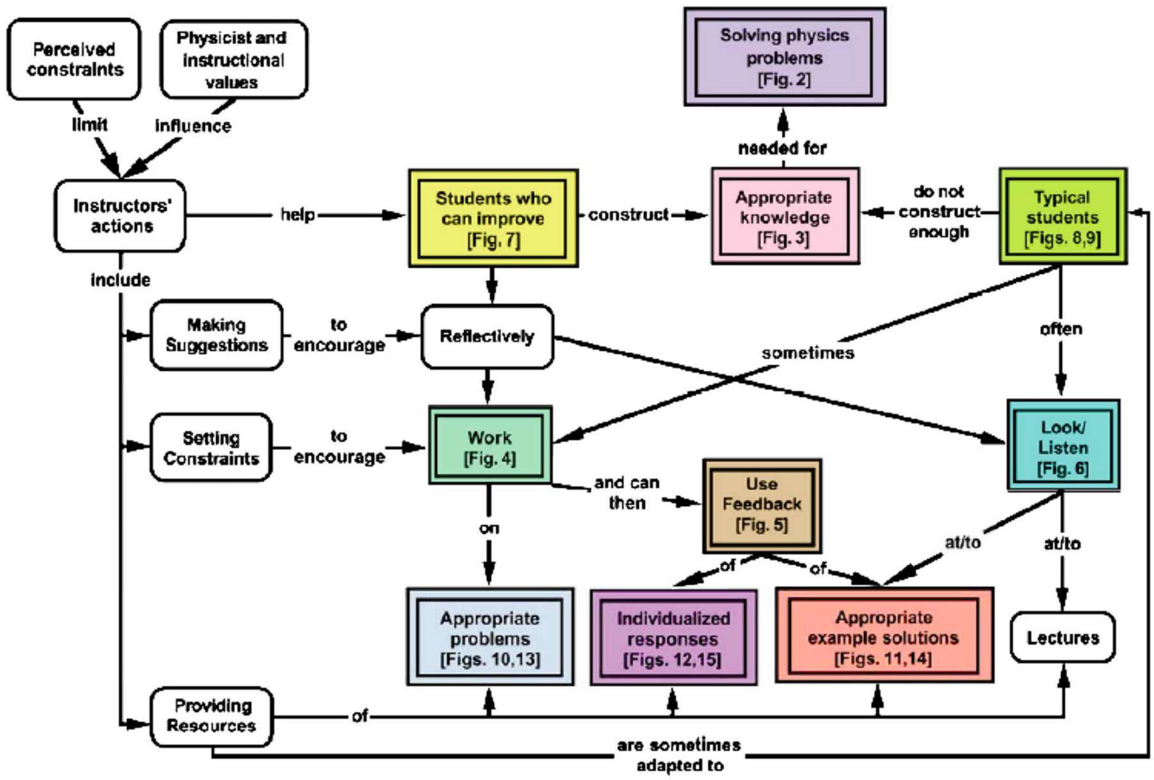


Figure 2-1: The top level concept map (Fig. 2 in Yerushalmi et al., 2007), which was created through analysis of six interviews with University of Minnesota physics faculty. The boxes with double lines represent principal categories, which in turn have their own concept maps .Figure numbers in the diagram refer to figures in the original paper, and not in this dissertation.

The number of years of teaching experience of the six faculty ranged from 2 to 43 and the number of times those six had taught an introductory-level physics course ranged from 1 to 79. At the University of Minnesota, the introductory physics classes have an explicit emphasis on problem solving and have lecture, laboratory, and discussion sessions. In the discussion sessions, students work in cooperative groups to solve a problem provided by the instructor. The laboratories also have an emphasis on problem solving, with students working in their discussion groups to solve a problem and check the validity of their solution through experimental methods. The lectures were under the complete control of the individual instructors. However, the discussion and lab activities were designed by the University of Minnesota PER group.

The ten principal categories in the IEM about which more elaborate information was obtained were represented with boxes shaded in different colors and each has its own child concept maps. For example, the child concept map for "Work" can be seen in Figure 2-2 and has connections to three other child concept maps: Typical Students, Appropriate Problems, and Appropriate Knowledge.

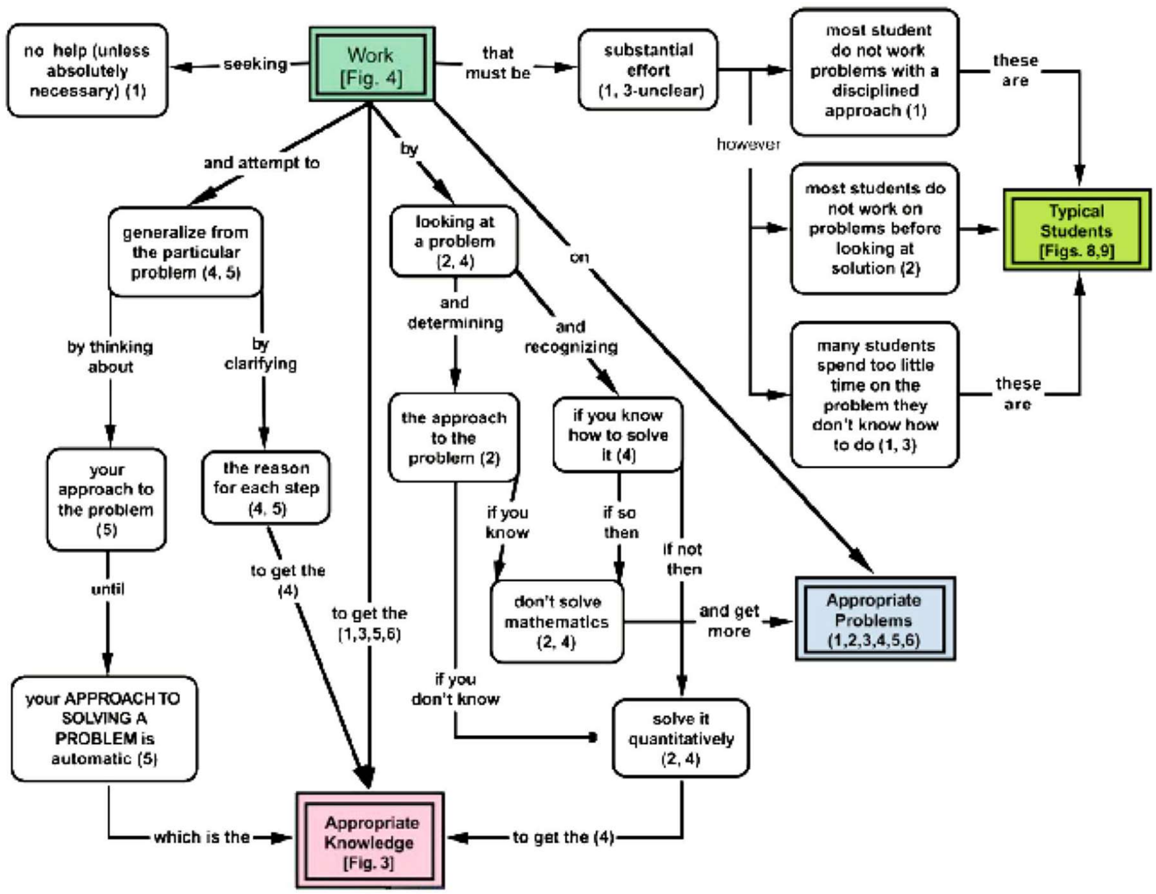


Figure 2-2: This concept map (Fig. 4 in Yerushalmi et al., 2007) was created by using statements from the interviews that illustrate instructors' beliefs about what students should do as well as what students actually do when solving problems. Figure numbers in the diagram refer to figures in the original paper.

2.2.2b Result 2: instructors' conceptualizations of the problem-solving process

An unpublished study by Kuo (2004) explored the beliefs that instructors had about the problem-solving process in physics. In the initial study with six faculty, the researchers categorized instructors' conceptions of the problem-solving process as either linear, cyclic, or artistic (Yerushalmi et al., 2007). The linear conception (described by three instructors) is that solving a problem involves performing a series of steps that leads to an answer. Unless a step is performed incorrectly, there is no need to go back to any of the previous steps. The cyclic conception (described by two instructors) is that problem solving is an exploratory, trial-and-error approach where mistakes and dead ends are a natural, expected part of the process. The artistic conception was described by only one instructor, who described a process that was completely unique to each problem, solution, and student. When Kuo analyzed the entire set of 30 interviews, he categorized 22 instructors as linear, seven as cyclic, and one as artistic. Even though no more categories emerged when the larger data set was considered, each of the categories was elaborated to provide a more detailed description of each of the three conceptions. For instance, about 30% of the additional interviews had statements that were not represented in the Initial Explanatory Model and were subsequently added to create a Refined Explanatory Model regarding the linear conception. Thus, this larger data set allowed for a fuller picture of the linear and cyclic conceptions of problem solving.

2.2.2c Result 3: Instructors' beliefs about grading

A portion of the interviews in which the physics instructors viewed and discussed sample student solutions specifically asked the instructors to rank them by the grade that each would receive in their class (Henderson et al., 2004). The instructors were also asked to provide numerical grades and explain what each number meant. A theme that emerged from these discussions was how the instructors viewed the "burden of proof" for the solution. First, instructors usually wanted students to show their reasoning to elaborate why they took certain approaches. Second, instructors felt an obligation to take points away from a solution that contained errors even if they were relatively minor, as well as a reluctance to deduct points from a solution that gave the correct answer without justification. Third, instructors were likely to project correct reasoning onto student solutions even when no justification was given in the solution.

2.2.3 Factors affecting physics instructors' decision to adopt RBIS

Previous research has shown that instructors' beliefs and practice are correlated, although not necessarily in a straight-forward way. In order to study physics instructors' beliefs and their relationships to their decisions on whether or not to adopt RBIS, Henderson and Dancy (2007) interviewed six instructors of physics who were categorized as being susceptible to using RBIS in their courses. This categorization was based on two criteria. The first was that the instructors were known as being thoughtful and reflective in their teaching practices in introductory physics. The second was that they were tenured and therefore did not have the concern of trying new strategies negatively impacting their future careers. All of the instructors were aware of the existence of one or more RBIS and had tried to implement them in their classes. The interviews focused on the faculty's perceptions of barriers to the use of RBIS in their courses. Some of the perceived barriers were institutional, resulting from aspects of the course format such as the number of students in the class, time allotments, and course content. Some of the perceived barriers were based on beliefs about students' attitudes towards school and resistance to using certain strategies that involved higher student engagement. A final perceived barrier involved departmental norms of how a class should be run and what kind of support an instructor would have if they tried a non-traditional pedagogy. Overall, the instructors claimed to be willing to use RBIS, but found the institutional constraints too great.

In another study, Henderson and Dancy (2012) conducted a large, national survey of physics instructors in which they studied the factors correlated with the adoption of RBIS. The survey results showed that an overwhelming majority of physics instructors knew about at least one RBIS. Faculty were most likely to have heard about RBIS from attending the New Faculty Workshop sponsored by the American Physical Society and the American Association of Physics Teachers, attending workshops or talks, or reading journal articles.

In contrast to some popular beliefs, the results did not support the idea that an instructor's rank or age significantly affected their willingness to or probability of use of RBIS. Furthermore, class size, research productivity, type of institution, and percentage of job responsibilities related to teaching also were not correlated with use of RBIS.

In fact, the greatest predictor of an instructor using an RBIS was being female. The authors conjectured that female faculty beliefs about teaching and learning might be more consistent with the approach of RBIS and that they therefore persevere through implementation difficulties more than their male counterparts.

2.2.4 Summary of research on teachers' beliefs

There are several important take-aways from the research on teachers' beliefs:

1. What a teacher believes about themselves, their students, their subject, and learning affects how they teach. However, the relationship between beliefs and classroom practice is complex and could be clouded if factors from different areas conflict.

2. Studying teachers' beliefs is not necessarily straight-forward. Teachers may not be able to verbalize their beliefs or may report a belief that does not correlate with their practice. There may be pressure, perceived or actual, that would bias reporting of beliefs.

3. Research on understanding teachers' beliefs can have practical applications in reforming curricula and teaching. Instructors who do not believe that a teaching method will be effective will likely not implement it in a way in which it can be effective. Furthermore, instructors' beliefs about institutional barriers, student resistance, and lack of support contribute to their decisions about whether or not to use particular teaching methods, especially those that require special time and effort to implement.

4. Interviews with postsecondary physics instructors' have been used to generate an initial explanatory model of their beliefs about problem solving. A subset of the interviews has been used to identify 10 principal categories, two of which (regarding the nature of the problem-solving process and the grading of problem solutions) have been elaborated using a larger set of the interviews.

2.3 Problem solving and Homework

Because the current study examines physics instructors' views on the teaching and learning of problem solving in their introductory courses, it is important to review the literature regarding problem solving, particularly in physics. I will limit my review to studies involving the specifics of how problems are solved by individuals with differing levels of expertise and the research on homework in physics classes. I will highlight three specific areas that are related to this study. The first is a review of what problem solving is and how it is presented in textbooks and problem-solving guides. The second is the research on differences in problem-solving strategies between experts and novices. The third is research on homework and the types of problems and strategies that improve students' problem-solving.

2.3.1 Problem solving in Physics

Problem solving has been defined as "the process of moving toward a goal when the path to that goal is uncertain," (Martinez, 1998, pg. 605) and it has been studied in many forms over the last several decades. By its very nature, problem-solving cannot be distilled into a recipe or algorithm. Textbook author Ohanian writes, "The solving of problems is an art: There is no simple recipe for obtaining the solutions." (1985, pg. 39) Similarly textbook authors Giambattista, Richardson, and Richardson write, "No single method exists that can be used to solve every physics problem." (2004, pg. 13) Still, physics textbooks and curricula often include advice, tactics, and guidelines to help students solve problems.

2.3.1a General problem-solving strategy

The frameworks that have been presented in various textbooks, journal articles, and curricula for solving problems are all or nearly all derived from that described by mathematician George Pólya in his practical book, *How to Solve It* (Pólya , 1945). Pólya's framework consists of four stages labelled Understanding the Problem, Devising a Plan, Carrying out the Plan, and Looking back. Each of these 'stages' is presented as having a highly recursive nature, meaning that at any point, one might have a question that requires revisiting a previous stage. At each stage, there are questions that one can ask to help determine a path through the problem. There are also specific benchmarks for each of these parts to indicate when one is ready to do the next thing.

Pólya's framework begins with grasping the context, the information given and the target of the problem. Pólya suggests looking for similar problems that have been solved before and using them as a template for solving the current problem. The intent is to look at the underlying structure of the problem to find another problem that fits the pattern rather than to try to match problems based on surface features such as the objects in the problem. One then determines a plan and carries it out, all the while checking to ensure that the plan makes sense. After the problem has been solved, the last part is to look back on the problem to reflect on how the solution was carried out, check to see that the answer is reasonable, and think about other ways to do the problem to confirm that the answer is reasonable.

2.3.1b Physics textbooks problem-solving

As a backdrop to examining instructors' beliefs about teaching and learning problem solving, I reviewed 15 introductory physics textbooks and 2 physics problem-solving guides to see what they presented regarding physics problem solving. In order to look for commonalities in their presentations, some of the textbooks I reviewed were different editions of the same textbook. Several had very different presentations of problem solving from one edition to the other. The books I used for this review are as follows:

- Bassichis, W. H. (1988), *Don't Panic*
- Cutnell, J. D. & Johnson, K. W., (1995) *Physics 3rd Edition*

- Giambattista, A., Richardson, B. M, & Richardson, R. C. (2004) *College Physics V1*
- Halliday, D., Resnick, R. & Walker, J., (1993) *Fundamentals of Physics 4th Edition*
- Heller, K. & Heller, P. (1997), *The Competent Problem Solver*
- Hubbard, K. A. & Katz, D. M. (2002), *The Physics Toolbox*
- Mazur, E., Crouch, C. H., Pedigo, D., Dourmashkin, P. A., & Bieniek, R. J. (2015). *Principles & practice of physics*
- Ohanian, H. C. (1985) *Physics*
- Physical Science Study Committee (1965), *Physics 2nd Edition*
- Reese, R. L (1998), *University Physics*
- Roller, D. E.& Blum, R. (1981), *Physics: Volume 1*
- Serway, R. A. & Jewett, J. W. (1990), *Principles of Physics 3rd Edition*
- Serway, R. A. & Jewett, J. W. (2004), *Physics for Scientists and Engineers 6th Edition*
- Serway, R. A. & Jewett, J. W. (2014), *Physics for Scientists and Engineers 9th Edition*
- Sternheim, M. M. & Kane, J. W., (1991), *General Physics 2nd Edition*
- Tipler, P. A. (1982), *Physics 2nd Edition*
- Tipler, P.A. (1999), *physics for scientists and engineers 4th edition*

Within these textbooks and problem-solving guides, there was a wide range of presentation of problem-solving strategies. Four textbooks did not seem to address problem solving at all and did not structure the worked examples in a way that would provide students with insight on a process (Bassichis, 1988; Physical Science Study Committee, 1965; Sternheim & Kane, 1991; Tipler, 1982). One of the four did not even contain worked examples (Physical Science Study Committee, 1965). The other three did have worked examples, with the most unique presentation found in a textbook named Don't Panic (Bassichis, 1988). In this book, there was no discernable structure to the example solutions; however, there was ample explanation of the reasoning behind the solution construction.

Of the remaining 12 texts, the presentation of problem-solving ranged from a short section written with advice about problem-solving in general to problem-solving tactics spread throughout the entire textbook giving specific skills for specific types of problems being discussed in the book. Some presentations were organized in numbered lists or organized strategies (Gaimbattista, Richardson, Richardson, 2004; Mazur, 2015; Heller & Heller, 1997; Hubbard & Katz, 2002; Serway & Jewett, 1990; Serway & Jewett, 2004; Serway & Jewett, 2014) with between 8 and 14 steps. Others gave paragraphs of prose from which steps could be inferred (Ohanian, 1985; Roller & Blum, 1981). Finally, a few texts started with a general presentation of problem solving with specific tactics for the first topic, then added additional tactics or insights when additional topics were introduced (Cutnell & Johnson, 1995; Halliday, Resnick & Walker, 1993; Reese, 1998; Tipler, 1999).

Interestingly, of the 12 books that included strategies or steps, only three (two textbooks and a problem-solving guide) explicitly used their own process, tactics, or strategies to solve the worked examples (Heller & Heller, 1997; Serway & Jewett, 2014; Mazur, 2015). Thus, most of the texts do not give students any concrete examples of how the process they present might be applied.

When comparing Pólya s problem solving framework to the presentations in the physics textbooks, it is not difficult to see how the presentations in the physics textbook map onto the stages of Pólya's framework. However, the way the problem-solving strategies are presented in the physics textbooks may make a subtle but significant difference in how the process is perceived.

For example, by presenting the problem-solving process as a list and giving no explicit attention to the recursive nature of the process, as emphasized by Pólya, students might easily get the impression that problem-solving is a linear process and that following the steps should lead to the correct answer. Any mistakes are a result of an incorrect performance in one of the steps. Furthermore, a presentation of problem-solving tactics that involves specific tactics for specific topics may give the impression that there is no general problem-solving strategy; one must learn specific methods different topics in physics.

2.3.2 Novice versus expert problem-solving strategies

Because the focus of this dissertation is to examine physics instructors' beliefs about the processes students must undertake outside of class to learn to solve problems, it is useful to look at the research on how experts and novices solve physics problems. This work extends back more than 50 years and one main line of research has been to characterize the different ways in which novices (typically undergraduate students taking an introductory physics course) and experts (typically graduate students or faculty) solve problems.

2.3.2a Experts' approach to problems

Experts approach problems by first performing a qualitative analysis, including drawing pictures or diagrams and deciding on which physics principles might be applicable to solving the problem (Larkin & Reif, 1979; Maloney, 1994). Once they have determined the best approach, they use a working forward strategy to solve the problem (Heller & Reif, 1984). This is not necessarily the most efficient way to solve every problem, but it works on every problem. Throughout their decision making and solution processes, they check to see that the process is reasonable by employing lower-level unit analysis checks and higher-level reasonableness checks by comparing to expected real world results (Chi, Feltovich, & Glaser, 1981). Their knowledge is grouped and connected in a way that allows them to consider different principles to see if they are applicable and useful in the situation presented. This was shown in a study done by Larkin et al. which studied the problem-solving process of an expert with a think-aloud protocol (1979). The researchers analyzed the statements made by the expert which showed that principles were grouped together as methods, rather than individually, and he used an approach which they described as "a process of successive refinements" (Larkin et al., 1979 pg. 200).

One criticism of these sorts of studies is that the items that were given to experts to solve were not "problems." As mentioned earlier, problem-solving is "the process of moving toward a goal when the path to that goal is uncertain" (Martinez, 1998). Thus, whether or not an item is a "problem" depends on the solver. Because the items used in these earlier studies tended to be end-of-chapter problems from introductory physics textbooks, the experts in those studies could see how to solve them rather easily, making them "exercises" rather than "problems." Singh (2002) did a study that addressed this problem by giving physics instructors a simply-structured, but highly non-intuitive problem using concepts from introductory mechanics. The intent was to give the experts a true problem to see what strategies they used. The analysis of the interviews largely confirmed that instructors do indeed begin with a qualitative analysis, including considering limiting cases as well as similar problems they have previously solved when they are faced with a "real" problem (Singh, 2002).

2.3.2b Novices' approach to problems

Novices, who are typically students in introductory physics classes, have a much more disjointed knowledge organization and are more likely to see physics principles as separate approaches that work in individual situations. They are likely to focus on the surface features of a problem, which include the objects like inclined planes, projectiles, frictional forces and proceed to use approaches for similar problems (Chi, Feltovich, & Glaser, 1981; Heller & Reif, 1984; Singh, 2008a). They sometimes look for similar problems and use similar approaches rather than looking at the underlying principles. Finally, they can often use a "means-end analysis" which is where they look at the goal of the problems and what information they have been given and find equations that bridge the steps in between them (Zajchowski & Martin, 1993). There is not usually an inclination to check the reasonableness of the answers.

In studying how novices approach problems, there has been more recent attention to students' solution processes. Two independent studies from 2007 looked at what students did while performing a means-end analysis or looking at the surface features of a problem (Tuminaro & Redish, 2007; Walsh, Howard, & Bowe 2007). Both found very similar “micro-processes” in their analysis. One study termed the micro-processes “epistemic games” where the students engage in a very structured process to solve the problem (Tuminaro & Redish, 2007). The other study termed these micro-processes “hierarchal approaches” (Walsh, Howard, & Bowe 2007). Understanding the logical and consistent approach that students use will help to address the steps that need to be taken to improve their problem-solving.

2.3.3 Homework

Homework problems are the primary way that most physics students practice problem-solving. In a traditionally-structured course, there is lecture, lab, and recitation. Even if the instructor incorporates problem-solving practice into some portion of the course, there is still a homework component where the students are assigned problems to do outside of class. When these problems are selected from the textbook, they are commonly referred to as end-of-chapter (EOC) problems. This section reviews studies of physics instructors’ views of homework problems and studies of research-based homework problems.

2.3.3a Instructors’ beliefs about homework

A study by Ding (2014) looked at physics instructors’ views of different types of research-based problems. He found that instructors make heavy use of EOC problems and rely on them for most of the homework. Other problems that have research backing such as synthesis problems, context-rich problems, or estimation problems are valued, but not widely used. The research study found several beliefs associated with homework and student learning. First, instructors believe that students need to solve a lot of problems to learn physics. Second, instructors believe that students improve their reasoning skills by solving EOC problems. Third, while they may value research-based problems like synthesis problems, they believe that the students' poor performance on them are discouraging and thus counter-productive. Fourth, they believe that practical use in their courses is not feasible because of the grading load.

2.3.3b Research on physics homework

Ding (2014) points out that EOC problems are often one-step or multi-step problems that are categorized by section so that the student does not need to make any decisions about the principles that are necessary for solving the problem. In an oft-quoted study, Kim and Pak (2002) found that students in South Korea who had solved an average of 1500 problems in preparation for the university entrance exam were very good at solving for numerical answers but also had significant conceptual problems and that there was little correlation between conceptual understanding and the number of problems they solved.

There have been many studies on practical, effective ways of helping students learn how to approach problems with a focus on the conceptual underpinnings of the problem. This has led to development of different kinds of problems, activities, and curricula such as context-rich problems (Yerushalmi & Magen, 2006), isomorphic pair problems (Singh, 2008a, 2008b), synthesis problems (Ding et al., 2011), strategy writing (Leonard, Dufresne, & Mestre, 1996), physics jeopardy problems (Van Heuvelen & Maloney, 1999), comparison problems (Mestre et al., 1993), explicit problem-solving methods (Heller & Reif, 1984), and computer coaches (Ryan et al., 2016) to name a few. While there are differences in what these problems have the students do, the underlying commonality is that they force the student to attend to the physics principles of the problems and not just the surface features. The research on the use of these problems shows that exposing students to these sorts of principle-focused problems greatly improves both their conceptual analysis of problems and their quantitative problem-solving (Ding, 2011; Heller & Reif, 1984; Leonard, Dufresne, & Mestre, 1996; Mestre et al., 1993; Ryan et al., 2016; Singh, 2008a, 2008b; Yerushalmi & Magen, 2006;). Many of these studies tested a control group (who received no intervention and did the homework assigned in the class) and a trained group (who were explicitly taught methods or given specific instruction in how to approach the problems). Some studies also included a third "exposure" group (who interacted with the principle-focused problems but were not given either scaffolding or prompting). Perhaps unsurprisingly, the trained groups, who were given explicit instruction, always out-performed the other group or groups (Ding, 2011; Heller & Reif, 1984; Leonard, Dufresne, & Mestre, 1996; Mestre et al., 1993; Ryan et al., 2016; Singh, 2008a, 2008b; Yerushalmi & Magen, 2006). However, what is notable in the studies involving a third group is that students who were simply exposed to these types of problems also showed improvement over the control groups (Ding, 2011; Mestre et al., 1993; Singh, 2008b).

2.4 Where this study fits

The research on problem solving strategies of experts versus novices gives a great deal of insight into the differences in how each of these groups approaches problems. The research on problems and strategies that can improve students' problem solving shows that there are paths which can guide students to better approaches through understanding physics principles, which is an assumed goal of teaching physics. The present study attempts to link the two strands of research by investigating what instructors believe about how students should be taught to solve problems. We know there is a mismatch between how instructors solve problems themselves and how their students solve problems. While instructors may say they want students to learn principles, we must look at how they describe problem solving to students and what they advise their students to do.

More generally, this area of study is necessary to address the low rate of adoption of research-based instructional strategies. This issue is not specific to physics education, and the results could have a broader impact in other fields. Knowing what instructors believe is important to designing effective professional development opportunities. Without this insight, educational reformers are left to speculate about or assume the causes for resistance to adoption, which may be counter-productive. For instance, knowing that instructors are willing to try RBIS means that one can spend time on how to effectively implement them, rather than arguing for their use. On the other hand, if instructors are not convinced that their own ideas, such as that simply doing more EOC-type homework helps students, are not consistent with systematic measurements, they will not be receptive to new ways of thinking about homework. Turning the research focus to instructors' beliefs is the next step in getting reformed education into the classroom.

Chapter 3: Interview Summary

In this chapter, I describe the participants, artifacts, and protocols for the collection of the interview data on which my work is based. As stated previously, the interview data was collected in 2000 and the initial analysis, leading to the Initial Explanatory Model (IEM) has been described in two research papers (Henderson et al., 2007; Yerushalmi et al., 2007) as well as in the unpublished dissertations of Charles Henderson (Henderson, 2002 and Vincent Kuo (Kuo, 2004). Although these interviews are nearly two decades old, there is good reason to believe that the ideas expressed by the physics instructors then are still representative of the beliefs of physics instructors today. As seen in the research literature in the previous chapter and stated earlier, there is an adoption problem of reformed physics curriculum. Physics instructors still believe that doing more homework problems helps students understand, they revert to common, accepted practices in their instruction, and they are still being prepared in a graduate school system that has not changed in that time (Henderson, 2012; Ding, 2014). Thus, there is good reason to believe that the ideas of physics instructors have remained relatively constant in that time.

3.1 Participants

Thirty postsecondary physics instructors from universities, private colleges, and two-year colleges in the greater Twin Cities area agreed to participate in 1.5 – 2-hour interviews designed to capture the instructors' practical ideas regarding teaching. All had taught a calculus-based introductory physics course at least once in the 5 years preceding the interview. The instructors each had between 2 and 43 years of experience teaching at the postsecondary level and had taught a calculus-based introductory course between 1 and 79 times. While the sample was based on instructors willing to be interviewed, there was a diverse range of experience so that a wide range of ideas and beliefs about teaching physics and problem solving was represented. There was a strong gender bias in the population as all but two of the instructors were male. Because of the small number of females in the study, masculine pronouns will be used throughout to protect the confidentially of all participants. Table 3-2 summarizes the participant information.

Table 3-2: Overview of the interview participants.

Number of participants	30
Male; Female	28; 2
Years of teaching experience	2—43
Number of times teaching calculus-based introductory physics	1—79
Instructors employed at the University of Minnesota	6
Instructors employed at a two-year college	6
Instructors employed at a private four-year college	10
Instructors employed at a Minnesota State University	8

3.2 Interviews

The artifacts on which the interviews were based included student solutions, instructor solutions, and different ways of stating a particular physics problem (see Figure 3-1 below) that had been given on a final exam at the University of Minnesota. These artifacts represent typical items that are found in an introductory physics course; instructors often create problems, assess student solutions, and write example solutions for their homework and/or exam problems for their students.

This problem was chosen because the problem context might be found in virtually any introductory physics course, it requires multiple physics concepts to solve, and there are multiple reasonable approaches to solving the problem. Although basing the interviews on a single problem limited the scope of the interviews as well as the generalizability of the results, it was decided that using more than one problem would be more than could be useful in the limited time available. Before the interviews, the problem, as shown in Figure 3-1, was sent to all of the instructors, who were asked to solve it on their own in preparation for the interview.

Problem B

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

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

Note: The choices are based on common student problems.

Figure 3-1: Problem statement that was sent to the instructors to solve themselves before the interview. The interview artifacts were all based on this problem.

In addition to the three types of artifacts mentioned above, a fourth artifact was created during the interview. When the interviewer heard the instructor say something about problem solving, he or she wrote the statement down on a card. At the end of the interview, the instructor was given all the cards to sort in several ways (described later). This will be referred to as the "sorting task."

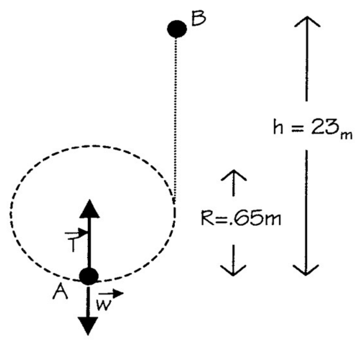
The research team used a semi-structured interview protocol along with the artifacts to elicit the instructors' ideas and beliefs about physics problem solving. The interview was broken into four parts, each focusing on one of the types of artifacts already described. These parts and artifacts are described below in the order they were presented in the interview.

3.2.1 Artifact type 1: Instructor Solutions

The three instructors' solutions vary widely in how much detail each includes for solving the problem. Instructor Solution 1 (IS1- Figure 3-2) is the sparsest. It includes a basic diagram of the situation with the target and given variables labeled. Many algebraic steps are omitted and almost no explanation or commentary is included. This solution is similar to those often found in the solution manuals accompanying introductory physics textbooks.

Those familiar with the relevant physics principles would find this solution clear and be able to follow it while filling in the details. For instance, there is a variable, v_A that is used in the equations, but which is not explicitly defined anywhere. It is simply assumed that the reader will understand that this symbol stands for the velocity at Point A (which is labeled). Since it is the simplest solution of the three, it may be viewed as the most practical, time-efficient solution for an instructor to provide to the students.

Instructor solution I



The tension does no work

Conservation of energy between point A and B

$$Mv_A^2/2 = mgh$$

$$V_A^2 = 2gh$$

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

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

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

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

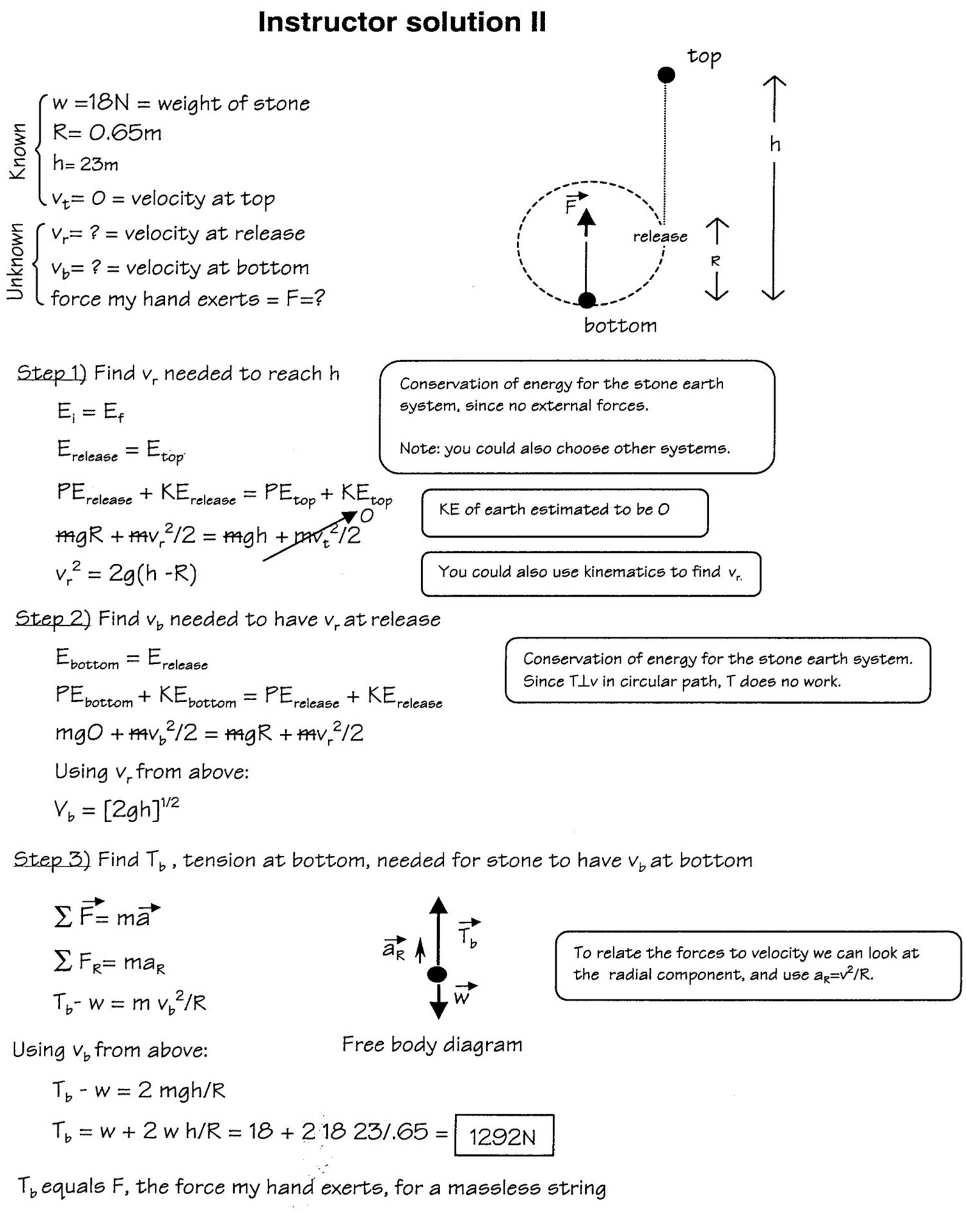
Figure 3-2: Instructor Solution 1 is the sparsest presentation of the three solution. Most of the steps and reasoning are implicit, making it most useful to those already well-versed in the physics.

Instructor Solution 2 (IS2- Figure 3-3) includes more detail than IS1. It has both a picture of the scenario and a free-body diagram, a complete list of known and unknown variables, full explicit expressions of the relevant physics principles, and statements of assumptions throughout the solution. The variables are also labeled with words to explicitly define them. Also, what was accomplished in a single step in IS1 ("Conservation of energy between point A and B") is divided into steps 1 and 2 here.

While not the most efficient solution, it may be closer to many students' thought process in using the conservation of energy principle.

The solution process is presented in three steps and has explanations of each of the steps. The three steps reflect a "working forward" approach that has been described in the literature as used by experts, often when solving exercises, rather than problems. Such an approach is seldom used by novices. In particular, a novice would likely find the first two steps non-intuitive because they solve for two quantities that may not seem to be relevant to finding the target quantity. The mathematical manipulations in this solution are more explicit than in IS1. In particular, the algebra explicitly begins from the general form of the physics principles used in the solution. However, further algebraic steps such as substitution and canceling of variables are left implicit.

The solution states an assumption, "KE of the earth is assumed to be 0" that most students would not have even considered. Commentary on other possible solution paths is also included, although no reasoning is given as to how the decisions leading to this particular solution path were made. The solution includes a physical interpretation of the answer at the end.



Instructor solution II

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

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

Step 1) Find v_r needed to reach h

$E_i = E_f$

$E_{release} = E_{top}$

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

$\cancel{m}gR + \cancel{m}v_r^2/2 = \cancel{m}gh + \underbrace{\cancel{m}v_t^2/2}_{0}$

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

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

Note: you could also choose other systems.

KE of earth estimated to be 0

You could also use kinematics to find v_r.

Step 2) Find v_b needed to have v_r at release

$E_{bottom} = E_{release}$

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

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

Using v_r from above:

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

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

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

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

$\sum F_R = ma_R$

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

Free body diagram

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

Using v_b from above:

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

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

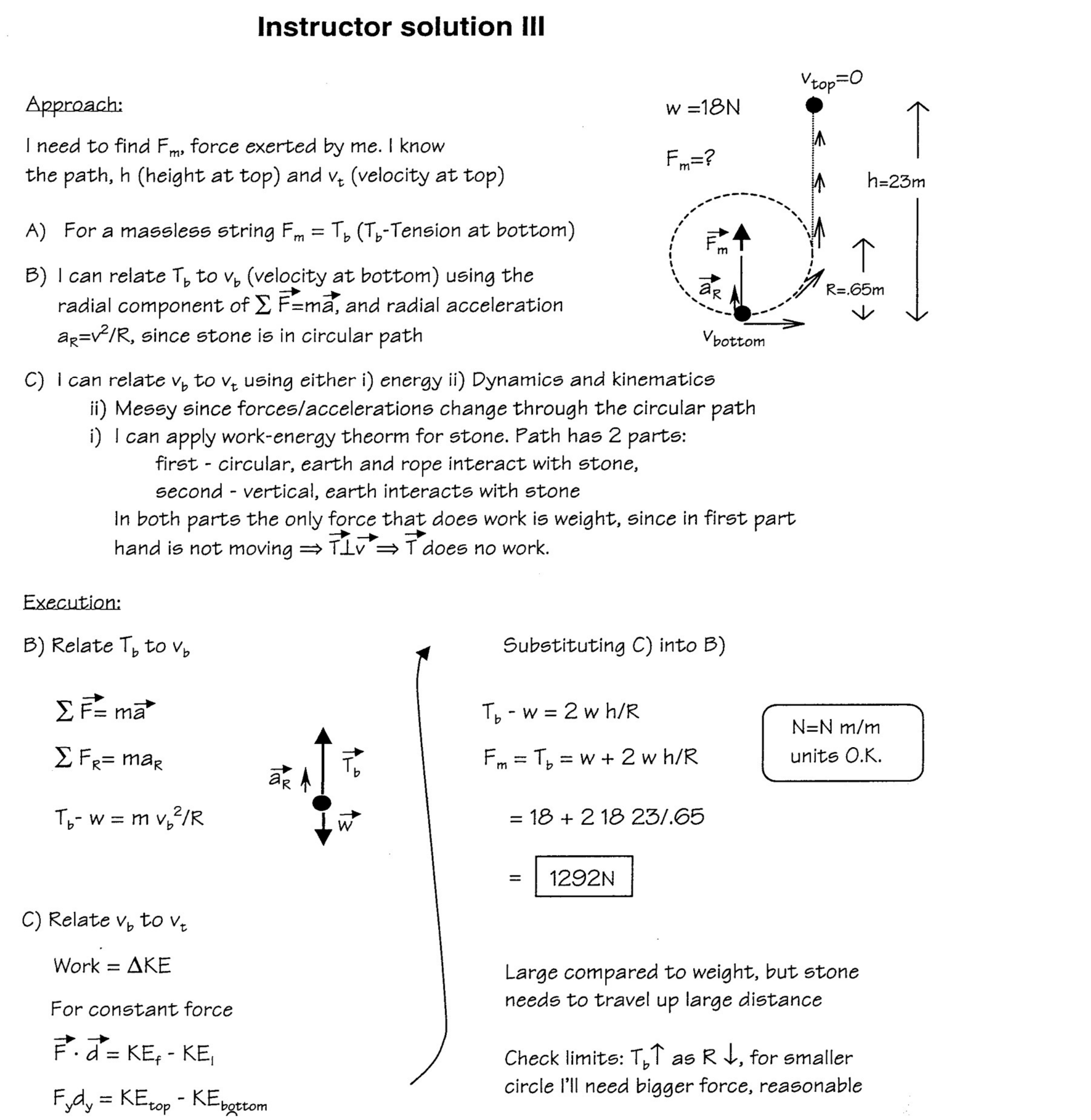
T_b equals F, the force my hand exerts, for a massless string

Figure 3-3: Instructor Solution 2 uses a solution process similar to IS1 but gives much more detail about the solution process.

Instructor Solution 3 (IS3- Figure 3-4) has the most detail of the three solutions, including both a qualitative (labeled "approach") and quantitative (labeled "execution") description of the solution process. The picture is the most detailed of the three instructor solutions and is labeled with given, implicit, and target variables along with velocity and centripetal acceleration vectors. This is a level of detail that is virtually never found in student solutions. As with IS2, a separate free body diagram is included.

The “approach” section is presented in a conversational manner that displays the decision process (e.g., part c describes why the energy approach is preferable to an approach using dynamics and kinematics). In contrast with IS1 and IS2, IS3’s reasoning begins with trying to find the target variable first, then sets up sub-problems to find quantities necessary to solve for the target variable. This logic might be more accessible to students.

In part (C) of the execution section, IS3 is written as using the work-kinetic energy theorem rather than the conservation of energy (as was done in IS1 and IS2), although the mathematical expressions are identical in this case. Unlike the other two solutions, IS3 includes an explicit evaluation of the answer at the end of the solution.



Instructor solution III

Approach:

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

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

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

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

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

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

first - circular, earth and rope interact with stone,

second - vertical, earth interacts with stone

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

Execution:

B) Relate T_b to v_b

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

$\sum F_R = ma_R$

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

C) Relate v_b to v_t

Work = ΔKE

For constant force

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

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

Substituting C) into B)

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

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

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

$= \boxed{1292N}$

N=N m/m units O.K.

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

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

Figure 3-4: Instructor Solution 3 uses a process different from that in IS1 and IS2. It provides more detail than IS1 and IS2 with regard to the rationale behind the solution path used.

3.2.2 Artifact type 2: Student Solutions

The second type of artifact was five anonymized student solutions labeled A—E (see Figures 3-5, 3-6, 3-7, 3-8, and 3-9). These solutions were taken from actual student exams at the University of Minnesota. All solutions were rewritten for clarity, but the content was left unchanged. The researchers wrote notes pointing out mistakes in the solutions to facilitate the physics instructors' assessment of the solutions during the interview, but no markings associated with grading were included. Solutions A, B, and C have incorrect answers with varying numbers and types of mistakes, such as errors in mathematics and physics. Although solutions D and E both have the correct answer, D makes two mathematical mistakes that cancel each other out. Solution E has no mistakes noted, however, it might be considered incomplete because of its sparseness.

For this portion of the interview, the instructors were asked to assign a grade to the solutions assuming they had been produced by students on a test in one of their own courses and that the instructors had given whatever instructions they typically give on expectations for problem solutions. Because some instructors give very explicit instructions about what an exam solution should contain, and some do not, a wide range of ideas was elicited from the instructors during this portion of the interviews. Henderson et al, (2004) discusses results from this part of the interviews.

Student Solution A

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

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

$$V = \sqrt{Ra}$$

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

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

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

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

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

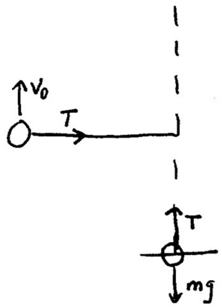
Does not sum forces

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

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

Figure 3-5: Student Solution A is incorrect. The two mistakes made were using the height of release instead of the height at the bottom of the swing and not including the weight of the object when finding tension.

Student Solution B



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

Free fall:

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

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

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

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

uses Δy instead of y

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

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

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

Makes math error

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

Does not sum Forces

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

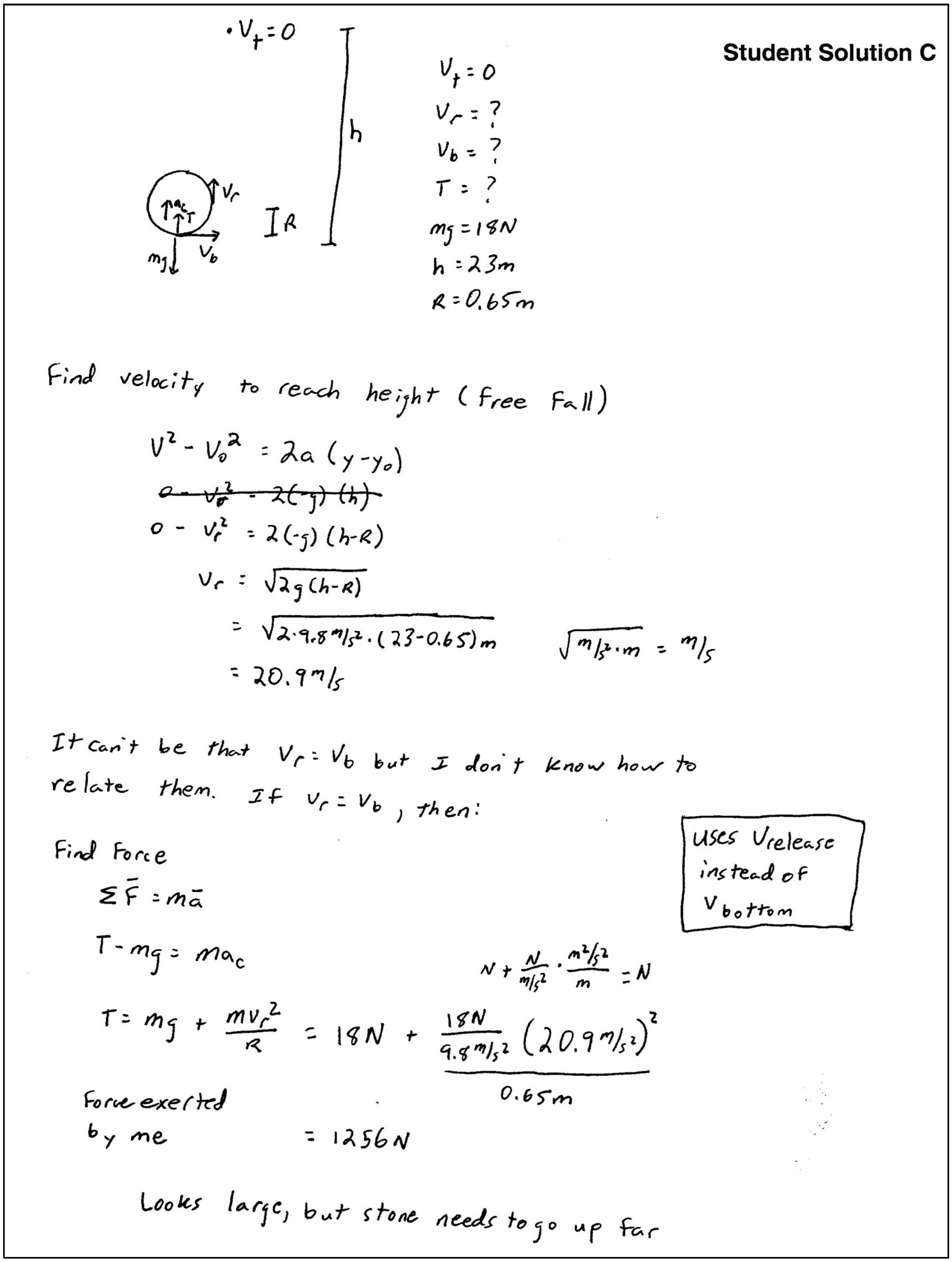
$$= \frac{mg\,\Delta y}{(y_0 - 1/2)R}$$

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

Force Exerted by me

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

Figure 3-6: Student Solution B is incorrect.



Student Solution C

$\cdot V_t = 0$

h

$I\,R$

V_r V_b ma_c T mg

$V_t = 0$

$V_r = ?$

$V_b = ?$

$T = ?$

$mg = 18N$

$h = 23m$

$R = 0.65m$

Find velocity to reach height (free fall)

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

$$\cancel{0 - V_0^2 = 2(-g)(h)}$$

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

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

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

$$= 20.9\,m/s$$

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

Find Force

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

$$T - mg = ma_c$$

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

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

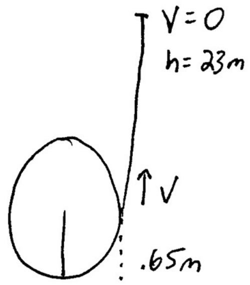
Force exerted by me $= 1256N$

Looks large, but stone needs to go up far

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

Figure 3-7: Student Solution C is incorrect.

Student Solution D



Energy conservation between top and release

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

$v^2 = 2gh$

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

$V = 21.2$

uses h instead of h - R

makes sign error

changes sign

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

$\therefore$ Energy is conserved and velocity is the same

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

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

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

$= 1292N$

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

Figure 3-8: Student Solution D has a correct answer.

Student Solution E

$$V^2 = 2gh$$

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

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

Figure 3-9: Student Solution E has a correct answer.

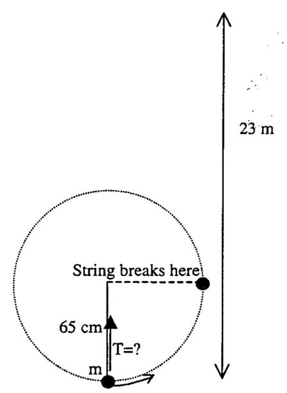
3.2.3 Artifact type 3: Problem statements

The third artifact for the interviews was four different statements (A-D) of the single problem given to the instructors and on which the student solutions were based. This artifact was meant to simulate various ways instructors might choose to present a problem to students in writing.

Problem A is most similar to the problems traditionally found at the end of a textbook chapter. It is stated in abstract terms and contains exactly the information necessary for answering the question (Figure 3-10). All quantities are given in SI units and the stone is described using its mass, as opposed to its weight. The quantity to be solved for (tension in the string) is named explicitly in the problem statement. The problem is broken up into three sub-parts (A, B, and C) that, if solved in order, lead to finding the desired quantity. This traditional formulation of a physics problem gives students many textual cues that aid in its solution. It does not require the student to construct his or her own path to the solution and minimizes the thinking students do to consider principles relevant to solving the problem. A provided picture means that students do not need to do much work to visualize the situation.

Problem A

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



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

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

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

Figure 3-10: Problem A presents the problem in a way similar to traditional end-of-chapter problems in textbooks.

Problem B is the problem statement that was sent to the instructors prior to the interview (Figure 3-1). In this formulation, the problem is posed as a multiple-choice problem. It is given a basic context (whirling a stone) and is written in a way that puts the reader as the actor in the problem ("You are whirling a stone tied to the end of a string in a vertical circle…"). No diagram or picture is provided. As with problem A, the exact amount of information necessary to solve the problem is provided.

Problem B might be considered a "story problem" that includes concrete objects in the situation (i.e. string, stone, person). The multiple-choice nature of the problem might give the students the impression that the problem could be solved quickly or that the "obvious" wrong answers could be eliminated by some means other than solving for the correct answer. Since the incorrect multiple-choice answers are based on common student mistakes, this statement of the problem might give instructors information about what problems students are having with less work grading. However, it might be more difficult to give students feedback on their performance.

Problem C (see Figure 3-11), like Problem B, provides no picture or diagram and is written in the second person. The problem is written in a story-like fashion giving a context for why one would be swinging an object on a string. The problem statement includes extra information not needed for its solution and no explicit question is stated in the problem. It is up to the solver to decide what quantities should be found to answer the question. Quantities are given in English units (feet as opposed to meters) which is typically much more familiar to students from the United States. The problem provides the maximum weight the string can hold which provides another potential approach for a solution.

Problem C is an example of a context-rich problem, which is a way of stating a problem developed by the University of Minnesota Physics Education Group (Heller & Hollabaugh, 1992; Heller, Keith & Hollabaugh, 1992). In a context-rich problem, students are provided with a real-world context that can help them to visualize the situation and provides some motivation for solving the problem. Relative to the cognitive apprenticeship (Brown, Collins & Duguid, 1988) framework within which introductory courses at the University of Minnesota are taught, context-rich problems help give authenticity to the problem-solving tasks that students are asked to perform. Context-rich problems are designed to be straight-forward to solve using expert-like problem-solving strategies, but difficult to solve using novice problem-solving strategies and help push the students to think about the physical principles useful for solving the problem. The lack of a direct question is meant to force students to understand the situation well-enough to formulate a specific question for the problem on their own.

Despite the trappings of the problem, context-rich problems are not meant to be more "fun" for the students, and there is no evidence to suggest they like them more than more typical problems. In fact, they usually find them harder (Yerushalmi & Magen, 2006).

Problem C

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

Figure 3-11: Problem C is an example of a context-rich way of stating the problem.

Problem D is nearly identical to the Problem B except that no numerical values are given (Figure 3-12). Instead, specific symbols are named to represent physical quantities in the problem (the radius is given as "R" and the maximum height is "H"). It provides a diagram that labels the defined quantities and denotes five points along the trajectory of the stone. The main question is asked in the statement of the problem, but like Problem A, Problem D includes three qualitative sub-questions that are similar to those that some instructors might include to provide students with guidance in solving the problem. However, because the main question (what force must be exerted on the string) is separated from the sub-questions and the connection between them is not necessarily obvious to novice problem-solvers, students may not be helped by the sub-questions or see a connection between the tasks.

Problem D

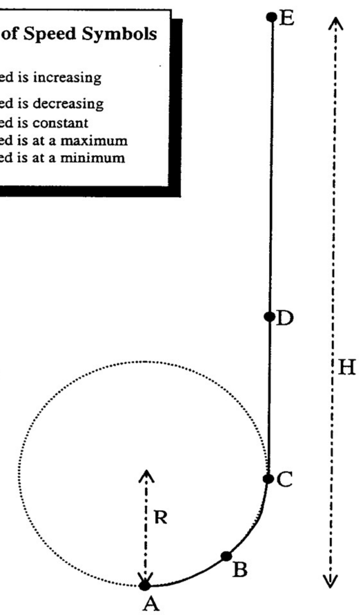
You are whirling a stone tied to the end of a string around in a vertical circle of radius R. You wish to whirl the stone fast enough so that when it is released at the point where the stone is moving directly upward it will rise to a maximum height, H, above the lowest point in the circle. In order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

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

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

Change of Speed Symbols

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



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

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

Figure 3-12: Problem D is nearly identical to Problem B except that no numerical values are given and there are three qualitative sub-questions that might be similar to what some instructors include to help their students think about the problem.

3.2.4 Artifact type 4: Sorting task

The final artifact consisted of statements and phrases related to problem solving that the instructor made during the course of the interview. These statements were written individually on index cards using the instructor's exact words.

In the fourth and last portion of the interview, the interviewer gave the cards to the instructor and asked him to sort the cards into categories. The decision of what the categories were and how many categories there were was left up to the discretion of the instructor. After sorting the cards, the instructor was asked to name and describe the categories in his own words and explain why he categorized the cards the way he did. Since the categories were in the instructor's own words, there was a range of number and titles of categories from each interview. Examples of common categories include general math, applying principles, and problem-solving heuristics or techniques. Next, the instructor was asked to identify categories that students find difficult and how the instructor would help students to overcome those types of difficulties (e.g., by providing solved examples or problems). The next task was for the instructor to order the cards within each category from what the instructor thought was the easiest thing to learn to the hardest then describe their reasoning in the ordering. They also were asked to identify which things students should be able to do by the end of the course and what portion of the students can actually do them. The final questions in this section of the interview focused on comparing students who improved their performance in the categories versus those who did not. The instructors were asked to describe the characteristics that helped or hindered students in the course. The instructors were asked if they were satisfied with their course outcomes and what they would change to be more satisfied. Finally, the instructor was asked to reflect on things they could change and things they would like their students or institution to change to improve the outcomes of the course.

3.3 Interview protocol

The interview protocol was written to elicit the ideas of the instructors about the teaching and learning of problem solving and the full protocol, including the wording of the questions asked, can be found in Appendix A. The artifacts were constructed in such a way that there would not be an obvious correct or "ideal" answer. This dissonance gave the interviewer the ability to probe the comments of the instructors and have them compare what they liked or did not like about each one. Even though the focus of the interview was problem solving, the intent was to explore the range of ideas that instructors have about teaching problem solving, how students approach or should approach it, how they build their course to support their goals, and how successful they feel in meeting their goals. While the interview protocol was structured, the interviewer had the freedom in each interview to ask follow-up questions or to ask for more explanation when needed.

For each portion of the interview, instructors were first asked to describe what they did in class and then presented with the artifacts. This allowed instructors to give a more accurate description of what they did without being biased by characteristics of the artifacts. For example, in first part of the interview, instructors were asked about whether they give homework and why and if they give out solutions to the problems. Then the artifacts were presented so that the instructor could compare their practice with the three options. Even if they did not give solutions to homework or exams, they could still comment on the presented solution and discuss what they liked or disliked about each one. The artifacts provided a common foundation for all of the interviews even though the instructors had a variety of practices in their courses.

Chapter 4: Methodology and Methods

This work performed here can be described as a "convergent study." In a convergent study, one begins with a theme or construct that emerged from previous research (here, beliefs about problem solving held by physics instructors). One then narrows the focus (in this case, instructors' beliefs about student work) to obtain a more detailed picture of a part of the previous original construct. At the same time, one anticipates that other themes may emerge when working with the larger dataset.

Such a study is amenable to grounded theory methodology, and I describe the methodology and methods used in this chapter. The explanation of the methods includes several illustrative examples.

4.1 Grounded Theory Methodology

Grounded theory methodology was developed in the 1960's as a reaction to the great body of work being performed in psychology that produce confirmatory studies, but little in the way of new theory, stunting the growth of the field (Glaser and Strauss, 1967). The originators of grounded theory wanted to find a way to open the research to unexplored possibilities, to give insight into new directions, and allow the data to speak for themselves rather than be limited to interpretation from the perspective of existing theories.

Over the years, this research tradition has been adopted by many other disciplines and has developed into a research methodology, or a system of methods and rules for the generation of theory from systematic research (Corbin & Strauss, 2008). These methods are designed to allow common ideas within the data to emerge, rather than imposing a pre-existing framework on the data. However, grounded theory methodology does not require a complete lack of theoretical grounding preceding the analysis. It is most useful in areas where there is limited research or where research projects are focused on expanding a previously understood idea or theory.

Some of the specific qualitative analysis methods employed in this study that align with Grounded Theory methodology are:

Coding: There are two types of coding that I employed in the interview analysis: open coding and axial coding. Open coding is a systematic initial approach to qualitative data, which in the present study consists of interview transcripts. The approach is to write short descriptive comments or "codes" to note interesting words, phrases, or ideas that may reoccur throughout the dataset. Axial coding is finding a global code for a concept which combines the individual codes into a coherent group. Not all the codes need to match a single definition but can provide the range of ideas that fits underneath the global code. In this research, I refer to my global codes as "Themes."

Constant comparative analysis: In this study, the coding process is used as a basis for the constant comparison analysis. When there is a new part of the data that seems related to a previously coded portion, the researcher compares the new with the previously coded item(s) (which could be one or many) to decide if the new data belongs to an existing code, or if it represents a new insight.

Memoing: As the researcher performs the constant comparison, she formalizes her ideas, questions, and thoughts by writing memos. This helps identify trends in the data and the memos can also be used in the constant comparison analysis. Since the semi-structured interviews each have an internal structure, as well as commonalities across interviews, memoing is useful to keep track of ideas from each interview that seem to be connected to previous interviews. A conceptual sorting of the memos then leads to an outline of any emerging theories.

These methods help to guard against creating ideas and themes from the data that are a result of the researcher's own bias. While personal bias is unavoidable in qualitative analyses, it can be minimized by using systematic approaches that focus on grounding the themes in the data themselves.

4.2 Methodology of the present study

This work discussed here is a convergent study focusing on the completeness and robustness of the "Work" child map (Figure 2-2) of the IEM (Kuo, 2004; Yerushalmi et al., 2007). The analysis will utilize both an *a priori* and an emergent theme approach (Henderson et al., 2007). The initial interview analysis blended the approaches to provide a useful construct which I used here. The interviews were focused on a specific topic, which was the *a priori* construct of using problem solving in teaching. However, the initial study also explored the range of beliefs about the role of learning from problem solving by looking for emergent themes. In the present study, the *a priori* concept of Work is the focus for this study; however, as stated in Chapter 2, the analysis is open to and expecting themes that did not appear in the initial analysis. The intent of the study is to provide a robust model of beliefs about the concept of Work.

4.3 Overview of Study Methods

There are three main stages to this study. Stage 1 consisted of the analysis of the preexisting interviews from the original research. In this stage, I analyzed 25 of the instructor interviews to independently establish emergent themes. Twenty-four of these interviews were of instructors not at the University of Minnesota, and whose data was not used to construct the IEM. The last of the 25 was one of the six interviews of University of Minnesota faculty whose interview was used to construct the IEM and was included unintentionally due to a clerical error. However, because the goal of this part of the study was to find the breadth of ideas held by physics instructors, the inclusion of this interview does not affect the results. Having one instructor represented twice is rectified when all the ideas are incorporated into one list.

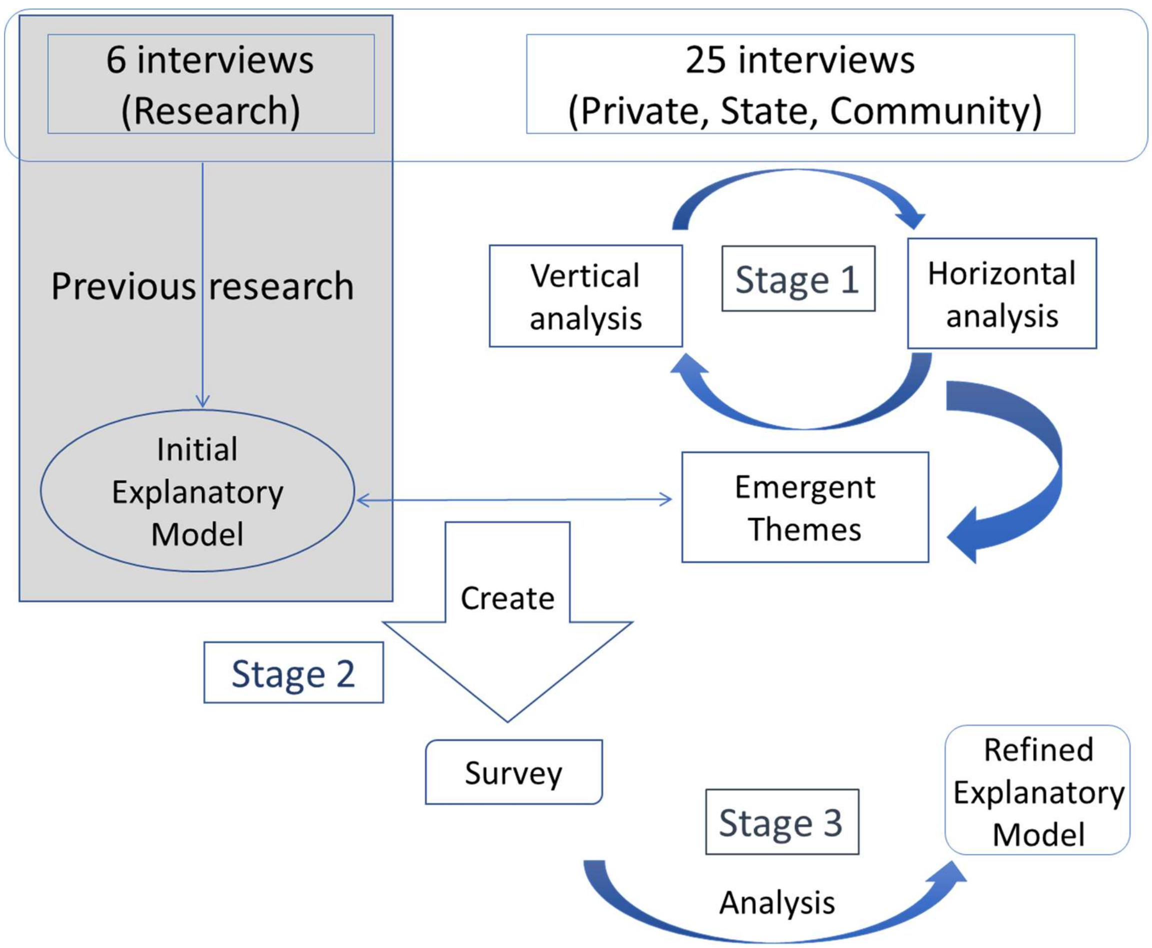


Figure 4-1: Diagram showing the three stages of this study and their relationships to the previous research involving the 6 instructor interviews.

In Stage 2, I used the emergent themes from Stage 1 to create a survey to be sent to postsecondary physics instructors in the state of Minnesota. The purpose of the survey was to test the range and relative prevalence of these themes in a larger population.

Finally, in Stage 3, I analyzed responses to the survey combined with the interview analysis to create a Refined Explanatory Model of physics instructors' beliefs about student work. These three stages, including their relationships to each other and the pre-existing data and analyses, are shown in Figure 4-1.

Figure 4-2 illustrates the a priori and emergent themes discovered through the analysis of the interviews, including both present and past work. The top level consists of the fundamental *a priori* concept of using problem solving in teaching, since the intent of the interviews was to elicit instructors' beliefs about student problem solving. The emergent themes from the initial analysis (Henderson et al., 2007) are represented in the second level. The ten principal categories found in that study make up the Initial Explanatory Model (Figure 2-1). For space reasons, I have explicitly represented only a subset of those ten principle categories. Of those, I have taken up the theme of "Work" as my *a priori* concept (Figure 2-2). The purpose of this study is to create a full concept map of instructors' beliefs regarding the use of homework in learning physics by analyzing the interviews not used to construct the IEM then to compare back to what was contained in the Work principal category. This approach blends an emergent theme analysis with a convergent study to fully incorporate the ideas found in the 30 interviews.

The third level represents the emergent themes from this study. There were six main emergent themes from my analysis: (1) obligation to work, (2) do/don't, (3) think/understand, (4) be/have, (5) procedure, and (6) work with others. Each of these themes is discussed in greater detail in Chapter 5. I also included several ideas from the "Use Feedback" theme from the IEM in my analysis because I wanted to explore instructors' ideas regarding students doing work with peers.

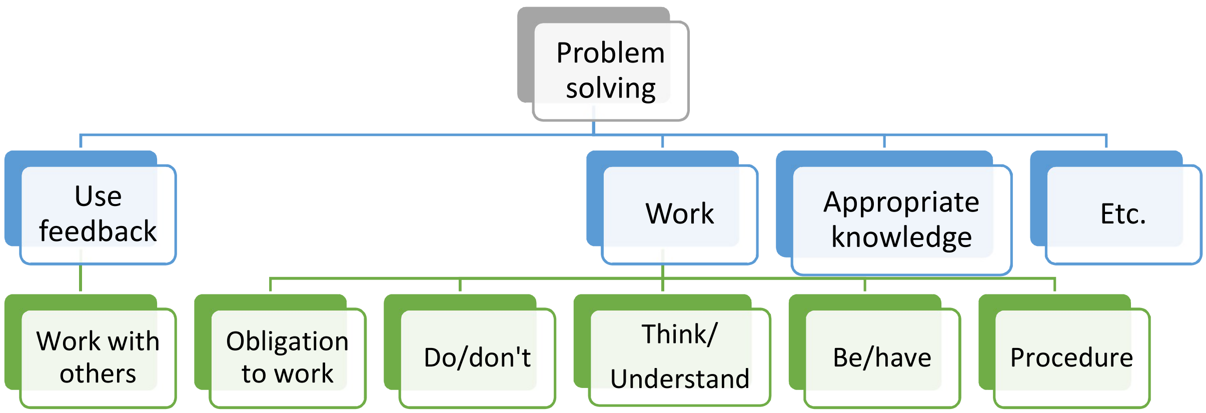


Figure 4-2: This chart illustrates the *a priori* and emergent themes of the first two cycles of analysis of the interviews. The top row represents the first *a priori* concept of problem solving which was used in the interviews. The second row represents the emergent themes from the first analysis which then became the *a priori* concepts for the second round of analysis. The bottom row represents the emergent themes of this study which informed the creation of the survey.

4.4 Stage 1: Interview Analysis

I divided the 25 instructor interviews I analyzed into four groups. The numbering of these interviews was constructed by a blind randomization process. I read the interviews in three groups of six (Cycles 1, 2, and 3) and one group of seven (Cycle 4). I refer to the analysis of each group as a "cycle." Unless it was revealed in the interview, I did not know the experience level or institution type of the physics instructor being interviewed.

I performed a vertical and horizontal analysis (described below) of the transcripts by group. The goal in these analyses was to find emergent themes related to what instructors thought students should do outside of class to develop their problem-solving skills that were not in the initial explanatory model and to reinforce themes that were in the Initial Explanatory Model. In both cases, I was seeking to develop the themes based on the additional interviews.

The interviews were transcribed by the original research team and are available both in printed and digital forms with each time the speaker changed numbered throughout the transcript. The length of the numbered statements varied widely, from a one-word response to an extensive monologue that could include several ideas. In this document, I refer to the entire conversational turn as the “full statement” and the portion within the conversational turn specifically regarding Work as the “target statement.”

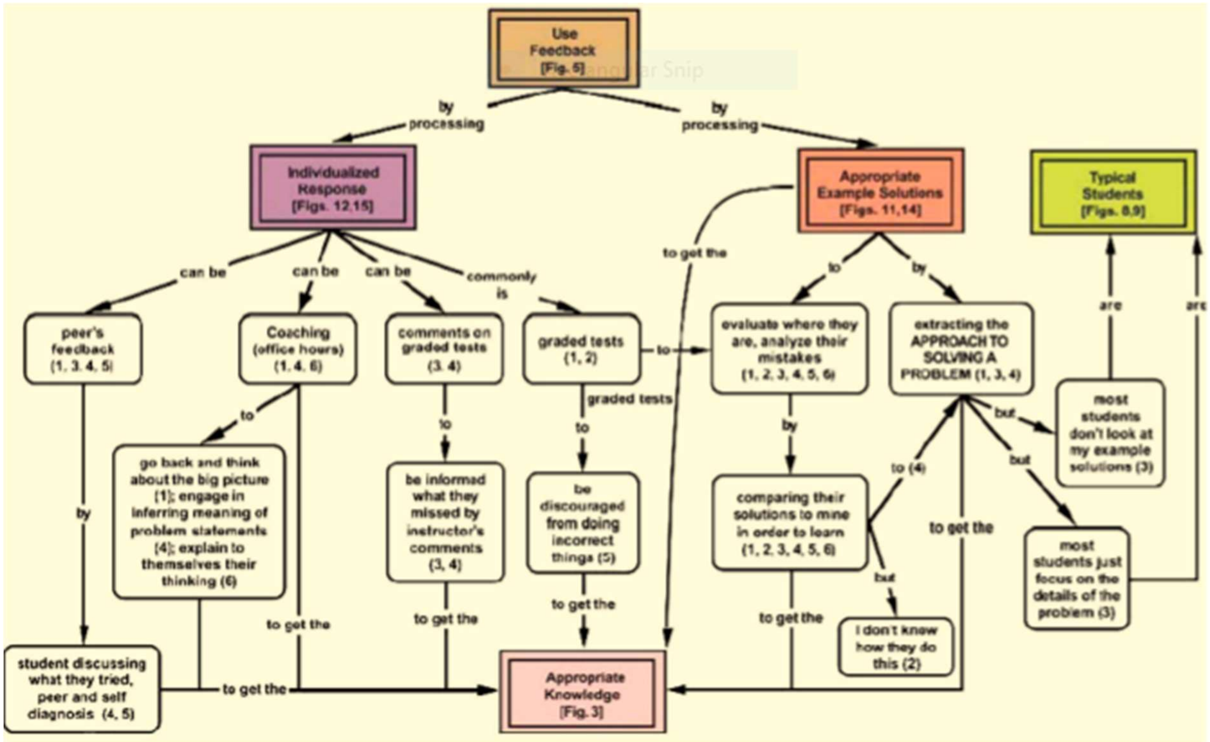


Figure 4-3: The Use Feedback map (Yerushalmi et al., 2007) has several parts that relate to students working independently of instructor assistance. Several of the themes from this map will be included in the *a priori* construct for the present analysis.

4.4.1 Vertical analysis

A vertical analysis is a qualitative method where a piece of data (in this case one complete interview) is analyzed as a single coherent set. In this study, I read each interview as a standalone document and interpreted each instructor's statements based on what the document contained. At this stage, any comparisons of statements were performed internally.

Figure 4-4 illustrates the vertical analysis process for a cycle of interviews (only three interviews, rather than six or seven, are shown in the figure for clarity). This

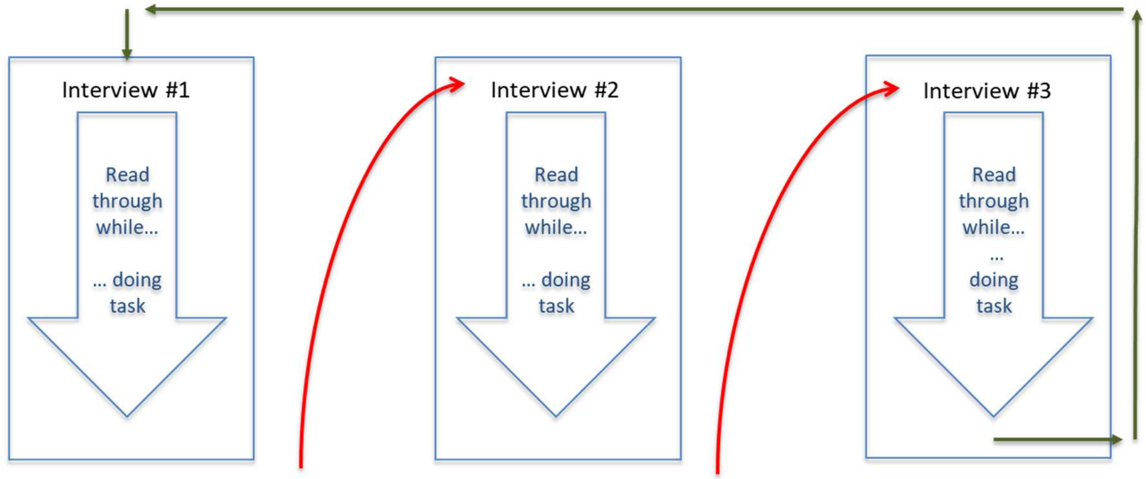


Figure 4-4: Diagram illustrating the vertical analysis process for a cycle of interviews. There were three rounds of analysis. In each round, all 6 or 7 interviews were read once and a different task was performed with all the interviews.

process consisted of three rounds of analysis. In the first round, I read each interview once, copying any full statement that referred to the principal category of Work into a table in a separate document. Once I read through all the interviews in a group, I then began a second round of analysis where I read through all the copied statements for all 6 or 7 of the interviews. During this second round, I selected the portion of each of the full statements that pertained to Work and copied them to a separate spot in the table. I refer to these portions as target statements, and I copied only as much of the full statement as was needed to express the portion related to Work. These target statements sometimes included incomplete thoughts and sentences. Throughout this process, I did not attempt to reword what the instructor said, even if it was grammatically incoherent.

Table 4-1 shows a section of the analysis document from Interview 15. The first column shows full statements made by the instructor which contained either explicit or implicit statements about Work. The number preceding the full statement is the number assigned to the conversational turn from which the statement is copied. The second column contains the portion of the full statement that most directly pertains to Work (target statement). As shown in the table, the entirety of statements 177 and 193 addressed Work-related ideas, while only parts of statements 181 and 197 did so.

Table 4-1: This table is a snippet of the analysis document from Interview 15.

Full statement	Target statement	Coding
177: Yes. I always tell my students that the first equation they write down should contain the target variable.	I always tell my students that the first equation they write down should contain the target variable.	Do: first equation contains target variable
181: Yes. And this person sort of did it here, because when you write that the sum of the forces is m**a**, well, you're really writing down the equation for the tension. So I find that I always tell them to start with the answer and work backwards.	So I find that I always tell them to start with the answer and work backwards.	Procedure: work backwards from the answer
193: Defining the target variable, yes.	Defining the target variable, yes.	Do: define target variable
197: I do like my students to draw this general sort of diagram here that shows the **r** is 0.65 meters, and the **h** is 23 meters. I think that's probably a good idea. I like, I really emphasize diagrams very strongly. Particularly in situations like this.	I really emphasize diagrams very strongly.	Do: draw diagrams

The reason for copying the full statements from the interviews was to begin with a coarse analysis of the interviews that was biased towards including, rather than excluding statements. In the second round, I wanted to select only the parts of the statement that illustrated ideas that the instructor had about Work. Having the full statements in close proximity for reference allowed for more fine-grained analysis without needing to make interpretative decisions at this point.

In the third round, I read through all the target statements for all the interviews in the group and chose a descriptive code for each. These are shown in the rightmost column of Table 4-1.

4.4.2 Constant Comparative Analysis and Coding

Throughout the vertical analysis process, I also performed a constant comparative analysis. While reading through each interview, I thought about how the interviewees spoke about their ideas about Work and how it was the same or different from the other interviews I had read thus far. A benefit of going through the interviews in each cycle a total of three times and only generating codes on the third iteration is that I had already seen the data to be coded twice before I started creating specific codes. This allowed me to use more informed codes, even in the initial cycles. One challenge of grounded theory methodology is to delay the defining of themes before enough statements have been found to ensure the theme is fully represented. Given the relatively small number of interviews, it was not expected that all ideas would be represented fully so there was always attention to new ideas no matter what part of the analysis I was doing. This was one reason why I chose to assign interviews randomly to each cycle. I wanted to have a good chance that multiple perspectives and beliefs would be represented in each group and thus reduce the temptation to identify commonalities within the groups. For instance, if there was a tendency among instructors in a particular type of institution to emphasize the following of a procedure in problem solving, I did not want to miss other ideas within that group that were different or miss connections that could be made across institutional categories.

In line with grounded theory methodology, I first used an open coding process. During the first two cycles, I created codes paying attention to the other information I had seen and the phrasing that the instructor used. It is important not to interpret or group statements too early because such a procedure might hide other ideas that emerge throughout the coding process. For instance, if an idea about drawing diagrams was weakly represented in the first cycle, and strongly represented in the last cycle, I wanted to have the ability to include the earlier interviews in the full grouping by keeping the categories flexible throughout the entire analysis process.

When common ideas continued to emerge, I developed general codes (axial coding) so that I would be able to group them in the horizontal analysis. I paired open coding with axial coding by keeping the descriptive codes generated during open coding paired with the general codes created in axial coding. For example, each entry in the third column of Table 4-1 consists of a general code (either Do or Procedure in this case) paired with the descriptive code that was originally created for the target statement. Thus within the Do(/Don't) general code, I have three descriptive codes of "first equation contains target variable," "define target variable," and "draw diagrams." While all three descriptive codes fit within the emergent theme of Do/Don't, they represent very different tasks that a student can do when working. All codes were left with this level of definition throughout the entire process so that they could be globally compared.

While there were several *a priori* ideas that informed the initial open-coding, as I completed more cycles of coding, I began to distinguish among codes and create new general codes as the analysis progressed. For instance, I expected to see specific actions that instructors said students should do, but the prevalence of what they should not do led to expanding the original code of “Do” to “Do/Don’t.” I also saw that the mental work discussed in the interviews had a qualitatively different characteristic, therefore, I created the code for “Think” and later included “Understand.” One code that was not anticipated was the “Be/Have” code where instructors spoke about the mindsets of the students while they are engaging in homework. While this was not explicitly addressed in the research questions, it was part of the context of doing homework. The emergence of the themes came from both the expanding descriptive codes and the prevalence across the interviews.

Even though the structure and artifacts of each interview were identical, each interview had its own unique path. There was no global pattern of when an instructor was most likely to talk about what students should do or learn when solving problems. Some interviewees generalized from the artifacts to global student problem solving, while others were focused closely on the interview problem. This led to a high variability in how many statements were originally selected from the interview. Interview 30 had only 14 coded statements whereas Interview 2 had 80 coded statements.

In interviews where the instructor was closely focused on the artifacts, I attempted to find implicit ideas they had about what students should generally do, not just what needed to be done for the focus problem. Example of this were comments about drawing a free-body diagram of the physical situation. Interview 17 comment 333 said.

> "And this category is taking the picture. Which probably involves a free body diagram or at least maybe at the beginning stage it involves a force diagram. And transforming that into a set of equations that are useful. Doing the required manipulation...algebraic manipulation."

This statement was focused on drawing free-body diagrams also called force diagrams. Free-body diagrams are not a general strategy for solving problems in physics. However, drawing diagrams (and pictures) is a generalized strategy. In the focus problem, both could be used, but the free-body diagram is a common component since the original problem asked for the tension in the string. If the interviewee commented generally about drawing diagrams, that was included this analysis, but specifically referring to free-body diagrams was not included since it is not a generalized strategy.

4.4.3 Horizontal Analysis

Horizontal analysis is a qualitative method for comparing similar pieces of data in order to find commonalities. It differs from constant comparative analysis in that it is the systematic comparison of data that has already been interpreted through coding, rather than of raw data that has not yet been coded. The goal at this phase was to group descriptive codes together into a smaller number of classifications. While a horizontal analysis in an interview context usually would be a comparison of responses to a particular question in the interview, that was not useful in this case because the interviewees had such different ways of interacting with the artifacts and interviewers. In this study, I compared the general codes across the interviews to provide a range of ideas and beliefs within each of these codes.

Once all the interviews in a single cycle had been coded, I copied the coding columns of those interviews (the third column in Table 4-1) into a spreadsheet. I then grouped the general codes together and created a separate sheet for each of these general codes which were Obligation to work, Be/Have, Do/Don't, Think/Understand, Work with others, and Procedure. Once all the general codes (still paired with descriptive codes) were together, I made a list consisting of each code and the interviews in which it appeared.

For the general codes of Obligation to work, Work with Others, Be/Have, Think/Understand, and Procedure, there were few enough descriptive codes per interview that I delayed a horizontal analysis until all 25 interviews had been coded. Because of the large number of statements assigned with the Do/Don't general code, I performed the horizontal analysis to look for commonalities at the end of each cycle. However, the codes used in Cycles 2, 3, and 4 were generated based on the interviews within those cycles and were not explicitly chosen from previously generated codes.

The horizontal analysis also had the effect of removing redundancy in the counting of codes within each interview. Each interviewee had a unique approach to talking through the interviews with being repetitive in their explanations. However, for a given descriptive code, an interview in which it appeared was noted only once regardless of how many times it appeared in the interview. Since the goal of this stage of the research is to represent the range of beliefs instructors have about problem solving, the frequency with which a problem-solving component was mentioned within a single interview is not important.

The purpose of the horizontal analyses was to find the fewest number of coded items and analyze the relative prevalence across interviews (rather than within a single interview) of the specific codes. This identified the themes that were discussed by different interviewees and the range of ideas within codes. At this point, I will formalize my terminology to avoid confusion.

Theme- To better distinguish between the two different types of codes (general and descriptive) from here on, I will refer to the general codes developed through axial coding during the vertical analyses as Themes. There are six themes that emerged in this analysis, Work with others, Obligation to work, Do/don't, Think/understand, Be/have, and Procedure. These are in the bottom row of Figure 4-2.

Category- Within each theme, there were common ideas that I refer to as categories. These are ideas within the themes that describe what the theme encompasses. Thus, they are more general than the descriptive codes, but less general than themes. The descriptive codes from the vertical analysis were used either as categories or elements at this point in the analysis. For example, in the Be/Have theme, there are three categories which are: be willing to, while working, and attitudes. These give a more specific classification under the broader themes.

Element- Each category is made up of elements, the smallest description of activities of or mindsets during problem solving while doing homework. The elements define the range of what in encompassed in the categories. Using the Be/Have theme and the "be willing to" category as an example, the elements are spend time/work, struggle, try new/start over, and get help/ask questions. These are specific things that came directly from the interviews.

The full horizontal analysis was performed with each of the six themes. The approach in each case was to find the fewest unique descriptions of what was said while representing the range of ideas expressed. I used a snowball method to compact all the codes into a representative list of categories and elements with the number of interviews that used each one. I read the list of codes from each interview and started a list of the categories and elements. As I continued to read the codes for each interview, I either added the interview number to a category or element on the list or I wrote a new one.

4.4.4 Cycles 2 through 4

I performed the same vertical and horizontal analyses with Cycles 2 through 4. Constant comparative analysis was an integral part of the reading in these cycles since I was building codes throughout the process. I was able to identify common themes more readily while questioning if there were nuances to each code that needed to be explored. For instance, all but four of the interviewees mentioned drawing a picture or diagram in some form. Some interviewees specified that these needed to be labeled or carefully drawn. Some interviewees distinguished between a picture and a diagram, but not in sufficient detail to create a separate definition for each. Furthermore, there was some ambiguity as to whether this diagram is for the benefit of the student solving the problem or if it is a communication device in the presentation of the problem. As these issues arose through the vertical and horizontal analyses, I was able to read subsequent interviews with a special focus on whether there were interviewees that gave more details in these areas. I was able to use the knowledge of the preceding interviews to narrow down the coding terms, but it was also helpful to identify potentially new or unique codes in the latter interviews.

4.4.5 Memo writing

Throughout the first couple of vertical and horizontal analytical cycles, I used the memo writing method to record and explore ideas that had come up in the cycle, questions I was considering from the interviews, and concepts that I wanted to focus on specifically in the next cycle of analysis. This process was important for formalizing my thoughts on trends or particularly interesting issues that arose, even if it did not explicitly address my research questions. This provided a broader context for the analysis and reasons for formalizing the general codes that I used.

The following is an excerpt from a memo during the first cycle of analysis:

> I'm noticing two reasons for "doing" things or just writing them down. The first reason you do things is to "figure it out." One aspect includes drawing a picture (diagram), writing down the givens, knowns, target quantity, unknowns. Another aspect is writing down physics concepts and equations. The second reason for "doing" is for communication. Communication relates to coherent solutions and showing reasoning for the purpose of showing understanding. Instructors acknowledge that students can figure out things without showing reasoning. This concept relates to the <u>burden of proof</u> in the grading paper.

In this reflection, I was trying to distinguish two reasons that instructors gave for writing things down. There seemed to be two distinct purposes for writing while solving a problem—one was to aid in the process of figuring the problem out, and the other was to communicate the solution process. I took these questions into the next cycles to see if there was more information to expand on these categories which were not part of the Initial Explanatory Model.

I also used the reflective writing as part of the constant comparison analysis. The following memo is an example of this:

> In this cycle, I saw more emphasis on procedure and steps. More instructors were inclined to give <u>instructions</u> for problem solving than to give <u>strategies.</u> Disciplined, methodical, detailed. There is still a focus on the principles.

I was able to distinguish this trend of focusing on a procedure from a strong trend I noticed in the first cycle where instructors were more inclined to speak about the questions students should ask themselves rather than give a prescriptive process for solving problems. Differences in basic approach to problem-solving was a theme that had been explored in earlier analysis of these interviews and was one of the research questions added in the survey portion of the study.

Chapter 5: Interview Analysis Results—Stage 1

In this chapter, I will discuss in detail the results from the vertical and horizontal analysis of the interviews, describe the emergent themes, and compare them to the Initial Explanatory Model (IEM) and other previous work. I will begin with terminology that will be helpful in understanding both the interviews and coding scheme used in the analysis.

5.1 Terminology with examples

Throughout the interviews, the instructors used certain terminology that is widely understood in the physics teaching community. While not 100% of all physics instructors will use the same vocabulary and there may be multiple words used for the same idea, these terms will be understood by large majority of physics instructors in the US. This section explains and defines such terms that came up in the interviews and are used in the analysis of the interviews and the survey in this study. The terms are defined loosely and not necessarily taken to be the formal definitions. This is meant to be a guide for how the terms used in the interviews were interpreted.

While the term **homework** could be utilized in multiple ways even within a single physics class, here, the term is used to refer exclusively to physics problems assigned by the instructor for the students to solve outside of class time. Homework requires students to utilize information within a physical context to answer a question, typically by solving for a physical quantity relevant to the problem. Most commonly, these problems are selected from the textbook or another question bank. Homework may or may not count for a part of the course grade or be graded and returned with feedback for students.

Furthermore, students may or may not have access to the answers and/or solutions to these assigned problems.

Concepts/principles

In the interviews, the instructors used the terms **concepts** and **principles** interchangeably, thus we will here treat them as synonymous. Concepts common to a first semester introductory mechanics course include kinematics (the study of motion), Newton's laws of motion (involving forces or interactions between objects), energy, momentum, and rotational motion. Each of these concepts has contexts in which they are applicable and useful. For instance, the concept of energy conservation is always applicable, but may or may not be useful for solving a problem depending on the information available in the problem.

Equations/expressions

Every concept or principle in introductory mechanics can be represented mathematically by an **equation** or **expression**. Even though a strict definition of expression is not the same as an equation, we treat them as synonymous here because they tended to be used synonymously by the instructors in their interview statements. An equation states a quantitative relationship between quantities in symbolic form (e.g., $E_f - E_i = E_{in} - E_{out}$ for conservation of energy) and the equation corresponding to a specific principle is non-unique. Different instructors and textbooks use different forms but would generally recognize forms other than their own as valid.

In the interviews, it was clear that some instructors considered stating or writing an equation to be equivalent to stating the corresponding principle explicitly while others required stating the name of the principle separately before the equation is given in order to have specified the concept.

Knowns and unknowns/Givens/Variables/Target variable

In a typical physics problem, information is presented within a context and a question posed that requires the application of one or more physics concepts to answer the questions. The information presented is typically referred to as the **knowns** or **givens** of the problem. In the artifact problem (Figure 3-1), the knowns include the radius of the circle, the weight of the object, and the maximum height of the trajectory. Commonly used physical constants, such as the standard acceleration of gravity, are considered known as well.

The given information can be represented with symbols that are often called **variables**, some of which are represented by canonical letters. In some cases where there is more than one quantity in the same category, such as forces, subscripts or other compound symbols may be used. Because these are not necessarily canonical, it is often necessary to **define** the **variables** used to represent the physical information. If a particular usage is common, some instructors may just assume the most common meaning of an undefined variable.

Unknowns, as the term implies, are quantities whose values are not stated in the problem. In the problem used in the interview, because the mass of the thrown object is not stated explicitly, it is considered an unknown. Although this implies that there may be a very large number of unknowns, only a small subset of these is necessary for solving the problem. Sometimes, an unknown that at first seems relevant or necessary for solving the problem turns out not to be. This is often referred to as “dropping out of the equation.” The unknown that a solver focuses on in order to solve the problem is called the **target variable** (or quantity). In the interview problem, this could be the tension of the string at the lowest point of the circle.

Picture/diagram

In problems where a picture is not provided, it is common for the solver to draw a physical representation of the situation in a **picture** or **diagram**. To some, these terms have separate meanings. However, the words were often used interchangeably by the instructors during the interviews. A picture or diagram is a representation of the situation and usually contains a physical layout of the events and/or symbols specifying the knowns and unknowns. In problems involving movement, directions and representations of movement are often included. This representation can serve as a check of a student’s interpretation of the problem and can help in the communication of the solution or in diagnosing errors in the solution.

Approach/procedure/steps/plan/method

The instructors often referred to the **approach** or **method** that a student uses to solve a problem. This may be interpreted as the **plan**, **steps**, or **procedure**. It is sometimes used to refer to the concepts or principles of physics. An instructor might have differentiated using a kinematics approach versus a conservation of energy approach. Ultimately, it refers to the path the student chooses to solve a problem. A **procedure** or **approach** may refer to a pre-determined list of **steps**, or it may be a more generalized idea of logical steps that can be used to solve a problem.

Multiple approaches/methods

Given that different physics principles have substantial overlap in the quantities that they relate to each other, it is often the case that a given problem can be solved in multiple ways, using different principles. In the case of the interview problem, both conservation of energy and kinematics can be used to solve the problem, although conservation of energy results in a mathematically simpler solution. In cases such as these, instructors often mentioned having **multiple approaches** to solve a problem.

Solve symbolically/don't substitute numbers

The instructors in the interviews often used the phrase "**solve symbolically**" or specified to their students that they should not replace symbols with numbers until the end. They usually mean that all algebraic manipulation should be done using only the variables. Only when the target variable has been solved for in terms of known quantities should students put in numerical values. Such a solution method has many advantages, a few of which are: (1) the algebraic expression for the target quantity can be checked for its dependence on known quantities, providing a way to catch possible errors in the solution, (2) the algebraic expression is general and not tied to any particular set of values, making it possible to use it to calculate an answer for multiple sets of known quantities, (3) students are generally somewhat careless about including units when putting in numbers and this method minimizes errors due to using values with incompatible units.

Units/check units/unit analysis

Almost all quantities in physics have an associated **unit** of measurement (a few quantities are pure numbers, with no units). The units give a physical meaning to the quantities and thus are an important part of their specification. Many instructors talked about requiring their students to state units explicitly with numbers, when appropriate.

Checking units or **unit analysis** is one method for checking the correctness of an answer (e.g., a length could be expressed in meters or feet, but not in seconds or pounds).

Check reasonableness

Another method for checking the correctness of an answer is **checking the reasonableness** of the answer. One example of this is that the acceleration of an object sliding down an inclined surface should never be larger than the standard acceleration of gravity[1]. As with checking units, this method does not ensure that the answer is correct but does ensure that it is not obviously incorrect.

5.2 Emergent Themes

In this section, I will describe the six themes, including their associated categories and elements, and discuss the prevalence of each of the themes. The six themes are Obligation to work, Do/Don't, Procedure, Think/Understand, Be/Have, and Work with others. The first four themes most directly address the why and how of homework while the last two are more focused on the context in which homework is best done. The themes are not described with a parallel structure because they all did not have the same characteristics. In some cases, the theme is described fully because of the similarity of the comments and in other cases, there are multiple levels including Categories and Elements

[1] One real-life example of this is an answer on an exam I was grading that specified the speed of water coming out of a hole in a large tank to be greater than the speed of light. Unfortunately, at least one student declared this to be a reasonable value.

to express the full range of ideas. The themes are presented as is appropriate to its content.

5.2.1 Obligation to work

Statements pertaining to this theme came almost exclusively from the question in the interview where the instructors were asked why they assign homework. Because of the nature of the interviews, not all the instructors answered in a way that could be specifically coded as giving a reason for the homework. This is the narrowest theme in the sense that there was not a range or variety of opinions to document, therefore I do not have categories or elements associated with the theme. There were several ways in which instructors give the motivating factor of assigning homework. Of the 15 out of 25 (60%) interviews that had codable statements for this theme, almost all of them communicated a sense of "forcing," "encouraging," "incentivizing," or "giving a motivation" to students to do the homework because otherwise, students would not do it. This indicates that instructors value the actual work that students do. Some instructors gave more explicit statements of the importance they placed on homework. Instructor 10 said that "the key to learning is practice and repetition." Instructor 11 said, "The purpose of homework is to understand the material and learn how to solve problems… it is difficult to learn the subject without doing work." Instructors 16 and 21 said that homework is "crucial to getting anything out of the course" and "necessary for learning" respectively. Instructors differed on how much of the course grade they assigned homework, whether it was graded, and how it was graded, but all the instructors assigned problems with the explicit or implicit intent that students were to solve them.

5.2.2 Do/Don't

The Do/Don't theme had by far the largest numbers of coded statements. Within this theme, I focused on the physical actions that instructors want students to do. These actions can broadly be described as procedural actions, monitoring actions, and actions for achieving mastery. I decided to code mental processes under a different theme (Think/Understand), although this does not mean that the instructors always distinguished between physical and mental actions. Some of the categorizations may be merely a matter of semantics.

Procedural actions included writing things down and reading. These are actions that students can perform while solving problems. The items that instructors most commonly mentioned that students should write down were pictures, units, knowns and unknowns, process, and reasons. The most commonly mentioned items to read were the textbook, instructor feedback on graded assignments, and the problems themselves. While several instructors mentioned reading the book, others cautioned against "just reading the book" as a sufficient strategy for understanding the concepts.

Monitoring actions included activities that one might think of as cognitive or metacognitive, such as justifying problem-solving steps, checking units or answers, and comparing answers with solutions. As noted before, these had a close, sometimes indistinguishable relationship with the Think/Understand theme.

Achieving mastery actions included spending time on the course by practicing problems, working alone or in groups, getting help/asking questions, and learning to apply the concepts. These actions go beyond what a student would do while just trying to solve the problems. They are supplementary actions necessary for students in order to have a full understanding of the concepts.

5.4.3a Prevalence

Because of the higher number of coded statements in the Do/Don't theme, I compared their relative usage using three levels of prevalence. If an element showed up in more than 50% of the interviews (>12) they were considered highly prevalent. Elements that showed up in 30%-50% (8-12) of the interviews were considered moderately prevalent, and elements that were in 10%-30% (3-7) of the interviews were mildly prevalent. These levels of prevalence are used as an organizational tool for seeing how much of the instructors' time talking was used in mentioning common items. I used the prevalence measures only in this theme because of the large number of coded statements. I did not assume that a lack of statement implied a belief that something is unimportant. The main purpose of levels of prevalence was in the creation of the survey questions and responses. A complete list of the elements with the three levels of prevalence is found in Table 5-1.

Table 5-1: Do/Don't Theme: This table contains elements with one of the three levels of prevalence. The highly prevalent elements were in more than 12 of the interviews, the moderately prevalent elements were in 8-12 of the interviews, and the mildly prevalent elements were in 3-7 of the interviews. Elements found in only one or two interviews were not listed.

Highly prevalent ideas (>50% or >12 interviews)
- Draw picture or diagram (sometimes specified as labeled)
- Write down known and unknown quantities
- Write down the approach, steps, reasons, or justifications
- Write down and check units
- Get help, talk and ask questions
- Use a method or procedure

- Relate components of the problem (e.g. Words to variables, knowns to target quantity, picture to equation)
- Use instructor solutions to compare and correct answers
Moderately prevalent ideas (30%-50% or 8-12 interviews)
- Practice doing problems
- Work in groups or alone
- Read the book, feedback, and problems
- Spend productive time which includes not rushed or spread out and struggle with the problems
- Don't do things without thinking or understanding
Mildly prevalent ideas (10%-30% or 3-7 interviews)
- Write down the equations and principles
- Write down the coordinates
- Write down the target quantity
- Solve symbolically (numbers last)
- Use numbers if useful
- Don't look at answers or solutions first
- Do something (try)
- Learn and apply the principles

5.2.3 Procedure

The Procedure theme is closely related to the Do/Don't theme. At several points during the interviews, some of the instructors offered a summary of steps of how to approach a physics problem. These steps corresponded to activities that were coded in the Do/Don't theme, but the instructors put them in an explicit order. These parts of the interviews were coded as "procedure." In these portions of the interviews, the instructors discussed the steps they thought were needed to solve a problem. Table 5-2 incorporates all the procedural steps mentioned and lists them in roughly chronological order for solving a typical introductory problem. The right column shows which of the interviewees mentioned a given procedural step. This coding is important for the comparison of this study to a previous study that found two-types of problem-solving conceptions, linear and cyclic. Listing steps of a problem-solving process is one sign of an instructor having a linear conception of problem-solving; however, it is not the only one. I discuss these conceptions and compare them to my analysis further in the next section.

Table 5-2: Procedure: This table lists elements of problem-solving procedures mentioned in the interviews which are arranged in a chronological order. The first column contains the procedural step, and the second contains the interview which mentioned the step. No single interview contained all the steps of the procedure. The steps are arranged roughly in chronological order by how the instructors talked about them.

Procedural steps	Interview
Read problem	17
Draw picture (labeled)	3, 8, 9, 10, 11, 12, 17, 19, 24
Identify known, unknowns, target quantity, equations	3, 8, 12, 17, 24
Think	3
Work backwards for answer	15
Find principle/write relationships	3, 9, 10, 12, 24
Plan/self-questioning/evaluate	3
Follow example or steps	9, 10, 12, 15
Describe approach conceptually	11
Solve (symbolically) the math, get answer	3, 9, 12, 17, 19
Reflect on reasonableness	3, 17, 24
Check units	12, 24

5.2.4 Think/Understand

All but three of the interviews had statements coded in the Think/Understand theme (88%) making it the second largest theme in terms of total number of coded statements. It is the most diverse theme in that over half of the elements were found in only one interview, and there are more individual elements than in the Do/Don't theme. Within the Think/Understand theme, I identified three categories which were "Think," "Understand," and "Self-questioning." The elements in each of these categories are listed in Tables 5-4, 5-5, and 5-6. I will discuss each of these categories and highlight common elements within and across the categories. In particular, just over half of the interviewees said that thinking about the physics concepts was part of the problem-solving process, whether it be understanding them or using them. Codes related to concepts or principles are highlighted in the tables because it is the most common element across the categories.

5.4.5a Think

Some instructors simply said that students needed to think as part of the problem-solving process. In many cases, this was elaborated by a more specific action, but there were four instructors that did not clarify, saying only that students needed to spend time thinking in organized, logical ways. This fits with elements in the Do/Don't theme, where one of the prevalent ideas was that students should not to do anything without thinking or understanding. When a more specific type of thinking was specified, instructors mentioned that students should think about physics concepts and problem-solving techniques, as well as the problems themselves. Five instructors specifically mentioned that the students should make mental models, although they did not define what a mental model was. The full list of elements within the category of Think are shown in Table 5-3.

Table 5-3: This table lists the elements for the Think category within the Think/Understand theme. The first column contains the element, and the second column contains the interviews which contained the element. The elements relating to concepts or principles are bolded.

Think	Interview
Think	1, 2, 3, 23
About - **Concepts** - Techniques (methods, approaches) - Problems - Other problems - Previous knowledge - Whole picture	 1, 3, 5, 8, 22, 23 1, 2, 3, 6, 23 2, 3, 8, 14 4 2 2
Mental model	1, 4, 5, 19, 23
While watching	2, 7
Logical/organized	2, 3, 4, 21
Interpret/analyze	5, 6
Apply formulas	8
Phases of the problem	19
Realize	1, 2, 3
Figure out	15
For yourself	2
Next steps	8
Target	2, 4
Problem information	2, 19
Make connections	2, 3
Equation meaning	4
Other methods	2, 5
When wrong	2
NOT - Read => equation => answer	8
About answer	3, 24

5.2.5b Understand

The Understand category contains both the understanding of the principles and the understanding of the skills that a student needs to master into order to be a successful problem solver. The most common element instructors mentioned to understand was a student's own mistakes. This was often mentioned in the context of what students should do with the instructor solutions to problems. Instructors wanted the students to both compare their solutions to the instructor's and then understand where the mistakes happened. There are also statements regarding understandings of how problem solving works, that one needs to think, how to approach problems, that there are multiple techniques, and that the process is non-linear. There is an emphasis on understanding the concepts such as when and how to apply them and the "bigger" qualitative picture. Finally, there are statements regarding understandings of specific things like how to convert units, what to abstract and write down, and the meanings of symbols. The full list of elements can be found in Table 5-4.

Table 5-4: This table lists the elements for Understand category in the Think/Understand theme. The first column contains the element, and the second contains the interview which contained the element. The elements relating to concepts or principles are bolded.

Understand	**Interview**
Mistakes	1, 2, 5, 9, 13, 14, 15, 16
Reasons for - Choices - Picking direction - Steps - **Using principle**	 18 7 5, 10 4
Everything	3
That you need to think	3
When to write down	8
That process is non-linear	5
Qualitatively	5
Equation=principle	4, 12
Relationships of objects/concepts	4, 13, 24
Context	3
What to abstract	4
Need to demonstrate	9, 14
When/how to apply principles	9, 14, 19
How to approach problems	9
Meaning of symbols	10, 23
Few things to apply	10
Process > answer	10
There are multiple techniques	13, 16
Doing yourself is challenging	13
Bigger picture of concept	16
Convert units/vectors	24

5.2.6c Self-questioning

Some instructors spoke about questions that students should ask themselves throughout the problem-solving process. These questions ranged from the reasonableness of an answer to what the problem is asking the student to solve. These questions all show a mental monitoring of the situation and are closely related to the monitoring actions from the Do/Don't theme. The main difference here is that they are mental actions rather than physical ones. These self-questions give the most explicit direction of what the students should think as they are solving problems. Self-questioning showed up in over 12 interviews. The elements under the self-questioning category are listed in Table 5-5.

Table 5-5: This table lists the elements for Self-questioning category in the Think/Understand theme. The first column contains the element, and the second contains the interview which contained the element. The elements relating to concepts or principles are bolded.

Self-questioning	Interview
Answer reasonableness	5, 7, 19
Which questions to ask	1
Appropriate concepts (useful/applicable)	1, 2, 3, 5, 12, 22, 23
Compare answers	5, 7
Assumptions	1
Techniques	2, 5
Evaluate while working	5
Problem components	8
Plan	3, 21
Target quantity	2, 15, 17
Options	2, 17

5.2.5 Be/Have

The Be/Have theme relates to attitudes or characteristics that instructors feel are important for students to possess. Some are related to how students go about solving problems and provide a prerequisite mindset for the student. Many of the phrases used by instructors sound like advice in how to be successful in physics or what students need to anticipate in the course. Examples are being willing to work, to struggle, to start over, to seek help, or to ask questions. None of these are “actions” that the student will take; however, they characterize a readiness to take action if the need arises. In addition to statements about anticipating what one might do, there are statements about the mindsets that might benefit or hinder students. Examples from the Attitudes category are:

- Positive (attitude) (Interviews 2, 6, 9)
- Confident/relaxed (Interview 20)
- Curious/motivated (Interview 4, 10, 12, 13)

This alludes to the instructors’ beliefs that students need to have faith in their struggles and not to let challenges or perceived failures derail the students’ success. The instructors wanted students to know and anticipate these struggles, not because they indicate that students might be underprepared for the course but because they are a normal part of learning physics.

This theme also included directive work-related statements. While working, instructors advised being organized, being clear, being methodical (systematic), being ready to iterate (let go of previous ideas), and having a plan. Again, these are not actions that a student takes but the manner in which the student does their work. These statements implied that instructors have seen that students who do not carry out their work in these ways find their ability to solve problems hindered. A full list of categories and elements for this theme is in Table 5-6.

Table 5-6: This table contains a full list of categories and elements under the theme Be/Have. The first column has the category, and the second has the element with interview which contained the element.

Category	Element (Interview #)

Be willing to	- Spend time/work (12, 13, 30, 19) - Struggle (6, 13, 19) - Try new/start over (6, 15) - Get help/ask questions (9, 17)
While working	- Be organized/clear (13, 18, 20, 21, 24) - Systematic/methodical (11, 13, 16, 17, 30) - Have a plan (5) - Have multiple techniques (5)
Attitudes:	- Positive (6, 9, 2) - Not afraid/intimidated (6, 9) - Not frustrated/patient (6) - Confident/relaxed (20) - Curious/motivated (4, 10, 12, 13)

5.2.6 Work with others

The Work with others theme overlaps an element in the Do/Don't theme. This is considered a theme because it was an *a priori* concept from the IEM that I intentionally selected to probe in this study as seen in Research Question 3. This theme represents a more complex set of ideas so it is not considered an element in the same way that, say, drawing a picture is. Instructors' statements about Working with others or alone had a range of ideas including positive ideas and reservations about both working with others and alone. I will give some illustrative comments which I used to develop the theme and ultimately used to write the survey section.

5.2.4a Positive/negative group work statements:

Instructors made more statements about working in groups than working alone, and many of them were generally positive about students working together. Interviewee 6 said, "(a)nd I encourage them to work in groups. Most like to work in groups. And then there's discussion going on and that's probably where most of the learning happens." Several mentioned that the benefits included getting other students' perspectives and the ability to discuss ideas with somebody else.

There were instructors who seemed to suggest that group work was an integral part of the learning process. One instructor who was very positive about group work said,

> "I believe that they'll learn a lot from each other by working the problems together with other students. As opposed to isolation. I think they'll learn more what mistakes they're making. I think it's because they learn best when they work with other people. The other person may have another perspective, may have a different idea, may have had a similar problem, a similar difficulty that they had figured out. And I think it's that process of them talking with one another that's very helpful in their really learning what's important about the physics." (Interview 15)

Some instructors gave a nuanced view of group work or were in support of both group work and working alone because that allowed the benefits of both to be achieved. In the case of potential problems that could arise in a group setting, Interviewee 16 said, "Namely that students can and do work together on homework, which I think is great from a pedagogical or instructive point of view, but it does mean that some students, you know, student's homework grades don't necessarily reflect their own abilities." This statement reflects the concern that some students may simply be pulled along during group work without fully understanding what is happening. This can give a student a false sense of confidence or force the student to simply copy solutions just to keep up.

In support of working both in groups and alone, Interviewee 17 said, "I encourage people to in fact talk about the problems, work together, but make sure at some point you're solo on a few problems. Make sure that you contribute as much to the group discussions as you're getting back." This statement illustrates some instructors' concern that working in groups may leave students able to do problems only in a group setting, which would cause them difficulties on individual exams. Interviewee 21 also highlighted the benefits of working both in a group and by oneself by saying, "I do encourage students to work together on homework, first to do as much as they can on their own and then get help… Helping somebody else out is good for you and being stuck and then getting help is good for that person, so working together is, I think valuable." Thus, instructors viewed being stuck as both a positive and negative thing. On the positive side, students are forced to start thinking about broader ideas when they are trying to work around a problem. On the negative side, students might simply become frustrated in an unproductive way by not being able to move forward. An absence or abundance of struggle were both considered detrimental.

5.2.4b Positive/negative working alone statements:

One instructor seemed to imply that students working by themselves is the best if they can do it. Interviewee 2 said, "Some students can battle it out on their own, and when they finally do figure it out, they're that much better off for it. Others will battle on and never figure it out and just be confused and frustrated." This statement again shows the positive and negative sides of struggling. In many ways, it seemed that instructors assumed that students would work in groups and spoke up in defense of working alone. For instances, Interviewee 6 said, "There's occasionally a student who just prefers to work alone." This does not show a negative view of group work but illustrates the idea that group work will not necessarily benefit everyone. If a student is completely resistant to working in a group, it is likely that they will not actually benefit from the experience.

5.2.7 Proportional analysis of main themes

The three largest themes in terms of number of coded statements were Do/Don't, Think/Understand, and Be/Have. In order to compare these themes with each other, I created a graph of the normalized distribution which can be found in Figure 5-1. This is found by calculating the relative proportion of statements that were made in one of the themes compared to the total number of statements in all three themes for each interview. The three other themes Obligation to work, Work with others, and Procedure had only one to three coded statements in an interview if there were any statements at all, so their relative prevalence was analyzed based on how many interviews contained statements. As stated earlier, the highest and lowest number of coded statements in a single interview were 12 and 80 respectively with the average being 30.6 statements. By comparing the normalized list, we can see the relative time spent on these three themes regardless of how many statements were made in the interview. This comparison illustrates three things. First, it shows that the Do/Don't theme was the largest part of all but one of the interviews. The interviewees spent a lot of their time talking about the physical actions that students should do or not do while working on homework. Second, it shows that the Think/Understand theme was prevalent across the interviews but has a wide range of prominence for each interviewee. In a few cases such as interviews 1-5 and 10, almost 40% of the statements related to the theme, whereas there were three interviews that had no codes within the theme. Third, while the Be/Have theme is the smallest of the three, there were 2 instructors who had about 40% of the statements in this theme. This might show that a small minority of instructors believe that the student's overall willingness and personal approach to physics is a significant part of their success.

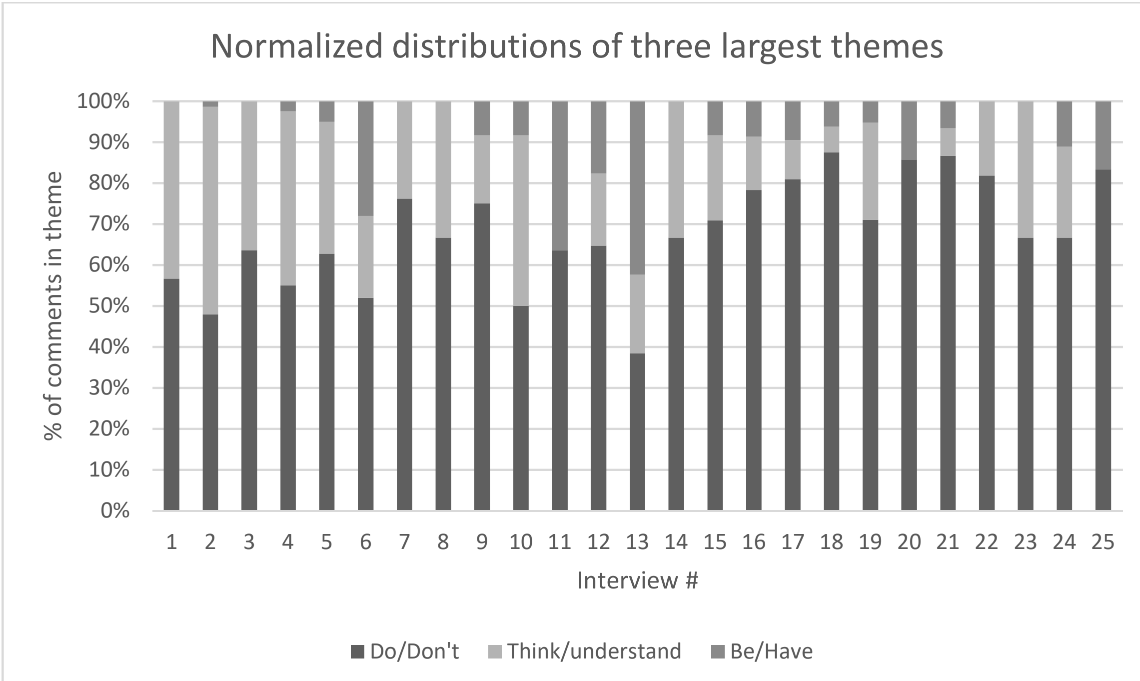


Figure 5-1: The graph shows the normalized distribution of the Do/Don't (darkest gray), Think/Understand (lightest gray), and Be/Have (medium gray) themes from each interview. This allow for a direct comparison of the relative percentage of statements made in each interview.

5.3 Comparing to the Initial Explanatory Model and Previous Research

5.3.1 Work

The Initial Explanatory Model for the principal category of Work is shown in Figure 2-2. Although the Initial Explanatory Model sought to define a process by which "Work" is done while I focused on the components of Work, the pieces of the Initial Explanatory Model all fit within the Emergent Themes found in this study. The individual parts of the Work principal category corresponded to Elements from the Interview Analysis. With a larger number of interviews to use, I created a global connection among the elements rather than just having a listing of all of the elements. A comparison of individual parts from the Work concept map from the IEM and the themes from this analysis are in Table 5-7. This obviously only includes the comparison of the parts of the Work on the IEM to the corresponding themes and elements. The themes from the interview analyses have many more elements.

Table 5-7: This table relates the ideas from the Initial Explanatory Model of Work to the themes and elements from the interview analysis. All the IEM elements fit under three of the major themes of this analysis.

Initial Explanatory Model- Work	Themes-Elements
- Don't get help until you need it - Don't look at solutions before working on the problem - Generalize the approach for the specific problem - Practice problems - Look at problem - Do the math - Spend time on problems	Do/Don't (Table 5-1) - Do something (try) - Don't look at answers or solutions first - Use a method or procedure - Practice doing problems - Read the problem - Solve symbolically - Spend productive time…with the problems
- Determining the approach - Understand the approach - Understand the reason for each step	Think/Understand - Think about Techniques (methods, approaches) (Table 5-3) - How to approach problems (Table 5-4) - Reason for steps (Table 5-4)
- Have a disciplined approach	Be/Have (Table 5-6) -systematic/methodical

In addition, elements from the Use Feedback map of the IEM (found in Figure 4-2) that fit into the themes found in this study are found in Table 5-8.

Table 5-8: This table relates the elements from the Initial Explanatory Model of Use Feedback to the themes and elements from the interview analysis. In this case, only a few of the elements of the Initial Explanatory model were considered.

Initial Explanatory Model- Use Feedback (selected elements)	**Themes-Elements**
	Do/Don't (Table 5-1)
Peer's feedback	- Work in groups
Student discussing what they tried- peer and self-diagnosis	- Work in groups
Comparing their solutions to mine in order to learn	- Use instructor solutions to compare and correct answers

The expansion of the Initial Explanatory Model was expected since this study analyzed interviews from instructors with a greater diversity of backgrounds and the research questions in this study were different. In the original study, the Initial Explanatory Model was only meant to provide a basis for exploring themes that arose from a very small subset of the interviews. It was never considered to be complete, but it did give insight into what could be studied with the full interview dataset. Additionally, the research team at that time chose to look at interviews with instructors from only one type of institution. This was done intentionally to increase the chances that more commonalities among the small population could be found. Another reason for having a significantly largely dataset than the IEM is that the research questions used in this study were not identical to the questions used in constructing the Work principal category map. For this reason, there were more elements elucidated in this study than in the initial one. This does not present a problem since the goal of this study was to look at a wider range of the ideas of what work means to instructors.

5.3.2 Linear versus cyclic beliefs about problem-solving

A dissertation study by Vincent Kuo looked at instructors' conceptualization of the problem-solving process (Kuo, 2004). In the initial explanatory model, the six instructors from a research-intensive doctoral granting institution were characterized as having a linear, cyclic, or artistic view of solving introductory physics problems. The linear view was described as a step-by-step procedure where each decision is clear if the problem-solver is careful and there is no need to start over if one has followed the procedure correctly. The cyclic view was described as a more general approach where the problem-solver has tools at their disposal to navigate the solution to a problem. Starting over is seen as part of the process and not considered a mistake. The artistic view was described as approaching every problem as a completely unique path that cannot be generalized to any sort of approach.

The Kuo study used these categories to study the full sample of 30 interviews and found that 22 of the instructors had a linear representation, 7 had a cyclic representation, and only 1 had an artistic representation of problem solving. Additionally, the study categorized types of metacognitive statements used by instructors from each of the groups. He found that within the linear conception of problem-solving, metacognitive statements were used in 29% of the statements. In the cyclic conception of problem-solving, metacognitive statements were used in 39% of the statements.

5.3.2a Algorithm- focused versus open-approach

One goal of the present study was to elaborate on the linear and cyclic characterizations of approaches to problem-solving by adding details of what each of the types of instructors might advise a student to do when they are working on homework, especially in terms of what components of or attitudes about problem-solving might be emphasized by either type of instructor.

In this study, I have replaced the terms linear and cyclic with algorithm-focused and open-approach, respectively, in order to broaden the scope of the meanings. Algorithm-focused and “linear” have similar connotations for how one approaches the problem-solving process using a step-by-step, predetermined approach. The main difference to emphasize between “cyclic” and “open-approach” is that the latter term communicates a broader set of choices with which one may begin a problem. Rather than guessing a path and seeing if it works out, there are options or tools for approaching different types of problems and the first step is choosing a good starting place. One might think of conceptualizing the tools and principles of physics as being a menu of options from which a student can choose to begin a path to a solution.

The reason for using different terms is to communicate a different context for how an instructor might conceptualize the problem-solving process. I describe the conceptualization in further detail in the following sections. Additionally, I will describe two potential distinct groups within the open-approach category. One group of instructors takes all options as equal (the “menu” group) while the other group emphasizes cognitive and metacognitive actions (the “questions” group) in the decision-making process. It is important to note that these two types of open-approach instructors communicated ways of solving problems in differently, but they might have very similar ideas about what is important. The key here is to know how they present problem solving to students and what the implications of those presentations would be.

5.3.2a1 Algorithm-focused traits

An instructor in the algorithm-focused category emphasizes the steps of a problem-solving procedure. He will likely have a list of steps (as discussed in the Procedure theme) for the students to follow when solving any problem. This instructor is likely to emphasize working carefully or being methodical and is not likely to view starting over as part of the process of problem-solving. The instructor will emphasize structure and organization in the approach to solving the problem. The interviews that most clearly show this approach to solving problems were 12 and 21.

Example from Interview 12:

"Draw the picture, label the picture, write down the information you know and what you want to know, recognize the principle, try to write an equation based on the principle, solve the equation."

5.3.2a2 Open-approach traits

An instructor in the open-approach category will focus on the options from which the students have to choose when approaching the problem. Rather than having prescribed steps, the instructor will have tools or techniques that might be useful in solving problems. This instructor will advise a student to try something and will consider dead-ends and starting over part of the process of problem-solving. The emphasis is more on putting information together to find a solution rather than on constructing an answer by following steps in a specific order.

In the interviews, open approach instructors seemed to talk about problem solving in two very different ways. Open approach (menu) instructors seemed to treat the options as more or less equally valid and would encourage students to try something and see if it works. If it does not, then the student should try something else. Interviews 3 and 6 most epitomized this kind of approach.

Example from Interview 6:

"…get those ideas out. Don't be scared of dead ends, that's part of problem solving… Bringing more than one concept. Describe approach… it's cyclic, because you start with something, you organize it, you have a dead end, you have to go back and brainstorm, and this is understanding the concept… Struggle, that's part of the attitude, that you are going to struggle."

Open approach (questions) instructors have the same view of tools and approaches being a menu of options, but they place a special emphasis on the questions that students should ask themselves as they make decisions about what to do. There still may be a trial-and-error component, but there should be reason for making decisions and not just blindly trying things. This instructor is concerned about the cognitive and metacognitive questions that lead a student through the problem-solving process. Interviewees 2 and 5 most clearly showed these traits.

Example from Interview 5:

"I want them to have some techniques that they can use so that…well, a number of things I want them to get out of it, as I think about it. One is…when you look at a problem, what is it, what tools are you going to pull out of the toolbox? Is this a Newton's Law type problem? Is this a conservation of energy type problem?"

5.4 Elaborating questions

The purpose of the present analysis of the full set of interviews was to inform that creation of a survey that could be given to a larger population of physics instructors. The two foci were to set the parameters of what the survey would look for and the content of the questions and answer choices to represent range of the beliefs of physics instructors.

To that end, I have developed elaborating questions to provide a means to answering Research Questions 1 and 2 in the survey.

Research Question 1:

What do physics instructors believe students should learn while solving problems independently?

Elaborating questions:

- Is the goal procedural, conceptual, a combination, or something else?
- Do instructors believe that doing homework is essential for learning to take place?

The implicit overarching question in this research is "why do physics instructors give homework?" It is an ubiquitous part of introductory physics courses, but there is not explicit research to answer that question. To break that question down, I looked at the goal of the homework. The interviews were not clear about a single goal, but instructors did talk about the process of problem solving and about physics principles. There needed to be clarification of what the instructors hope or expect that students will learn from doing homework. Secondly, even though homework is very common in physics courses, I wanted to ask the instructors what they thought about both the necessity and sufficiency of doing homework to reach the goal.

Research question #2:

What do physics instructors believe students should do while solving problems independently?

Elaborating questions:

- Are there distinct views on how the instructors view the activities of problem solving?
    a. Do the two categories of algorithm-focused and open-approach explain most instructors or is there support for a finer-grained distinction within the open-approach category?
    b. What are some distinguishing characteristics of the categories of instructors with regard to how they view the activities and mindsets of problem solving?

All the instructors talked about things that students do when they are solving problems. The first part of addressing this question is trying to establish a comprehensive list of activities and mindsets that instructors believe students need to do or have in their homework. The second part of addressing this question is looking at the different frameworks that instructors have when doing these activities. Having a list of activities does not tell us how the instructors expect the students should engage with these activities. Are these meant to be done in steps while problem-solving? Are they a menu of options to try to get closer to your goal? Are they a means to an end of ultimately solving a problem? These are important questions to explore because they give insight into how the instructors are presenting the problem-solving process to their students. I am looking at exploring the algorithm-focused and open-approach framework while testing the potential distinctions under open-approach of menu and questions. I also look at the distinguishing characteristics of these groups within the context of problem-solving in homework.

Chapter 6: Stage 2- Survey Creation and Deployment

6.1 Overview of Survey

In the earliest stage of this research, interviews with six faculty from a single institution were analyzed to build an initial model of instructors' ideas about problem solving (Henderson et al., 2007; Yerushalmi et al., 2007). Following that accomplishment, a few studies, including this one, were performed to analyze similar interviews with 24 more local faculty to test the initial model and create a more comprehensive and refined model. These studies resulted in more detailed information about instructors' ideas about specific aspects of problem solving, such as their conceptions of the nature of problem solving in the context of an introductory course (Kuo, 2004), and their goals and expectations for assigning homework (the present study).

The next natural step in this process is to study the ideas of an even larger number of instructors, from an even larger geographical area. For this next step, because of the time intensive nature of interviews, I turned to surveys as a data gathering instrument.

One feature of the surveys is that they were not designed to be a broad, open-ended instrument like the interviews. Instead, because I am interested in the specific aspect of "work" as it relates to problem solving, the survey is targeted towards answering my particular research questions. The format of a survey also allows me to draw firmer conclusions about the ideas that instructors may or may not have.

For example, because of the open-ended nature of the interviews, it is reasonable to use instructors' statements as an indication of belief. However, it cannot be assumed that the lack of a statement implies a non-belief. Although interviews 13, 18, 19, and 21 did not contain any coded statements about drawing pictures or diagrams, it cannot be inferred from this omission that these instructors do not believe that pictures or diagrams are important, since there was no explicit question about this feature. I can conclude from the other 21 interviews that did mention drawing a picture or diagram that it is a significant component of problem solving for a majority of instructors. The relative proportion of instructors who hold a certain belief can only be determined when all subjects must make a response that indicates the existence or absence of that belief.

Furthermore, using surveys with a larger number of physics faculty from a larger geographical area allows me to test for additional beliefs about problem solving or independent work that were not evident from the initial set of 30 interviews.

Finally, the results of this survey can be used to guide the design of future research to study the ideas of an even larger and more diverse population of physics instructors or to study ideas about different aspects of problem solving in a more efficient way than interviewing.

6.2 Survey content

The survey is divided into 5 sections, each dealing with a different aspect of “work” in problem solving. After question 1, which establishes the eligibility of the survey respondent as a member of the target population (physics faculty who have been the primary instructor for a calculus-based introductory physics course within the previous 10 years), the sections are:

Section 1: Defining homework. (Questions 2-9) This section asks about the use of homework in an instructor’s courses and addresses the instructor’s beliefs about the necessity and sufficiency of homework.

Section 2: Student approaches to homework. (Questions 10-12) These questions ask an instructor to rate the usefulness of some common student approaches to solving homework problems. The list of student approaches was developed from the interviews.

Section 3: Working in groups or alone. (Questions 13-19) This section asks instructors to comment on the pros and cons of students working on homework either along or in groups. In addition to being able to select pros and cons from a list developed from the interviews, open ended questions allow the instructors to add their own reasons.

Section 4: Instructor's approach to helping students. (Question 20-26) In this section, instructors comment on aspects on how they would help students doing homework, including what actions they think are critical for students to perform when solving problems and how they would advise students that they are helping.

Section 5: Demographic and background information (Questions 27-33): This section contains questions about an instructor's institution and teaching experience.

The full survey can be found in Appendix C. The correspondence between the research questions and survey items is as follows:

Research Question 1: What do physics instructors believe students should learn while solving problems independently?

- Is the goal procedural, conceptual, a combination, or something else?

- Do instructors believe that homework must be done for learning to take place?

Survey Questions : 6, 7, 8, 9, 11, 12, 22, 23, 24

Research Question #2: What do physics instructors believe students should do while solving problems independently?

2a. Are there distinct views on how the instructors view the activities of problem solving?

2b. Do the two categories of algorithm-focused and open-approach explain most instructors or is there support for a third category?

2c. What are some distinguishing characteristics of the categories of instructors with regard to how they view the activities and mindsets of problem solving?

Survey Questions: 11, 12, 20, 21, 22, 23, 24, 25

Research Question 3: How do instructors believe solving problems with others affect a student's learning?

Survey Questions: 13, 14, 15, 16, 17, 18, 19

6.3 Survey Design

The development of the survey incorporated several best practices as they relate to user-friendliness, and the writing and ordering of questions (Dillman et al., 2014).

6.3.1 User-friendliness

The survey I developed had several features designed to make it easy for respondents to complete. First, to keep the respondents motivated to complete the survey, the first questions were designed to be relevant to the entire survey target population and centered on a topic of concern to that population. In this case, this first questions asked about the instructors' homework, how it was used and counted in the course grade, and from what sources it was derived. Because homework is a part of nearly every physics course, these gave the respondents a chance to explain precisely how they used homework so that they could feel confident that the survey was relevant to them, even if they thought their practices were outside the mainstream.

Second, questions about a particular or similar topics were grouped together into sections to make them easier to think about. These sections were named so the respondent knew what types of questions were being asked in the section.

Of particular concern in surveys that ask about beliefs is the potential for social desirability effects, where respondents might give what they consider the most socially desirable answer rather their own answer. To offset this possibility, survey items were worded positively or presented in the most positive way. For example, in the section 4 about how instructors help their students, the prompts always use positive language like "helping students" and "useful." Because one of the reasons that physics instructors do not use RBIS is because they are concerned it will harm the students (Goertzen et al., 2010a), I wanted the instructors responding to the survey to feel as though their thoughts, opinions and beliefs are being represented in an authentic way. For instance, if an instructor feels that working in groups is counter-productive to the learning of the students, I did not want the survey questions and answers to feel condemning of that opinion.

Another concern is the tendency of respondents to acquiescence to questions. To counter this, the survey posed questions in which instructors were asked about lists of items in two ways. First, respondents were asked to give their opinion about each item in the list individually or to rank the items. Second, the same items were presented in one list and respondents were asked to choose a limited subset of items that they considered the most important. This pairing of questions tested the correlation between the most selected items versus the highest ranked items.

The other way this was considered was in authentic representations of negative opinions. One of the reasons to avoid negative statements is that they can be confusing when used in an agree/disagree item because of the potential double negative. If an item is confusing, then the responses can be tainted and may not be usable in analysis. The questions in this survey are almost completely posed in a positive manner; however, this presented a challenge for representing the emergent themes in an authentic way. In the Research Question 3 which focuses on working in groups there needed to be a presentation of both the belief that students *should* work in groups and that they *should not* work in groups. We felt that is was not sufficient to only have a response item disagreement to represent the latter group. This led to the Opposing Opinion questions where we could state negative opinions that could be selected rather than just dissenting from a positively worded item. An example of the Opposing Opinion item can be found in Figure 6-1. There are two statements made- one which is a positive outcome of group work and one which is a negative outcome. This allowed the survey participants to chose align or agree with an explicitly negatively worded statement rather than just disagreeing with a positively worded statement. Because the items presented two ends of a spectrum and did not ask the participant to agree or disagree, the ambiguity of the negative statement was eliminated. This item also allowed a degree of alignment instead of just a bipolar opinion.

Everyone contributes when the group is stuck. (2)	○	○	○	○	Only a few students do the work while others watch.

6.3.2 Question posing and ordering

In writing the survey questions, attention was given to writing answer choices that included all reasonable possible answers. Although most of the answer choices were based on empirical data from the interviews, we wrote the survey to include the range of beliefs that we thought physics instructors might reasonably have, even if some of those beliefs were not found in the interviews. As discussed earlier, the interviews cannot be said to represent all ideas or opinions.

Where appropriate, some items include an option to select “No opinion” simply because we cannot assume that everyone will have an opinion. This was used in Question 19 where the question statement was, “I think that most students benefit from working in groups.” While strong statements regarding say, group work versus working alone, were found in the interviews, not all instructors may believe that there is a preferred method. It would be disingenuous to offer only agree/disagree choices, and we would miss the opportunity to identify a population of instructors who do not hold an opinion.

On questions whose responses are on an ordinal scale, all the choices were labeled to be clear about what each of the choices mean rather than leaving it up to the interpretation of the respondent. For example, in Question 11, the statement was, “Please rank the usefulness of the following student behaviors:” The 4 choices after each statement were labeled “Not at all useful,” “Somewhat useful,” “Useful,” and “Very useful.” I chose to use 4-point scale so that there would not be a “neutral” response. The ordinal scales used a unipolar scale which means the lowest opinion that could be registered was essentially no effect. There was no way of indicating that the behaviors or practices listed would be detrimental or counter-productive.

Finally, attention was paid to the ordering of the questions depending on whether we wanted to use particular questions to prime the respondent for the section or if we wanted to use an “anchor” question as a confirmation of previous answers. For example, in Section 2: Student approach to homework, question 10 “I think that most of my students usually have a useful approach to doing homework.” (Agree/disagree) was used to prime the instructors to think about how they perceive the approaches of students to homework and this questions was followed by a list of student behaviors that they were asked to evaluate. In Section 3: Working alone or in groups, question 19 “I think that most students benefit from working in groups.” (Agree/Disagree/No opinion) was used as an anchor question for the section. That question was not put first to avoid having the respondent feel like they needed to make sure their subsequent responses were consistent with their answer to that question.

6.4 Length of survey and types of questions

There survey includes 26 questions, eight of which were free response questions that gave the instructors an opportunity to add information that was not in the survey questions, or to leave those questions blank. The software system within which the survey was written (Qualtrics™) estimated that it would take respondents an average of 12 minutes to complete the survey. Given the target population for the survey (physics instructors), we did not think this was an unreasonable amount of time that would hinder participation.

Table 6-1: Types of items and their frequency in the survey. Only those questions related to respondents' ideas about work are included (question 1 and demographic questions are not included).

Type of item	Number of items	Description
Open ended	8	These items allow the survey participant to add information, opinions, and other reasons that are not included in the choices for the content questions.
Description	4	These items allow the survey participant to specify what homework means in their courses.
Likert scale	56	These items give a statement and ask the survey participant to rank the degree to which they agree/disagree, find a behavior useful, or how often they advise students of a course of action.
Forced choice-multiple answer	4	These items give a list of choices and ask the survey participant to choose up to a specified number.
Forced choice-single answer	9	These items only allow for one choice from the provided answers. These included items giving opposing statements and having a four-choice

		range with which statement the survey participant more closely aligns.

6.5 Analysis consideration

When analyzing the results from a survey, as in any research, it is important for validation purposes to triangulate a respondent's answers. In this survey, each idea we wanted to investigate was probed using multiple questions, asked in a variety of ways. For example, in Section 3: Working alone or with groups, there are three different questions that probe beliefs about working in groups.

In Question 13, respondents are asked whether a number of student outcomes, all positively worded, were more likely to happen if students were to work in a group, work alone, or if the likelihood was equal in each case. Three example outcomes are:

- The time they devote to doing homework will be spent productively
- They tell other students their own ideas (either immediately or later)
- They think about the physics principles used in the homework.

These statements are representative of those made in the interviews of why an instructor believed that working in groups or alone was more beneficial. Although not seen in the interviews, two null choices ("equally likely" and "equally unlikely") were offered in case an instructor did not have an opinion about the best way to work on homework or did not see a benefit either way.

Question 14 then asked about the same idea in a different way. Respondents were given pairs of opposing statements with four choices indicating a spectrum between the statements. They were asked to select the choice most closely representing their view along that spectrum. The prompt was "Choose which statement you think is more true of your students when they work together on their homework." and examples of the pairs of opposing statements are:

They discuss the solution process with each other. /

They only compare final answers.

They spend less time in unproductive struggling to solve problems. /

They don't have the chance to struggle productively with the problems.

They explain the solutions process with each other. /

They just tell each other answers.

Finally, question 19 is a forced-choice item that states, "I think that most students benefit from working in groups." With the choices being "Agree," "Disagree," and "I have no opinion."

When trying to determine a respondent's attitude towards students working in groups, the responses to all of these questions will be considered. Responses that are consistent across all questions (for example, choosing "agree" to Q19, "working in groups" for most of the statements in Q13, and more of the positive statements in Q14) can indicate whether the respondent is strongly in favor of students working in groups or on their own. Responses that are not consistent can indicate that a respondent is in some kind of mixed state in between or has some ambivalence about the issue.

Table 6-1 lists the number and types of questions on the survey.

6.6 Survey features

The survey was written with the University of Minnesota Qualtrics ™ account and Figure 6-2 shows the opening screen of the survey. There was a completion bar at the top of each page.

Because not all of the questions would fit on the screen at the same time, when respondents chose to move to the next page of questions by clicking on an arrow at the bottom of the screen, a warning message would appear if there were any non-open ended questions left unanswered or if a question that required a limited number of choices had too many of the choices selected. Respondents were allowed to move on in the former case, but not the latter. No warning message was used for blank free response questions.

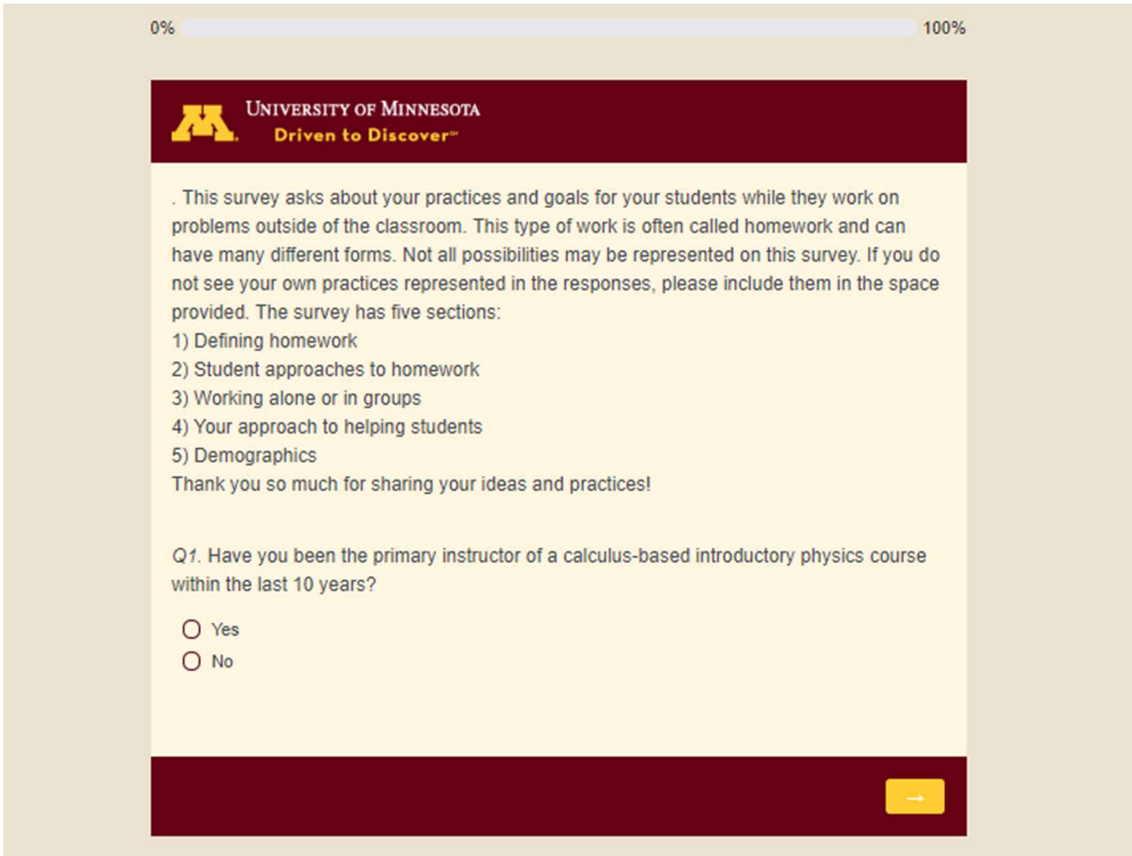


Figure 6-2: This is a screenshot of the first page of the survey.

6.7 Survey Participants Identification and Recruitment

The target population for this survey was post-secondary physics instructors in the state of Minnesota who has taught calculus-based physics in the last 10 years. The reasons for the requirements of the population were first to make sure that professors were exposed to the same conditions and that they had a specific context by which to answer the question and second to match the population from the interviews. In order to estimate the number of such instructors, I first used Wikipedia[2] to identify 76 public and private

[2] https://en.wikipedia.org/wiki/List_of_colleges_and_universities_in_Minnesota

postsecondary institutions in Minnesota. I then examined every school's website to determine if an introductory physics course was offered, finding 45 physics departments and programs that offer at least one physics course. With the information available on the websites, I counted the number of instructors associated with those 45 departments, including professors, lecturers, instructors, and adjuncts. Of the 45, there were 43 institutions where I could perform such a count, finding 258 total instructors (see Table 6-2). This represents an upper bound for the survey population.

Table 6-2: Institutions in the state of Minnesota that offer at least one physics course.

Institution type	Number of institutions	Number of instructors
Research	4	87
Private	15	93
State	6	37
Community	20	41
Total	45	258

Of the 45 institutions that offer a physics course, 25 do not have a degree in physics, though several offer a minor. Of the 25 non-degree granting institutions, 19 are community colleges. Since calculus-based physics is a requirement for many degrees and many community college students aim to transfer to a four-year institution, it is reasonable to assume that the community colleges will have a calculus-based introductory class. Thus, an estimated lower bound of the target population is 45, or one per school. More realistically, based on information I could access personally, through personal connections, and by a general e-mail appeal, I estimated the size of the target population as being between 109 and 190.

6.8 Solicitation and sampling

Table 6-3: Timeline for the survey approval, solicitation, and response collection.

Timeline	Milestone
April 4-5, 2018	Initial information letter (Appendix B) sent to the department contact
May 22, 2018	IRB approval
May 23, 2018	Small Beta test of survey
May 24, 2018	First Survey e-mail (Appendix B)
May 30, 2018	First Reminder e-mail (Appendix B)
June 7, 2018	Second Reminder e-mail (Appendix B)

Table 6-3 shows the timeline for the deployment of the survey. I first determined a contact person for each physics department. If no contact person was evident, I chose one of the instructors as a contact. In early April 2018, I sent out an initial information letter to each contact person explaining the study and asking them to disseminate the survey to the other members of the department when it was ready. I invited any questions about the study and gave them the opportunity to opt out of any further communication (no one chose to opt out).

In late May, when IRB approval was finalized, I sent the survey to three physics instructors at different institutions to test the survey and make sure it was working properly. Once I was confident the process was sound, I sent an e-mail explaining the research and containing a link to the survey to the remainder of the contact persons which included a request to forward the e-mail to the other physics instructors at the institution.

After one week, I sent a reminder e-mail to the physics contacts with a request to forward the reminder to other instructors in the department. In addition to the reminder, I also included a longer explanation at the end of the e-mail for survey participants who were curious about the study and were interested in more information. Finally, in early

June, I sent one final reminder to institutions that I reasonably believed still had instructors who might have still taken the survey. I also sent an e-mail expressing appreciation for everyone's time and attention to the survey. All survey correspondence can be found in Appendix B.

Chapter 7: Survey Analysis and Results

This chapter discusses the results of the survey as well as the implications of the findings. The discussion is organized by the research questions to which the survey was designed to find answers.

7.1 Response rate and attrition

Eighty-four individuals began the survey. Seventy-five of those identified themselves as instructors who had taught calculus-based introductory physics in the last ten years, while nine did not and were exited from the survey with no further questions. Furthermore, five of the 75 described themselves as teaching in a state other than Minnesota. Thus, there were 70 survey respondents who were postsecondary physics instructors in Minnesota. Using my estimate from the previous section of between 109 and 190 postsecondary physics instructors in the state of Minnesota, the response rate for the survey is between 37% (70/190) and 64% (70/109). Of the 75 instructors who began the survey, 66 instructors answered the final question regarding problem solving (Question 25) before the demographic questions at the end of the survey. Therefore the survey completion rate was 88% (66/75).

7.2 Research Question 1:

The first research question I explored was what do physics instructors believe students should learn while solving problems independently? In particular, I wanted to know if the goal is to learn procedural knowledge, conceptual knowledge, a combination, or something else. In addition, I wanted to know if instructors believe that homework must be done for learning to take place. The survey questions that address this research question are 6, 7, 8, 9, 11, 12, 22, 23, and 24.

7.2.1 Goal for homework

Questions 6 and 7 most directly addressed the question of the goal of homework. Question 6 asked the instructors to choose up to two of four commonly stated reasons for giving homework and Question 7 was an open-ended question asking for other reasons they gave homework. Questions 8 and 9 addressed the necessity and sufficiency of students doing homework to reach the goal(s) stated in questions 6 and 7. The results are summarized in Table 7-1 The uncertainties of the percentages are based on the standard error of a distribution which is given by $SED = \sqrt{\frac{N(p)*N(n)}{T}}$, where *N(p)* is the number of positive responses, *N(n)* is the number of negative responses, and *T* is the total number of respondents at that point in the survey.

Table 7-1: This table summarizes the selections from Questions 6 and 7 regarding the reasons for giving homework. The numbers in the third column indicate how many instructors used the open-ended response to indicate a third or even a fourth reason for assigning homework.

Reason for homework	Choose 2 response—Q6	Additional reasons—Q7
Success on tests/quizzes	15 (21±5%)	3
Practice applying physics principles in a variety of situations	55 (75±5%)	2
Gain an understanding of physics principles	40 (55±6%)	4
Practice general problem solving	36 (49±6%)	4
I don’t give homework	0	

The most selected goals for homework were “Practice applying physics principles in a variety of situations” and “Gain an understanding of physics principles.” Some instructors used Question 7 as a place to indicate one or more additional items from Question 6. In that case, I included those mentions in the results for Question 6. For example, if an instructor used Question 7 to include the other two purposes not selected in the response to Question 6, I added those mentions to the count of responses for Question 6. Thus, the total number of responses for Question 6 in Table 7-3 could have been larger than twice the number of instructors who answered that question (although it is not). With that in mind, the third most selected item, “Practice general problem solving” is not statistically different than “Gain an understand of physics principles.”

As we shall see, a central theme to instructors’ answers throughout the survey responses was focus on physics principles. All items that referred to physics principles either in thinking about them, learning to apply them, understanding them, were chosen or given positive scores over 50% of the time throughout the survey, and many topped 90%. (see Table 7-2) In items where instructors had to choose a subset of items from a list, those relating to physics principles were chosen either the most or second most from the list. In items where principles were being ranked as useful or necessary, over 90% of instructors ranked it positively. Although a few items were not ranked particularly highly, such as needing to write down the physics principles in words, this does not detract from the general theme of learning physics principles being the central goal for student learning.

Table 7-2: This table highlights the survey items that focus on physics principles. The first column lists the question items that related to physics principles along with the number of responses to the question. The second column describes the response type for the item, and the third column gives the percent response.

Principle question	Response-type	Percentage
Q11- Useful approaches to homework (N=68) (2) Deciding on a useful physics principle (15) Spending time learning how to apply the physics principles	4-point Likert scale: Useful and Very useful	 94% 96%
Q20- Helping students (N=67) (4) Think about the physics principles involved in the problem	4-point Likert scale: Always and Usually	99%
Q22- Necessary tasks for solving problems (N=66) (5) Writing down the applicable physics principles in words (6) Deciding which physics principles apply	4-point Likert scale: Frequently/sometimes necessary	 61% 98%
Q6- Purpose of homework (N=73) (2) Practice applying physics principles in a variety of situations (3) Gain an understanding of physics principles	Forced choice: Choose 2 from 5	 75% 55%
Q12- Essential approaches to homework (N=68) (2) Deciding on a useful physics principle (15) Spending time learning how to apply the physics principles	Forced choice: Choose 5 from 17	 85% (most selected) 62%
Q21- Helping students (most important) (N=67) (4) Think about the physics principles involved in the problem	Forced choice: Choose 3 of 7	93% (most selected)
Q23- Essential tasks for solving problems (N=66) (5) Writing down the applicable physics principles in words (6) Deciding which physics principles apply	Forced choice: Choose 5 of 18	 5% 79% (second most selected)

7.2.2 Necessity and sufficiency

In Question 8(1), 77±5% of instructors indicated that they “agreed” homework is necessary for students’ success, and, in Question 9, instructors said that 85% ± 13% of their students needed to do homework to be successful. Thus, instructors believe that doing homework is necessary for most students to be successful in reaching the goal of learning principles. This is supported by instructors’ responses to Question 2, in which 90±4% of instructors responded that they require students to complete some form of graded homework in their class.

However, in Question 8(2), only 41±6% of instructors indicated that they “agreed” students will be successful if they seriously attempt all the homework. Thus, most instructors do not seem to believe that simply doing homework, even if it is completed with a serious effort, is sufficient for students to meet the goals of their courses.

7.2.3 Summary

Physics instructors believe the main goal of homework is for students to practice applying, gain an understanding of physics principles, and to practice problem solving. This result is based not only on responses to the direct question regarding the reason for homework, but 12 other questions in which instructor indicated physics principles as the focus of the problem solving. Save for one survey item (Question 23(5)), all the items including physics principles were scored positively by over 50% of the instructors and most were scored positively by over 70% of the instructors.

Physics instructors also believe that homework is a necessary part of reaching that goal. Survey respondents overwhelmingly agreed that homework was necessary for success, and 90% of instructors require it in some form in their class. However, only a little over 40% of instructors believe that simply doing homework is sufficient for reaching the goal. When asked to give a percentage of their students that need to do homework to be successful, all the instructors except for two answered that was necessary for 60% or more of the students. For completeness, I note that given the questions asked in the survey, one cannot conclude that <u>not</u> requiring homework indicates that an instructor does not value homework.

7.3 Research Question 2:

The second research question was what do physics instructors believe students should do while solving problems independently? In particular, are there distinct views on how the instructors view the activities of problem solving? For example, what are the ways in which instructors frame problem solving to their students? Do two mindsets (similar to the linear and cyclic perspectives described by Kuo (2004)) fit the population, or is there evidence for more? Finally, what are some distinguishing characteristics of the categories of instructors with regard to how they view the activities and mindsets of problem solving? The survey questions that address this research question are 11, 12, 20, 21, 22, 23, 24, and 25.

7.3.1 Activities or mindsets

There were two primary focuses for the survey items related to this research question. The first was on the activities or mindsets of the students as they do homework as described in the instructor interviews in the Do/Don't and Think/Understand themes. The second focus was on how instructors framed the problem-solving process. The survey items related to this research question probed the idea that physics instructors have at least two global approaches to the problem-solving process. Two of these that have been characterized by previous research (Kuo, 2004) and my own analysis of the interviews I have termed "algorithm-focused" and "open-approach." Based on the interviews, I believed that it was possible that the open-approach framework had a further distinction of being either "Menu" or "Questions" type based on how they conceptualized the process by which students approached problem solving.

The survey items that focus on the activities or mindsets of students doing homework are Questions 11, 12, 22 and 23. These questions form pairs in which the first questions (11 and 22) list student behaviors and/or tasks and asked the respondents to rate how useful or necessary each one is. The results are listed in Tables 7-3 and 7-4. The second questions of the pair (12 and 23) then asked the respondents to choose their top 5 items from the lists in the previous questions. This pairing of questions was intended to probe the instructors' thoughts on each item, as well as a ranking of the items for comparative importance. I will refer to the individual scoring of each item as the *value* given to each item and the results from the limited selection as the *importance* of each item.

Table 7-3: Results from Questions 11 and 12. The student behaviors are listed by their value score (rating in Question 11). Asterisks are used to label the items that were the most frequently (*) or most infrequently (**) selected in Question 12.

Student behaviors	Percent-Useful/Very useful

1) Asking for help if they are confused*	98±2%
2) Spending time learning how to apply the physics principles*	95±3%
3) Deciding on a useful physics principle*	94±3%
4) Thinking about the reason for what they are doing*	94±3%
5) Solving more than the assigned/suggested problems	87±4%
6) Working with other people	82±5%
7) Reading example problems in the book or other resource	76±5%
8) Working independently	72±5%
9) Comparing their answers with answers available to them**	60±6%
10) Reading the book	52 ± 6%
11) Spending a significant amount of time of problems even when they are stuck	51±6%
12) Following a set procedure given in class of the book	43±6%
13) Looking for equation that relate known quantities to unknown quantities	38±6%
14) Looking for worked-out solutions to similar problems to use as a guide**	38±6%
15) Stopping work when they are stuck**	13±4%
16) Trying anything that seems related to the problem**	12±4%
17) Using any numbers right away**	3±2%

* Items selected by more than 50% of the respondents in Question 12.
** Items selected by less than 10% of the respondents in Question 12.

Table 7-4: Results from Questions 22 and 23. The problem-solving tasks are listed by their value score (rating in Question 11). Asterisks are used to label the items that were the most frequently (*) or most infrequently (**) selected in Question 12.

Physics problem-solving tasks	Percent-Frequently Necessary
1) Drawing pictures or diagrams*	91±4%
2) Identifying the quantity to be determined*	86±4%
3) Deciding which physics principles apply*	86±4%
4) Checking the reasonableness of an answer	80±5%
5) Being systematic	70±6%
6) Relating selected equations to the target quantity	58±6%
7) Picking a coordinate system	56±6%
8) Writing down all the information given the problems	55±6%
9) Writing down any applicable equations	53±6%
10) Solving equations symbolically before putting in numbers	50±6%
11) Doing a dimensional analysis of the final answer	47±6%
12) Reflecting on the major parts of the solution**	42±6%
13) Thinking about the next steps**	38±6%
14) Being willing to start over with a different approach	23±5%
15) Writing down the reasons for major steps in the solution**	21±5%
16) Writing down the applicable physics principles in words**	15±5%
17) Thinking of multiple approaches**	8±3%
18) Writing down all the steps before doing them**	5±3%

* Items selected by more than 50% of the respondents in Question 23.
** Items selected by less than 10% of the respondents in Question 23.

As can be seen from Tables 7-3 and 7-4, the highest importance items, defined as having been selected by more than 50% of the respondents in Questions 12 and 23, were also the most highly valued on Questions 11 and 22. The lowest valued items were generally given the lowest importance rating. I infer from this that these latter items, such as “using any numbers right away” or “writing down all the steps before doing them” were not seen as inherently useful by the instructors.

On the other hand, there were a few activities such as “Comparing their answers with the answers available to them,” and “Looking for worked out solutions to similar problems to use as a guide," that were rarely selected for importance, although they were given moderately high scores for value (60% and 38%, respectively). I infer from this that instructors believe these activities to have value, although they are not highly important to solving problems.

These ratings give insight into the activities that instructors believe are useful and necessary for students solving quantitative problems. There seems to be good agreement among physics instructors about what students should do when solving problems, which confirms that there is a limited number of activities that instructors believe need to be done in the process of problem solving. There were very few comments in the open-ended questions (Q24 and Q26) which indicated there are were items that were omitted from the lists. While individual instructors might have a few idiosyncratic things that they like to emphasize in their classes, the results of the survey indicate that the lists of problem solving behaviors and tasks derived from the interviews are well-representative of those on the minds of most physics instructors.

7.3.2 Global approaches to problem solving

Although instructors seem to agree on the basic behaviors and tasks that students should do during problem solving, not all instructors agree on the overall mindset or global approach that students should have while performing these tasks. The survey item that most directly probes an instructor's global approach to problem solving is Question 25. In order to avoid having an instructor's response to this question influence his or her responses to the other questions, this question was placed last in the survey, just before the demographic questions. The prompt stated, "Which one of the following do you think is the most useful to give to students in terms of helping them learn from doing homework?" and the results are shown in Table 7-5.

Table 7-5: This table gives the response choices and results for Question 25.

Response choice	Results % (N)
A general procedure for solving quantitative problems	38±6% (25)
General tools for solving quantitative problems	33±6% (22)
Questions students should ask themselves as they solve quantitative problems	24±5% (16)
Specific procedures for solving specific types of problems	3±2% (2)
Students should develop their own approach from solving problems.	2±1.5% (1)

Previous research has suggested two global approaches that instructors have to problem solving (discussed in Chapter 5: Interview Analysis). The two "procedure" choices of Question 25 were meant to correspond to Kuo's "linear" conception of problem solving, which I have termed "algorithm-focused." The "General tools" and "Questions" choices were meant to correspond to Kuo's "cyclic" conception, which I have termed "open-approach." The final response of Question 25 was meant to correspond to the approach Kuo (2004) described for one instructor as "artistic" and is a very small selection of the population.

Assuming that instructors with a linear/algorithm-focused problem-solving framework did indeed choose one of the two procedure options and that instructors with a cyclic/open-approach framework chose either the "General tools" or "Questions" options, then we see that while the procedure-focused choices were indeed the most popular (collectively), they are not nearly as dominant in the population surveyed as was suggested by a previous analysis of the interviews (Kuo, 2004). Combining the procedure choices and the tools and questions choices, we see that the open-approach choices were selected by 57% of the respondents whereas 41% chose the algorithm-focused choices.

From my analysis of the interviews, however, I suspected that Kuo's two main categories of "linear" and "cyclic" might actually be comprised of three or more distinct approaches or frameworks to problem solving. In particular, I suspected that the cyclic group might actually be composed of two types of instructors, one which use strategies and approaches of problem solving as a menu who would have preferentially selected the "General tools" option for Question 25, and a second type which also has a menu view of what can be done but emphasize guiding questions for making decisions who would have preferentially selected the "Questions" option.

One of the major goals of the survey was to try to gather additional evidence for the existence of these multiple distinct types of instructors and to expound on the distinguishing characteristics of each.

7.3.3 Group Comparison

First, I assumed that respondents' choices in Question 25 corresponded to which of the three potential groups they belonged to. I called these groups "Algorithm," "Menu," and "Questions" according to whether they selected the first or fourth, second, or third choice in Question 25, respectively. Because only one instructor selected the last choice, that person has been excluded from the analysis.

I then compared the responses of instructors in these three groups to other survey questions to see if there were distinct patterns in how they answered them. Specifically, I analyzed their responses to Questions 12, 21, and 23. Question 12 and 23 have been discussed previously. In these two questions, respondents chose up to 5 items that they deemed the most important from a lengthy list of student behaviors and tasks. Question 21 gave instructors 7 pieces of advice (from which they could choose up to three) that they could give to a struggling student and was meant to be a check on instructors' responses to Question 25. Below, I describe the quantitative analysis that I performed on these three questions that then discuss the similarities and differences among the groups of instructors who selected different answers to Question 25.

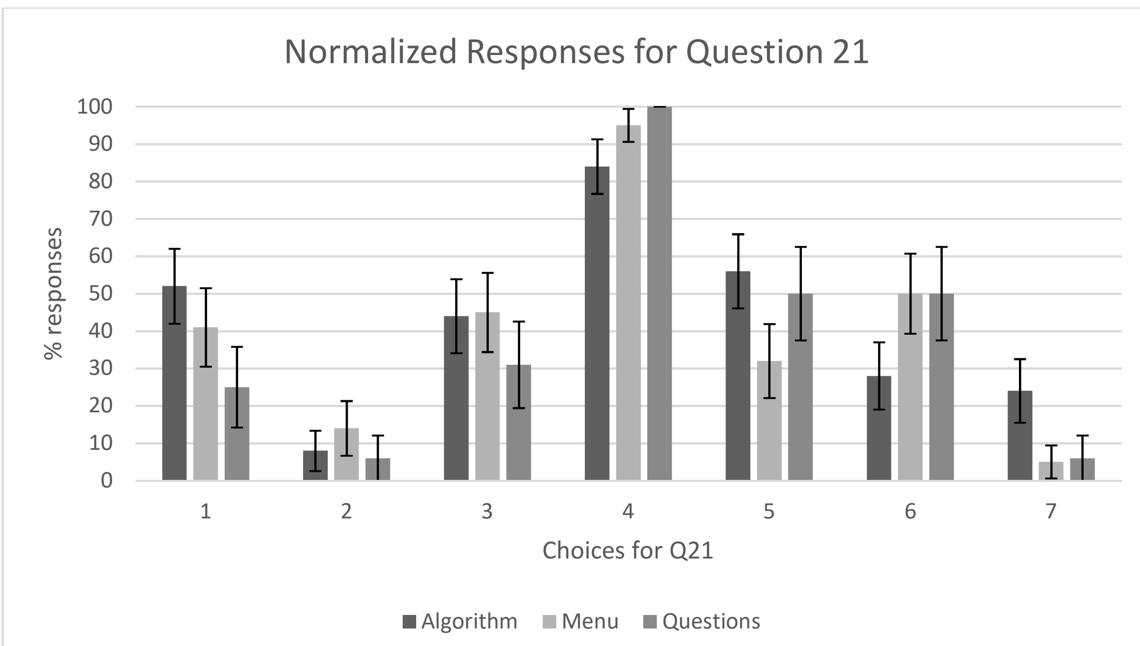


Figure 7-1: The normalized responses to Question 21 which asks what are the most common approaches when helping students. The responses are aggregated by the selection from Question 25.

Table 7-6: The top three choices of the aggregated groups from Question 21.

Algorithm	Menu	Questions

Most selected item	Think about the physics principles involved in the problem. (84±7%)	Think about the physics principles involved in the problem. (95±4%)	Think about the physics principles involved in the problem. (100±?%)
Second most selected item	Keep organized. (56±10%)	Be okay with starting over. (50±11%)	Be okay with starting over. (50±13%*)
Third most selected item	Follow the steps of a problem-solving procedure. (52±10%)	Have an initial strategy to every problem. (45±11%)	Keep organized. (50±13%*)

*Second and third choices were tied for the Questions group.

Figure 7-1 and Table 7-6 show results from each of the three groups for Question 21, which asked "Given the [following] list of advice [for students], which do you think are the most important (choose up to 3)?

1) Follow the steps of a problem-solving procedure
2) Try something and see if it works
3) Have an initial strategy to every problem.
4) Think about the physics principles involved in the problem.
5) Keep organized.
6) Be okay with starting over.
7) Write down their solution plan before spending much time on the details."

It was expected that items (1), (5), and)7) would have been the most popular choices for the "Algorithm" group and items (2), (3), and (6) would have been the most popular choices for the "Menu" and "Questions" groups with item 4 being of a greater importance to the "Questions" group. Item (4) was intended to probe the value that instructors placed on cognitive processes and might serve to differentiate the "Questions" group from the

"Algorithm" and "Menu" groups, but really it did not because it had physics principles which was shown to be valued highly by all instructors.

From Table 7-6, we see that the top three choices for the "Algorithm" group were actually (1), (4), and (5), the top three choices for the "Menu" group were (3), (4), and (6), and the top three choices for the "Questions" group were (4), (5), and (6). Thus for the all the groups, two out of the three choices were as expected. The dominance of item (4) was unexpected but is consistent with the great importance that physics instructors placed on any choices related to "physics principles" as described earlier.

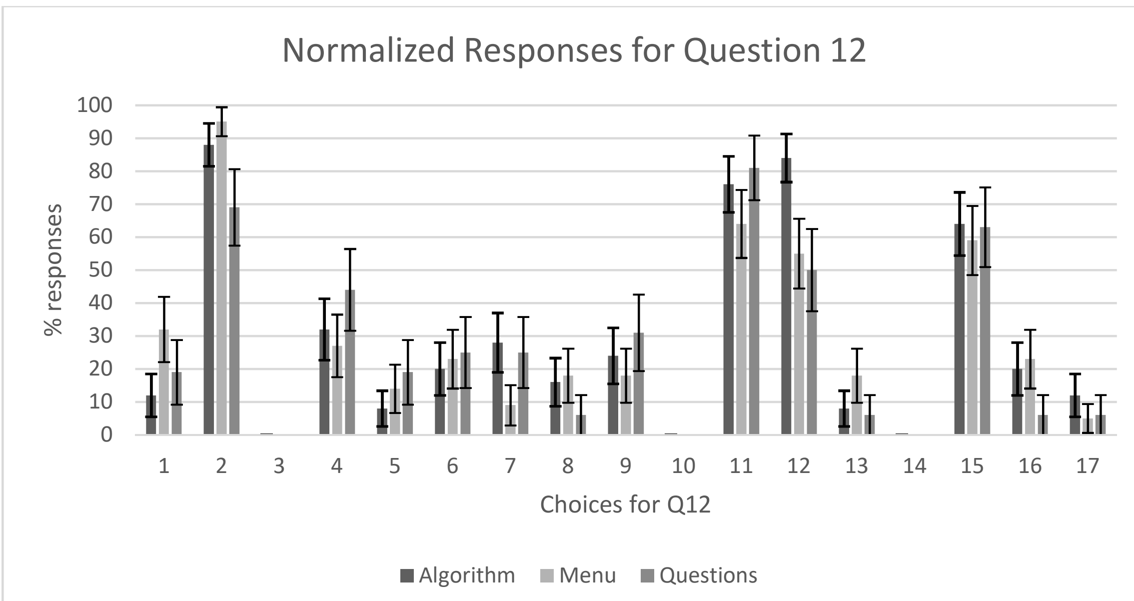


Figure 7-2: The normalized responses from Question 12 which asks the instructor to select the 5 most useful student behaviors from a list of 17. The responses are aggregated by the self-selection from Question 25.

Table 7-7: The top three choices of the aggregated groups from Question 12 regarding the usefulness of student behavior.

	Algorithm	Menu	Questions
Most selected item	Deciding on a useful physics principle. (88±7%)	Deciding on a useful physics principle. (95±4%)	Think about the reason for what they are doing. (81±10%)

Second most selected item	Asking for help if they are confused. (84±7%)	Think about the reason for what they are doing. (64±10%)	Deciding on a useful physics principle. (69±12%)
Third most selected item	Think about the reason for what they are doing. (76±9%)	Spending time learning how to apply the principles. (59±11%)	Spending time learning how to apply the principles. (63±12%)

Figure 7-2 and Table 7-7 show results from each of the three groups for Question 12, which asked instructors to pick out the 5 most important student behaviors in problem solving. As can be seen, there is substantial overlap in the selections of the three groups. Both “Deciding on a useful physics principle” and “Think about the reason for what they are doing” were highly rated by all three groups. In fact, Figure 7-2 shows that all three groups rated the same 4 or 5 behaviors significantly higher than all the rest.

One difference between the three groups was the uniformity with which they made their top three selections. The Algorithm group chose their top three behaviors much more uniformly than the other two groups (the percentages of their choices were significantly higher than those in the other two groups) showing that there may be more agreement or a common mindset among the instructors in that group.

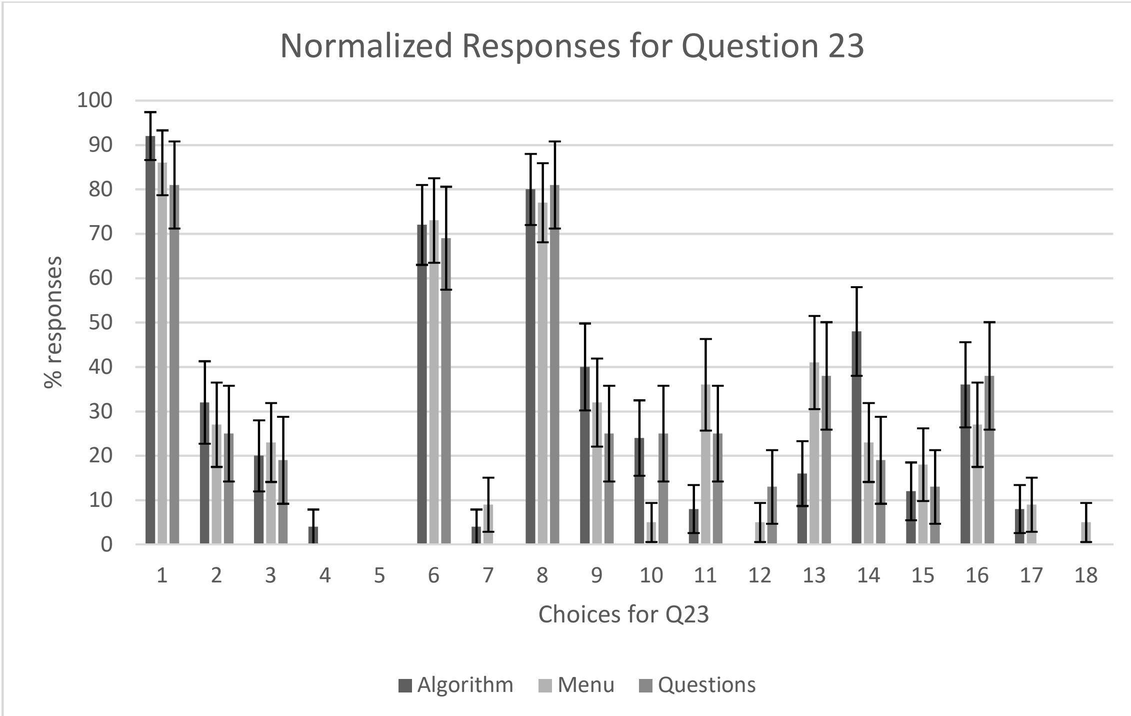


Figure 7-3: The normalized responses from Question 23 which asks the instructor to choose the 5 most essential task for problem solving from a list of 18. The responses are aggregated by the self-selection from Question 25.

Table 7-8: The top three choices of the aggregated groups from Question 23 which addressed essential problem-solving tasks.

	Algorithm	**Menu**	**Questions**
Most selected item	Drawing a picture or diagram. (92±5%)	Drawing a picture or diagram. (86±7%)	Drawing a picture or diagram. (81±10%*)
Second most selected item	Deciding which physics principles apply. (80±8%)	Deciding which physics principles apply. (77±9%)	Deciding which physics principles apply. (81±10%*)
Third most selected item	Identifying the quantity to be determined. (72±9%)	Identifying the quantity to be determined. (73±10%)	Identifying the quantity to be determined. (69±12%)

*The highest and second choices are tied for Questions group.

Figure 7-3 and Table 7-8 show results from each of the three groups for Question 23, which asked instructors to pick out the 5 most important tasks for problem solving.

The responses of all three groups are uniform, and even more so than in Question 12. As can be seen in Figure 7-3, three main tasks dominate the importance ratings for all instructors, illustrating strong agreement among physics instructors in general about what students should be doing when they are working on problems. One positive commonality among the groups is the high rating of cognitive processes while working. The top-rated item in Question 21, two of the top three in Question 12, and two of the top three in Question 23 were all cognitive-focused items. This shows that cognition is valued across the groups, and thus, by physics instructors.

7.3.3a Categories versus continuum model

If instructors could really be grouped into discrete categories based on their framing of the problem-solving process, I would have expected to see significant differences between the responses of the three groups to these questions. The fact that there was relatively little difference, especially in the different groups' responses to Questions 12 and 23, may indicate that the survey is not sensitive enough to detect differences between the groups, that Question 25 is not a good indicator of an instructor's group membership, or perhaps even that in actuality, there are no distinct groups.

A fourth possibility is that instead of falling into categorical groups, instructors lie on a continuum with respect to their framing of problem solving. Looking at Question 25, one could interpret the possible responses as representative of a continuum of how the problem-solving process is framed. On one end of the continuum (Specific procedures for solving specific types of problems) instructors give students a highly prescriptive and regimented procedure or procedures. On the other end (Questions students should ask themselves as they solve quantitative problems), the process is much less prescriptive, instead involving general heuristics that students learn. It is possible that the choice "Students should develop their own approach from solving problems" represents an even more extreme view on this side where the heuristics must be developed by the student himself or herself.

I performed one additional analysis to examine similarities and differences between the groups' responses to the items from Questions 12, 21, and 23. The idea is to quantify the extent to which the groups' responses overlapped with each other and to what extent they were statistically distinct as a group, without considering the content of the items. If there is truly no difference between the groups, I would expect to see no or very little statistical difference in the groups' responses to these questions on the survey. If there are categorical differences among the groups, I would expect to see significant statistical differences in the responses. If there is a continuum, I would expect the results to fall somewhere in between–that there will be both distinctions and statistical overlap among groups in their responses.

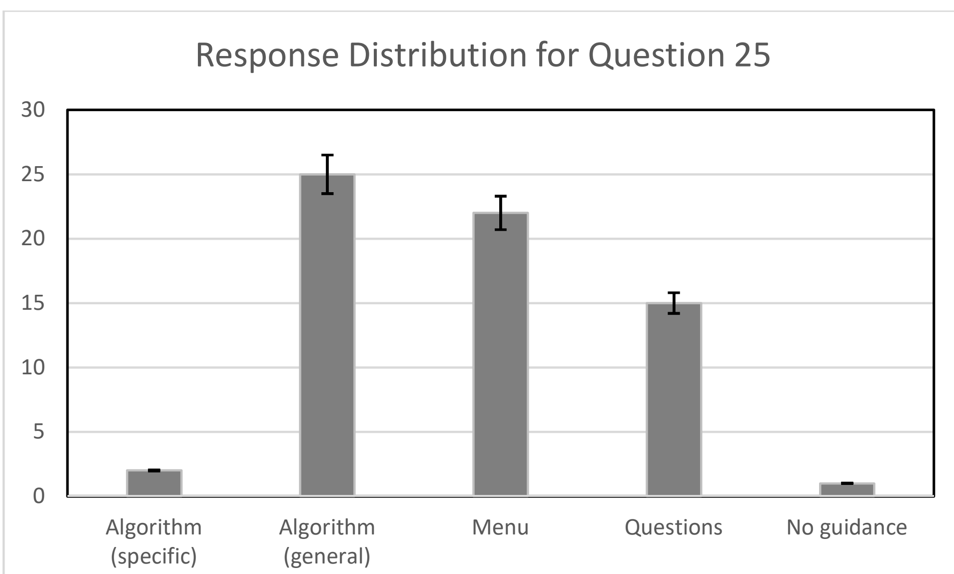


Figure 7-4: Graph shows the distribution of responses to Question 25 with the choices arranged in with a continuum interpretation.

7.3.3b Analysis of overlap and distinction among groups

The results are summarized in Table 7-9. Within Questions 12, 21, and 23 collectively, there were a total of 42 items that respondents could have selected or not selected. On 23 of these 42 items, the rate at which the item was selected by the different groups was not statistically different. For example, all three groups selected the first three items of Question 23 (drawing a picture or diagram, writing down all information given in the problem, and picking a coordinate system) at essentially identical rates. This can be seen in Figure 7-3 where the bars showing response rates for items 1, 2, and 3 are statistically equivalent of all three groups.

Of the remaining 19 items, there were 15 items where two of the groups selected the item at the same rate, but where one of the three groups was statistically distinct from the other two. For example, the response rate for item 12 in Question 12 (asking for help if they are confused) was equivalent for the Menu and Questions groups, but different for the Algorithm group. Finally, on four items, two of the groups were statistically different, while the response rate of the third group was statistically equivalent to both of the others. For example, on item 1 of Question 12 (looking for equations that relate known quantities to unknown quantities), the response rates of the Algorithm and Menu groups were distinct, but the response rate of the Questions group overlapped both of the others. The combination of distinction and overlap in the responses amongst these groups supports the idea that instructors' problem-solving frameworks fall along a continuum, rather than belonging to discrete categories. Categorical distinctions would tend to give much less overlap, but the distinctions among the group still supports differences among the population.

Table 7-9: This table shows the percentage of time the groups either distinguished themselves from the other two or showed overlap with one or both of the other groups.

Group	Distinct from other two groups (%)	Overlap one or both other groups (%)
Algorithm	8 (40%)	11 (55%)
Menu	3 (15%)	16 (80%)
Questions	4 (20%)	15 (80%)

7.3.4 Summary

There is a limited number of behaviors and tasks that instructors believe students should do while solving physics problems in the context of homework. Furthermore, there is high agreement in the value and importance of the activities or mindsets, and the lists provided contain almost all the items that instructors value. Based on previous studies, the interview analysis, and the responses to Questions 21 and 25 of the survey, there is support for the idea that there are different frameworks that instructors have for problem solving. However, the results of this survey do not provide a clear indication of what, if any, distinctions there might be between those groups. This could mean several things:

1) There are different groups, but this survey does not have the ability to find the distinctions.
2) There are not different groups and no survey will find the distinctions.

3) There are different groups and the distinctions will never be more pronounced than they are in these results. One reason for this could be that there are various beliefs along a spectrum rather than being categorical by nature. Since this survey was designed assuming that instructors would fall into categories, its questions are not appropriate for placing the respondents along a continuum.

7.4 Research Question 3:

The third research question was to what extent do instructors believe solving problems with others is beneficial to students' learning? Specifically, in what ways do instructors believe group work can be helpful or not helpful to a student's learning? The survey questions relevant to this are Questions 11 through 19.

7.4.1 Group work questions

The survey items related to group work appeared not only in Section 3 of the survey, which focused on group work, but also in Questions 11 and 12 of Section 2 which was focused on student behavior in general. In those questions, instructors rated and picked their top 5 most useful student behaviors.

Question 13 posed twelve possible positive outcomes of homework such as discussing the problem and principles (either immediately or later), understanding the solution process, and completing homework. Instructors were asked to choose whether those outcomes were more likely to happen while working in a group, independently, equally likely, or unlikely to happen in either case.

Question 14 presented statements representing the opposite ends of a continuum of possible outcomes of group work. For example, one such pair was "[Students] discuss the solution process with each other" and "[Students] only compare final answers." Respondents were asked to select from a four-point scale that indicated where on the continuum their beliefs fell. The purpose of this survey item was to give instructors an opportunity to indicate agreement with explicitly negative statements about group work without imposing the cognitive load of switching prompts between positive and negative statements.

Questions 15, 16, 17, and 18 were all open-ended responses giving instructors the chance to list other benefits and drawbacks of working on homework either alone or in groups that were not previously stated in the survey. All four questions appeared on the same page of the survey and did not require a response in order to move on.

Finally, Question 19 posed the statement "I think that most students benefit from working in groups." and asked instructors to indicate whether they agreed or disagreed with the statement, or if they had no opinion. As with Question 25, this question was intentionally left until the end of the section as an anchoring question to minimize the possibility that instructors' answers to this question would affect how they answered the rest of the questions pertaining to group work.

7.4.2 Overall opinion of group work

In Question 19, 88% of instructors agreed and 12% chose "I have no opinion." No one chose "disagree." Thus, a strong majority of instructors believe that working in groups can be valuable for students. For a fuller picture of these opinions, I examined the results of other survey questions.

7.4.3 Group versus individual outcomes

The outcomes that were most strongly associated with working in groups or working alone on Question 13 are shown in Table 7-10. These choices reflect what instructors believe to be the most likely results of either style of working. Instructors said that working in groups is more likely to result in the discussion of ideas and the solution process and students not getting stuck. They said that working alone was more likely to result in trying something out before seeking help and looking for resources (other than people) for help when they were stuck. The value they place on finding resources for help could be in the need to think about the resource and how it applies to the situation, a potentially valuable activity. For example, even if students are looking for a worked solution, there is still the thinking process of matching their own work and thoughts with the information in the resource.

Table 7-10: This table shows the results of statements in Question 13 that had a 50% or greater response rate.

Statement	Working in a group (%)	Working alone (%)
They discuss the solution process with other students (either immediately or later).	93%	
They tell other students their own ideas (either immediately or later).	91%	
They seek out other students' ideas (either immediately or later).	90%	

They do not get stuck on problems.	55%	
They try something before asking questions		60%
They look for external resources when they are stuck.		50%

7.4.4 Reservations about group work

Question 14 gives the most insight into reservations that instructors have about their students working in groups and the results are listed in Table 7-11. I focused mostly on the items for which a significant number of instructors indicated that their opinions were more closely aligned with possible negative outcomes of group work.

As can be seen from the results, the most prevalent reservation about group work shown in this set of questions is that there may be a strong imbalance of work among the group members. This idea was also expressed many times in the open-ended questions (Questions 15 through 18), which will be discussed later. Interestingly, many fewer instructors selected the outcome that only a few students understand what is going on. One might interpret this as an issue of fairness in doing the work, rather than in gaining comprehension of the material. However, as we shall see later, other responses may seem to contradict this interpretation.

The other five reservations were chosen by 20-25% of the instructors. Of these, the majority of responses showed only a slight preference towards the negative statement (respondents did not choose the option at the extreme end of the four-point scale). These reservations included having the time to struggle productively or being able to do the homework without rushing. Such responses were also seen in the interviews, paired with the idea that time was needed to think and understand how the principles worked. The last two reservations in Table 7-11 addressed the idea that groups do not truly work together collaboratively but are only mechanisms for students to confirm that the correct answer had been reached. Thus, instructors seem to believe that it is important for students to discuss the solution process, rather than just finding the path to the correct answer.

Table 7-11: This table contains the negative statements from Question 14 in the first column and the total percentage aligning with the statement with the percentage strongly aligning in parenthesis. These results show the percentage of instructors who aligned more with the negative impacts of group work.

Negative statement (N=68)	Total percent responses (strongly aligning)
Only a few students do the work while others watch.	69% (13%)
They wait until the last minute to do the homework.	26% (9%)
They only compare final answers.	25% (0%)
They don't have the chance to struggle productively with the problems.	25% (3%)
Only a few students understand what is going on.	22% (3%)
They just tell each other answers.	20% (0%)

To investigate how evenly distributed these reservations were among the respondents, I counted the number of reservations per instructor (defined as either aligning or strongly aligning with a negative outcome of group work) and divided the instructors into groups categorized by the number of reservations they expressed in Table 7-12. The number of instructors with no or only mild reservations about group work is a strong majority at 72%, again showing that group work is generally viewed very positively among physics instructors, but also that they also believe that there are some negative outcomes as well.

Table 7-12: This table gives the breakdown of the percentage of instructors that had reservations about group work.

Number of reservations about group work	Percentage (n)
No reservations (0)	21% (14)
Mild reservations (1-2)	51% (35)
Moderate reservations (3-4)	25% (17)
Significant reservations (5-6)	3% (2)

7.4.5 Open-ended Responses

The open-ended questions regarding working in groups versus working alone on homework drew the most responses of any of the open-ended questions. At least 60% of the survey respondents commented on at least one of the four questions in some form. Table 7-13 shows the number of instructors who commented on each of these survey items.

Table 7-13: The number of open-ended responses for the four items in Section 3: Group work.

Open-ended group work items	Number of responses
Benefits of working alone (Q15)	41

Drawbacks of working alone (Q16)	38
Benefits of working in groups (Q17)	38
Drawbacks of working in groups (Q18)	41

To analyze the open-ended responses, I performed a horizontal analysis similar to that for the interviews. I first numbered the open-ended responses from each of the questions for reference. Since the responses were already categorized by which of the four questions they were associated with, I then made a list of the ideas stated in the responses and recorded the numbers of the responses that included that idea. Some responses contained several ideas. For example, response 19 to Question 18 on the drawbacks of working in groups was, "reliance on others. Different paces of thinking. Different approaches of solutions, can be distracting. Can build false confidence." This response was coded as "Unequal participation," "False confidence (understanding)," "Inappropriate pace," and "Distraction." Table 7-14 lists the ideas found in each of the categories and gives the number of responses containing that idea.

Table 7-14: The ideas from the open-ended comments in Questions 15-18 regarding benefits and drawbacks of working in groups and working alone. The number in parenthesis refers to how many comments included that idea.

Benefit	Drawback

Group	Discussion of ideas (15) Hearing other perspectives (multiple approaches) (9) Comradery (social) (8) Productive time (5) Practice teamwork (job skill) (4) Everyone benefits (3) Harder problems (3) Better Understanding (2) Enjoyable/Fun (2) Focus on principles (1) Self-efficacy (1) Works best for some (1)	Inequal participation (18) False confidence (understanding) (6) Copying (cheating) (5) Don't learn for self (carried along) (6) Bad group dynamics (4) Distraction (4) Inappropriate pace (3) Social doesn't benefit everyone (2) Scheduling problems (1) Voicing dissent is hard (1) Bad for weak students (1) Reinforces bad habits (1) Prisoner's dilemma (1)
Alone	Responsibility/Ownership (9) Confidence (7) Understanding of work (7) Test practice (6) Pace (5) Works best for some (4) Learn valuable skills (4) No Scheduling (2) Better focus (1) None (1)	Stuck (14) No ability to talk or listen (13) Discouraged/frustrated (11) Time (inefficient) (6) Don't know reasons (2) Give up (2) Less practice (1) Less disciplined approaches (1) No sense of community (1)

7.4.6 Discussion of Results

7.4.6a Benefits of group work

The greatest benefits for group work were related to discussion among students regarding physics principles. This is also reflected in the responses to items in Question 13 regarding discussion and the sharing of ideas (see Table 7-10). Although discussion may seem like an obvious product of group work, the deeper connotation is that instructors believe that discussion of ideas between students is valuable. Discussion was posed both as talking to others and hearing from others, and there were indications that instructors believe both are valuable to a large majority of students. Discussing ideas was also mentioned in 24 out of 41 comments in Question 17 (combining "Discussion of ideas" and “Hearing other perspectives”) which asks about other benefits of working in groups (see Table 7-14). This redundancy of answers further supports the idea that instructors believe that discussion of physics problems is valuable for students.

The next greatest benefit of working in a group is not getting stuck (see Table 7-10). This is consistent with the popular response that getting stuck is a drawback of working alone (Table 7-14). However, not all instructors view getting stuck as a negative. For some, being stuck leads to spending time productively struggling and figuring more out by thinking and trying something. On the other hand, getting stuck can also lead to frustration and giving up which is ultimately unhelpful.

Overall, judging from the results of Questions 13 and 14, a large percentage of instructors agreed that group work is beneficial for most students. However, several comments from Question 17 specified that “good” group work is the key to unlocking its benefits. Many endorsements of group work were paired with statements such as “If done correctly…,” “If a group is managed…,” or that “the group truly work together.” However, there were no comments on the survey elaborating on what instructors thought were characteristics of a well-functioning group.

7.4.6b Drawbacks of working in a group

Despite the lack of comments on that characteristics of effective groups, many instructors did comment on what they saw as a characteristic of an ineffective group. Their biggest reservation is that groups can lend themselves to inequal participation. This may be more about lost opportunities for students to understand and wrestle with the concepts on their own. While responses to Question 14(5) seemed to indicate that students' personal understanding wasn't a major concern (discussed in section 7.4.4), 15 of the open-ended comments did allude to student understanding (False confidence [6], Don't learn for self [6], Inappropriate pace[3]). Perhaps instructors saw this as detrimental because it can leave students worse off than they were before either by having a false sense of confidence that they know more than they do or feeling more alone and isolated because other students seem to be understanding the material when the student is lost. There is no indication from the comments or responses that these drawbacks overshadow the overall benefits, however. It is more of a concern that students are aware of the pitfalls and work to avoid and minimize them.

7.4.6c Benefits of working alone

Although this research question is focused on instructors' beliefs about group work, there may be insights to be gained from instructors' views about the benefits of working by oneself. Even though there were no beneficial outcomes in Question 13 that instructors thought were more likely when students worked alone than when they worked in a group, 73% of instructors rated working independently as "useful" or "very useful" in Question 11. In Question 15 regarding the benefits of working alone, instructors said that time to think at one's own pace was valuable and could easily be lost if one were to work in groups all of the time. Even with the strong positive response to group work, we cannot ignore the importance and value placed on working alone.

7.4.6d Drawbacks of working alone

As was mentioned earlier, the biggest drawback instructors cited in Question 16 for working alone was the potential for a student to get stuck (see Table 7-14). While time spent thinking about the problem and struggling productively is viewed as a positive thing, there is the potential for students to not move beyond the confusion. Instructors noted in their comments that this can lead to frustration, be very isolating, and ultimately cause students to give up. This leaves students in a bad place but not necessarily worse off than when they started as could be the case for some drawbacks of group work.

The second biggest drawback of working alone cited by instructors was not having the ability to talk about their own ideas or listen to others' ideas. This could be interpreted as a potential solution to the problem of getting stuck and being unable to move on.

7.4.6e Best to do both

While the results of these survey items clearly show that instructors believe that group work can be beneficial to most students, the fuller picture is that they believe that it is best to have both. In Question 11 where instructors were asked to rank the usefulness of student behaviors, 82% and 73% of the instructors ranked working in groups and working alone as "useful" or "very useful," respectively. This is most clearly expressed in the open-ended comments and how the benefits and drawbacks of each balance each other. While working in groups, students can get pulled along and without fully understanding what is going on, but that can be counterbalanced by working by oneself. While working alone, students can get stuck and not be able to move forward, and this can be addressed by having other people with whom to exchange ideas.

Unfortunately, the interviews and the survey were not designed to get instructors' ideas about how students would, ideally, pair working in groups and alone. One instructor suggested that students start by working alone and then come together for discussion while another suggested exactly the opposite. Either way, the perceived benefit of doing both seems to outweigh the benefit of only doing one.

7.4.7 Summary of group work

Group work is valued by a strong majority of physics instructors. The greatest benefit indicated from the responses in the discussion of ideas, both expressing ideas and hearing from others. Other benefits included lessening frustration by usually being able to work through problems as opposed to giving up, as well as having a social aspect. Instructors do have reservations about group work in the ways that it may hinder learning. The greatest reservation was that everyone in the group was not contributing equally. Some instructors seemed more concerned that the distribution of work was unequal while others seemed concerned that unequal participation would translate into lesser understanding of the material for the students who were not contributing as much. Benefits of working alone were also expressed in the responses and there is reason to believe that instructors value both because there are benefits and drawbacks to each. These data strongly support the idea that instructors believe that group work is beneficial; however, this does not necessarily incorporate the complete picture of beliefs about how to incorporate both group and individual work.

7.5 Exploratory Factor Analysis

I performed an exploratory factor analysis on the survey results as a check for the statistical coherence of the survey itself. A factor analysis is a statistical test that can be performed with surveys with an adequate number of respondents to test for underlying variables in the survey. This can be done as a confirmatory factor analysis or as an exploratory factor analysis. I use it here as the latter. The purpose was to see which questions in the survey had responses that were correlated. Since some survey items were constructed purposefully to triangulate instructors' beliefs, it is expected that the responses to those questions should be correlated. Given that a factor analysis itself is a purely statistical test, unexpected correlations may also be observed between items that do not have any obvious relationship. This is where the researcher can make a determination about any underlying connection between the questions.

The statistical program R was used to run a factor analysis on the survey data. Because of the variety of questions on the survey, I chose to only include a subset of the survey data since certain types of questions do not work well with this type of analysis. The questions that were analyzed were 8, 9, 10, 11, 20, 22, and 25. These questions were single-answer, forced-choice and contained a total of 47 individual responses.

I excluded the first five questions asking instructors about the type of homework they gave, the entire section regarding group work, and all the demographic questions at the end of the survey. I also excluded the three forced choice questions that asked the instructor to choose a number of options from a list.

To determine the number of factors to include in the analysis, I examined the scree plot (Figure 7-5). This technique was developed by Cattell (1966) as a way for choosing the number of factors to include (Costello & Osborne, 2005). While there can be some ambiguity in determining where the "elbow" of the graph lies, it is fairly clear in this data set and led me to use seven factors. Significant factors have 4 or more items loading on them with coefficients greater than 0.4 (Costello & Osborne, 2005; Russell, 2002). This analysis showed the six of the seven factors that included 4 or more items from the survey and had loadings of > 0.4.

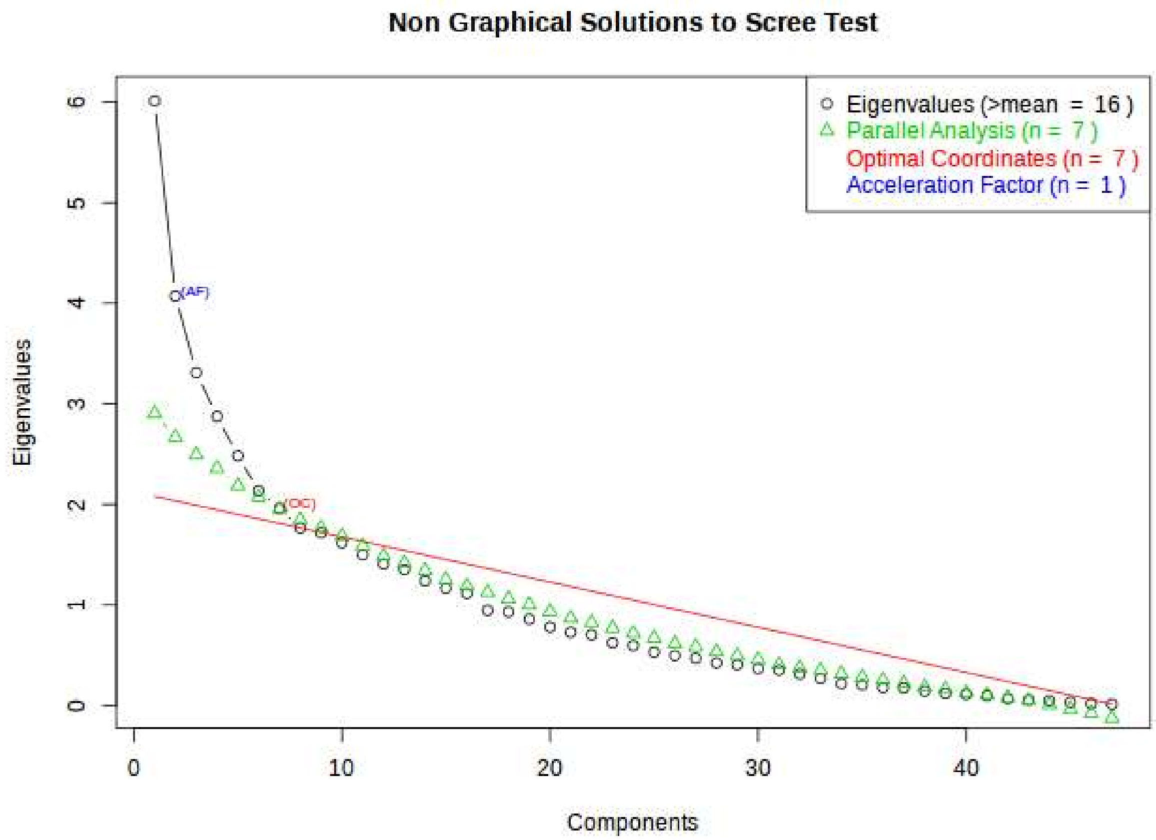


Figure 7-5: Scree Plot- The Scree Plot is used to determine the number of factors considered in the factor analysis. The Optimal Coordinates and the Eigenvalues overlap on the 8th component, so I chose to use 7 factors in the analysis.

Interpreting the factors, especially in an exploratory factor analysis is admittedly subjective. One looks at the items and that are included in the factors to see what their relationship is. In the case of the survey, I am using the exploratory factor analysis primarily as a validation measure of the survey because I intentionally wrote overlapping and triangulation items. This analysis is used to confirm that those triangulation items were effective. It also showed correlations of other survey items that were not intentional but can be used for insight into how the survey worked. The factor analysis does not allow for a description of the factors, except through interpretation of the items which were loaded onto the same factor. I have named the six factors as follows—Principle Factor, Approach Factor, Resource Factor, Write down Factor, Equation Factor, and Miscellaneous Factor. Table 7-15 gives a short description of the factors with the items that loaded onto them. The complete list of factors with loadings and individual items with topics can be found in Appendix E.

Table 7-15: Factors- This table lists the factors found in the exploratory factor analysis. It contains the name of the factor, the total number of survey items loadings onto the factor, the number of common items and topic, and the number of miscellaneous items and topics.

Factor name	Total items loading	# of common items	Common topic	# of misc. items	Misc. topics
Principle factor	7	5	Physics principles	2	Homework-necessary
Resource factor	5	4	Utilizing resources for learning	1	Draw Picture
Write Down factor	6	4	Things that should be recorded	2	- Ask for help - Think about process
Approach factor	5	3	Strategies for solving	2	- Stop when stuck - Pick coordinate system
Equation factor	4	3	Equation relationships	1	Write down information
Miscellaneous factor	4	0	---	4	- Spend time when stuck - Try anything related - Have initial strategy - Be systematic

The strongest three factors are Principle factor, Resource factor, and Write Down factor. These all had 4 or more common items which loaded onto them. The weakest factor was the Miscellaneous factor because there was no obvious relationship among the loading items. However, it is not unexpected for an exploratory factor analysis to show relationships that do not have any obvious connection. Having three factors that had four or more common items whose responses were expected to show correlation is consistent with the writing of those items for triangulation purposes and provides one type of evidence for the validity of this use of the survey instrument and of the data collected.

7.6 Overall Summary of Survey Results

Physics instructors are in agreement across the population surveyed that learning physics principles and how to apply them is the main goal of learning and that homework is important to success in learning physics principles.

Physics instructors are also largely in agreement on the activities and mindsets that are necessary and useful for using homework to arrive at that goal. The activities and mindsets presented for scoring to the instructors provided a succinct, inclusive list of items that instructors want students to use when doing homework. The lack of common additional suggestions from the survey respondents indicates that this list encompasses the majority of these activities and traits needed when solving problems for homework.

There is some support for the idea that there are distinct groups of instructors in the view of how these activities should be framed. However, no strong distinction was found in how the different groups answered other questions on the survey. One reason for this could be that there is a spectrum of beliefs and a survey that was written to detect discrete categories will miss the finer distinctions of instructors.

Finally, physics instructors overwhelmingly believe that working on homework in groups can be beneficial to most students. The largest benefit is the ability to discuss ideas and the solution process with other. Most physics instructors have at least one or two reservations about group work, the most common being that there tends to be an imbalance of work within the group. There is also evidence to suggest that instructors believe that students working both alone and in groups would be the best solution to the benefits and drawbacks of each.

Chapter 8: Conclusion

This chapter summarizes the findings of this work, suggests extensions of the research, and discusses implication for the field of physics education research.

8.1 Conclusions from the study

8.1.1 Research question #1

1.1 *What do physics instructors believe students learn by doing homework?*

While understanding physics principles and learning problem solving have long been cited as the goals of physics, there has not been a study of this kind where instructors have explicitly identified these as the main goals of a physics course. The knowledge base regarding instructors' ideas about homework have largely come from the research surrounding research-based homework methods (Ding, 2011; Heller & Reif, 1984; Leonard, Dufresne, & Mestre, 1996; Mestre et al., 1993; Ryan et al., 2016; Singh, 2008a, 2008b; Yerushalmi & Magen, 2006). Homework is assumed to be a common component in physics courses, but the reasons for assigning it have been left implicit or assumed as common knowledge, rather than investigated. This study provides evidence that the main reason physics instructors assign homework is to help students understand and apply physics principles. This is not a surprising result, but it is an empirical one. In the interviews, more than half of the elements in the Think/understand category contained either "concept" or "principle" as the object of thinking or understanding. This was supported in the survey results in two ways. First, survey items that address physics principles were ranked overwhelmingly highly. Second, the most commonly selected reason for giving homework was "practice applying physics principles in a variety of situations."

1.2 Is homework necessary for success?

Physics homework is ubiquitous in physics courses, though the reason may simply be that because it has always been done, it must have value. Studies have shown that traditional homework composed of end-of-chapter problems does not necessarily (and often does not) improve students understanding of physics principles (Ding, 2011; Pak & Kim, 2002; Singh, 2008a, 2008b). Regardless, my results show that physics instructors believe that homework is necessary for most students to be successful in their classes. There are three pieces of evidence from the survey that support this claim. First, in Question 8, $77 \pm 5\%$ of physics instructors agreed that homework is necessary for student success. Second, in Question 9 physics instructors said that on an average $85 \pm 13\%$ of the students in their courses needed to do homework in order to be successful. Third, from Question 2, $90 \pm 4\%$ of physics instructors required homework in their course in some form.

This work does not address *why* physics instructors believe that homework is valuable. There may be a mismatch between instructors' beliefs and the research literature on this point using the assumption that most instructors use EOC-type homework problems (Ding et al., 2011). However, this study did not investigate any alignment between what instructors say their goals are with what success in their classes means. If the assessments of the course do not actually require students to understand physics principles in order to be successful, then there is a mismatch between the instructors' stated goals and being successful in their course. For example, Eric Mazur at Harvard University has related how he discovered that students in his class were succeeding (getting A's) without understanding physics concepts at the level he desired (Mazur, 1997). Regardless, physics instructors believe that doing homework is a necessary part of the process of learning, and the survey results also suggest that they believe that doing more homework would improve students' understanding.

1.3 Is homework sufficient for success?

Physics instructors are less inclined to think that doing homework is sufficient for success in their classes. On Question 8 of the survey, only $41 \pm 6\%$ of physics instructors agreed that homework was sufficient for students to succeed in their class. Fifty-nine percent said they only "somewhat agreed" or "somewhat disagreed" that doing homework was sufficient. There seems to be reluctance to support the idea that simply doing all the homework, even with a serious effort, would necessarily lead to success in the class.

Saying that doing homework is insufficient for success may be based on several reasons. Perhaps the instructors have had students who were highly motivated to work and learn, but insufficient academic preparation resulted in them not succeeding in the course. The instructors may have more conditions in their mind about what "doing all the homework" truly means in the sense of solving all the problems are tried, having all questions about them addressed and resolved, and spending sufficient time on it. Having more information about the experiences that the instructor has had in their teaching career may provide more insight into what the instructor believes is sufficient for success in their course.

This raises a question about just what are the additional things that physics instructors believe students must to do be successful in their physics courses. They may believe that more homework is necessary, even more than they currently assign. They may believe that a certain skill level in a prerequisite math course is required or that students must perform more basic exercises before solving problems. Knowing to what factors instructors attributing a lack of student success can give valuable insight into their reluctance to adopt RBIs in the form of research-based homework problems.

Addressing this issue may be very complex since physics instructors develop their beliefs partly through experience. If instructors have their own explanatory reasons for the results they see in their courses, there is little reason to change them. If they haven't felt like their own solutions to the problem have been tried, they have little reason to completely give up on their beliefs.

8.1.2 Research Question #2

2.1 What do physics instructors believe students should do when doing homework?

The results of both the interviews and the survey are consistent with the idea that there is a limited number of types of actions that instructors believe students should be performing while solving problems and also that there is broad agreement on what these actions are.

Support for this claim comes both from the interviews and from responses to survey Questions 11, 12, 22, and 23 where instructors largely agreed on the usefulness and importance of various problem-solving activities. Additionally, the small number and lack of common responses in the open-ended questions 24 and 26 show that the lists of activities in those previous questions were considered reasonably comprehensive by a majority of instructors.

The fact that the list of problem-solving tasks is bounded supports the idea that physics instructors are uniform in some aspects of their pedagogy. This makes feasible endeavors such as creating computer coaches to support student problem-solving that are attractive to a large fraction of instructors (Ryan et al., 2016).

2.2 Are there distinct views on how the instructors view the activities of problem solving? What are the ways that instructors frame problem solving to their students?

Previous research on the interviews made the claim that there were two distinct problem-solving conceptions held by the vast majority of physics instructors (Kuo, 2004). (Here, I neglect the "artistic" problem-solving framework described by one instructor that seems to be rare.) My own analysis of the interviews supports this claim. Some instructors emphasized specific procedures with prescribed steps for how to solve problems and some instructors emphasized an open-ended approach to solving problems that involved taking the problem, its goal, and the tools available to reach that goal all into account when solving problems. I have termed these two frameworks algorithm-focused and open-approach.

From the way the instructors talked about helping students solve problems in the interviews, it seems as if an algorithm-focused instructor would most likely present steps of a procedure that would either generally work for most physics problems or a specific procedure for each kind of problem. In contrast, an open-approach instructor would encourage students to ask themselves certain questions as they solve problems, with an emphasis on using the goal of the problem and known physics principles as a guide to decision-making. Performing steps in a pre-determined order would not be necessary.

Do two categories fit the population, or is there evidence for more?

From the interview analysis, I proposed this elaborating question that would look for a finer-grained distinction within the open-approach framework. The reason for this was from interviewees that seemed to place an emphasis on questions students should ask themselves as they are solving problems. This group did not necessarily warrant a third category, especially not one that was separate from the open-approach framework, but it did seem like a distinct sub-set within the framework.

One of the things that I tried to test with the survey was whether there was evidence for more than just two categories or frameworks for problem solving. This was based on what seemed to be a distinct view within the open-approach framework that focused distinctly on the cognitive activities of students while they were solving problems. I found that two categories are not a sufficient description for the problem-solving frameworks. Rather, there is evidence to suggest that physics instructors fall on a continuum of problem solving ranging from having a very specific procedure to give students to the other end which is letting the students figure out their own approaches. This is shown in both what we did not see in the responses to the survey as well as we did see. If instructors were best described by categories, we would expect to see distinct divides in how they answered certain survey questions, and this was not the case. Instead, the survey responses showed some tendencies for groupings among instructors but not strong categorical divisions.

2.4 What are some distinguishing characteristics of the categories of instructors with regard to how they view the activities and mindsets of problem solving?

While this study does not provide strong evidence for distinct characteristics of physics instructors, there are weak indications from this data to show characteristics of different parts of a continuum. This is seen in the responses to Question 25 that showed that instructors regarded giving students different problem-solving approaches as valuable. When asked to choose the most important thing to give students in problem- solving, $41 \pm 8\%$ chose a procedure, and $57 \pm 11\%$ chose a more open-ended approach. Moreover, the five choices represent degrees of adherence to an algorithm-focused framework versus an open-approach framework. The choices ranged from very strict procedure approach to a completely open approach where the students find their own methods. Most instructors chose the middle options that allows for some amount of shifting among the options. See Figure 8-1 for the distribution of responses to Question 25.

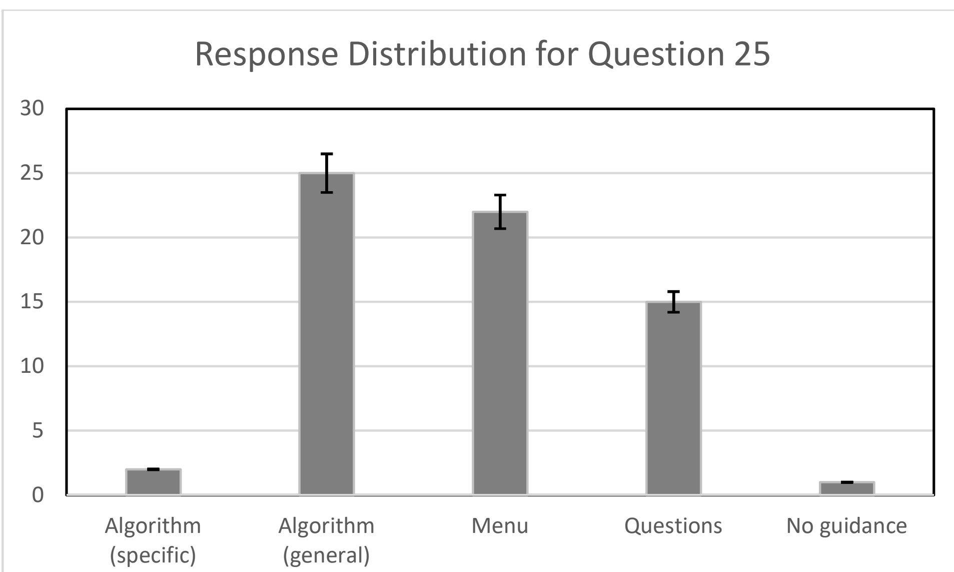


Figure 8-1: Graph shows the distribution of responses to Question 25 with the choices arranged in with a continuum interpretation.

Question 21 was meant to be a triangulation for seeing characteristics of a categorical distinction. There were 3 choices out of seven that were meant to align best with algorithm-focused and open-approach frameworks respectively. The results showed that the respondents who self-selected into the algorithm-focused or the open-approach group chose 2 out of 3 of the expected responses. The overlap of choices between the groups on other questions is the strongest indication that a continuum-model is likely a better fit than the categorical model of instructors. More work must be done to better characterize instructors' frameworks on problem solving.

8.1.3 Research Question #3

3.1 To what extent do instructors believe solving problems with others is beneficial to student's learning?

Although this study addressed only group work that occurred outside of class rather than in organized class activities such as lab or problem-solving groups, physics instructors overwhelmingly believe that working on homework in groups will benefit most students. On Question 19 of the survey, 88$\pm$4% of physics instructors responded that they believed working on homework in groups was beneficial to students. Similarly, on Question 11, 82$\pm$5% of physics instructors rated working in groups as useful or very useful for students.

However, instructors do not view working in groups as a panacea. While the general view of group work is very positive, most instructors also have at least one reservation about students working in groups. In survey Question 14, which posed 6 possible positive and negative outcomes of working in groups, 79$\pm$5% of instructors associated group work with at least one of the negative outcomes. Additionally, there were 41 comments on Question 18 regarding the drawbacks of working in groups.

It is useful to compare instructors' views on working in groups with working alone. On survey Question 11, 72$\pm$5% of instructors rated working alone as useful or very useful, close to the same fraction that did so for working in groups. Furthermore, in Question 13, half or more of the instructors said useful activities such as trying something before asking questions and looking for external resources were more likely to take place if a student was working alone as opposed to in a group. In the open-ended question regarding the benefits of working alone, 41 instructors made a positive comment. Thus, instructors believe that working alone also has value and should not be sacrificed for working exclusively in groups.

3.2 In what ways do instructors believe group work can be helpful or not helpful to a student's learning?

Instructors believe that working in groups is a good way to facilitate discussion about problems, which they see as valuable to student learning. In the interviews, several instructors indicated that they thought that working in groups was vital to the success of the students. The answer to survey Question 13 also shows that 90$\pm$4% or more of instructors believed that discussing ideas, seeking out other ideas and discussing the problem-solving process was more likely to happen when working with others. There was an implicit assumption in this question that such activities were beneficial for students and there was no explicit questioning of this assumption from the survey respondents. These benefits were reiterated in the open-ended Question 17 where the benefit of discussion in student groups was mentioned in 24 out of 41 comments. While some instructors highlighted the social aspect of working in groups, these responses show an underlying value placed on what students say or hear while they are working on homework.

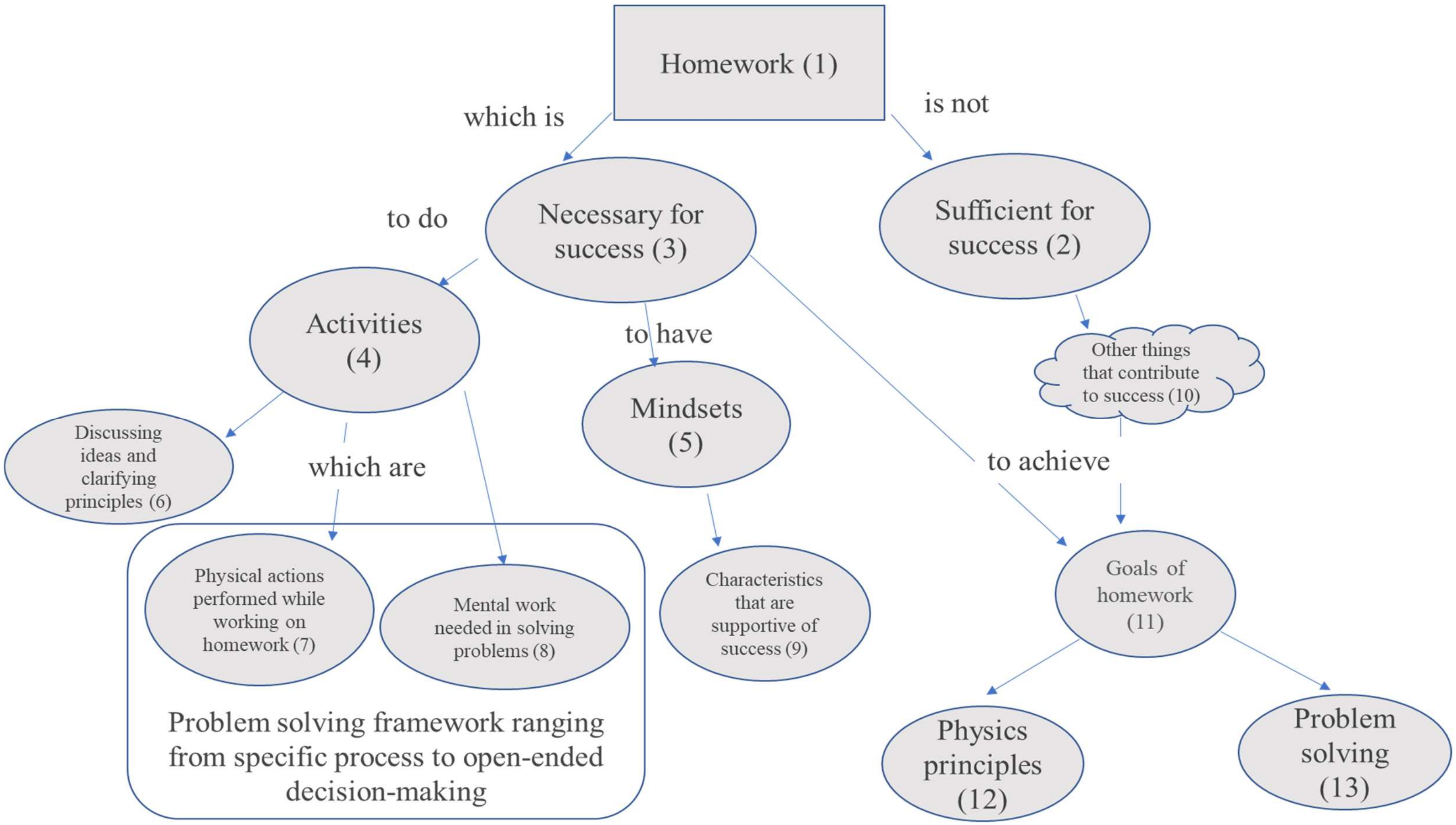


Figure 8-2: The concept map of the Refined Explanatory Model for Homework. The words in clouds represent potential connections to Homework but not elaborated in this study. The numbers in parentheses are to aid in the description of the model in the text.

8.2 Refined Explanatory Model

Based on the results of this study, I propose a Refined Explanatory Model of physics instructors' empirical beliefs about homework which is shown as a concept map in Figure 8-2. As I describe the map, I will use numbers in parentheses to refer to specific parts of the map. The parts of the map in ovals are based on results from both the interview analysis and the survey. The item in the cloud is a potential connection that was identified from the survey responses but was not elaborated in this study.

8.2.1 Description of the Refined Explanatory Model

This study focused on how homework (1) is a way to achieve the goals (11) of the physics course, which are learning physics principles (12) and problem solving (13). Homework (1) is considered necessary for success (3) by physics instructors, although it is not considered sufficient for success (2) by most. What other activities or characteristics (10) could supplement homework to make it sufficient was not elaborated. However, those might include elements such as student preparation, time devoted to study, attending lecture, etc. The specifics of what a student must do or have while doing homework include specific activities (4) and mindsets (5). The mindsets (5) are the characteristics that support success that students must have (9) such as being willing to start over or being patient. The specific activities (4) include physical actions performed while solving problems (7), mental work need in solving problems (8), and discussing ideas or principles with others (6).

The physical actions performed while problem solving (7) and mental work needed in solving problems (8) are comprised on finite number of items that are agreed upon by most instructors. The activities include what students should write down like pictures, given information, plan for solution, etc. They also include what students should think about like the concepts, the goal, and questions they should ask themselves as part of the process. These activities of problem solving are to be viewed within a framework of problem solving (boxed region). This framework is best described as a bipolar continuum. On one end of the continuum, there are instructors who think that problem solving is first about what students do which then informs what they should think. On the other end, there are instructors who view what the students think as the initial step which should then inform what they do. The reason that this is described as a continuum not as categories is because the survey and interview analysis results showed a spread of the population of instructors across these ideas and not a separation into categories.

Table 8-1: This table lists the items from Question 12, 21, and 23 by more than 30% of the instructors. This is not a comprehensive list.

Highest rated tasks (>30%) from Questions 12, 21, and 23
Focus on principles - Select - Apply - Think about
Think about reasons for what is happening
Ask for help
Identify target quantity
Draw pictures
Group work
Keep organized
Be willing to start over
Write down all applicable principles
Solve symbolically before using numbers
Check the reasonableness of the answer

Physics instructors believe that students need to talk about (6) what they are learning, what they understand, and what they are doing, as well as to hear the same from other students, in order to learn and improve in their physics knowledge. This is shown in the overwhelming positive response to group work. Since discussion is only really effective with other people, group work is considered important. There may have been other benefits considered by some physics instructors, but discussion in the number one benefit of working with others.

The mindsets (5) that instructors believe students should have are ways in which the students approach the homework. They are to be patient while doing homework especially when it is frustrating. They need to be willing to try something to see what happens. Then they must be willing to start again if what they try ends up being unproductive. They need to be organized which is a way that the activities are done but not an activity itself. These mindsets are more of an understanding of the process in the sense that the student has reasonable expectations of how the problem-solving process works and is willing to navigate it with an appropriate attitude.

8.2.2 Comparison to IEM and further connections

Because this concept map is based on both a large number of interviews and results of a survey, I can incorporate generalized concepts into the map, rather than just items from specific interviews as was done with the IEM of Work and other concept maps. However, the REM map of Homework (Figure 8-1) is not meant to replace the Work map in the IEM (Figure 2-1) nor be plugged into the IEM. If one were to conduct further research on other aspects of the IEM as I have with one aspect of the Work theme, it is likely that that further research would result in significant restructuring of the IEM. For example, in this study, I have made a direct link between doing homework (rectangle (1)) with the problem-solving framework (ovals (7) and (8)). In the IEM, the two principle categories analogous to mine are Work and Solving Physics Problems, which have no connecting path. It is important to remember, however, that the IEM was never meant to be used as a fully-grounded theory, but rather as a draft map to inform further research. With a different overarching research question, the interconnections will shift, which could lead to focusing on different parts of the interviews and different avenues of research. The IEM still provides valuable information into what the connections might be, and the interviews are a good place to begin looking for how physics instructors conceptualize issues related to problem solving.

One possible area for further research is related to my finding that most instructors do not consider doing homework to be sufficient for success in their classes. This begs the question, what else is needed? The IEM can give some insight into this. In the principal category Students Who Can Improve, the original six instructors talked about students' "natural ability." This may include a student's mathematical background, their previous experience with science courses, or their overall academic performance. Instructors may have an idea about the initial state of a student regarding their academic preparation that will give those students the best chance of being successful. Furthermore, the principal category Typical Students shows that these instructors also believe that there are students who could be successful but do not put in the effort or time needed to be successful. These ideas might be related to or connect with the Be/Have theme from in this study.

To gain further insight into the problem-solving framework that instructors have, one could look for statements in the interviews regarding the purpose of lectures, textbooks, and other resources in a course. While this was not directly addressed in the interview protocol, several instructors mentioned these, and they are included in the Look/Listen principal category. Moreover, the Solving Physics Problems principal category is where the linear and cyclic conceptions of problem solving are contained. Although this is a terminal concept map in the IEM, I believe it might be possible to move it to a more central part of the learning process and integrated into the Homework concept map.

8.3 Limitations

All studies are inherently limited. Some of these limitations are a consequence of the phase of the broader research project, and some are unavoidable parts of research.

8.3.1 Limitation of the interviews

The intent of the initial data collection protocol of this research study was to provide a semi-structured interview that focused on various aspects of teaching problem solving, but that was open enough that a wide variety of ideas could be expressed spontaneously. Because interviews are resource-intensive, they are almost always limited in the number of subjects, in this case 30. Furthermore, the 30 interviewees were all drawn from locations within a 2-hour driving radius of the Twin Cities. While there was significant representation from each of the four-categories of institutions- research, associates, private, and state, this does not represent a proportional sample of the instructors in the state. Additionally, there were only two females that were in the pool of interviewees.

The interviewees were volunteers; therefore, the sample was biased towards those who were willing to talk about their teaching practice. Whatever the other implications of this bias, we cannot necessarily expect that the interview sample represents the full range of ideas held by physics instructors, or even physics instructors in the state of Minnesota. Extrapolating the results to physics instructors nationally is not assumed and must be tested separately with a national sample.

8.3.2 Limitations of the survey

There are inherent limitations to surveys that I attempted to minimize, but that will always be present. 1) The population is biased towards those who are willing to take the survey. This could mean that only instructors who were favorably disposed towards physics education research took the survey while others ignored it. The results will not necessarily fully represent the population that is being surveyed. 2) When people self-report on their behavior, there could be factors that would cause them to not report accurately. Some of these include not being self-aware about what they actually do and wanting to believe something they do not, or the impression that the questions are making value judgements and wanting to choose what they perceive the "right" answer to be. 3) The interpretation of words, phrases, and questions may be different depending on the individual and not what was intended by the question when it was written.

8.4 Implications for Physics Education

One issue this study highlights is why it is so important to recognize the possibility that different instructors have different frameworks for problem solving. Even though physics instructors may agree upon a finite list of problem-solving actions, they may have diverse reasons and contexts for how they think these actions should be carried out.

8.4.1 Implications for Physics Education Researchers

This study can inform Physics Education researchers by providing a more complete view of the population of physics instructors if they are studying them. The move from a categorical explanation to a continuum representation is useful when studying physics instructors regarding their ideas and beliefs about problem-solving. From this study, we see that instructors might have similar ways of talking about actions students should take in solving problems, but they might have a different idea of the framework that should be used. A researcher should be sensitive to this possibility so as to be able to probe this difference. Additionally, it is important to not just have bipolar categories to describe the population.

This study supports the idea of continuum representation of physics instructors because of the larger population that can have enough statistical evidence to push beyond the individual differences which will show up in interviews. While this study did not have enough information to provide description of instructors based on where they fall on a continuum, it can push beyond the categorical representation by showing that the larger population is not best represented by two or three categories. This categorical representation was useful in showing a bipolar tendency, but it does not fully represent the population. This study informs the field of physics education research by expanding the categories of frameworks for conceptions of how homework is taken up.

8.4.2 Implications for Curriculum Developers

This study can inform how both education reformers and curriculum developers can bridge both the apparent and real divide between research-based instructional strategies and instructors' beliefs and practice. I have discussed what is known about barriers to adoption of RBIS, but it has not been established that instructors believe that these strategies are effective. If there is a fundamental conflict between the foundation of the strategy and instructors' beliefs, there is no reason to expect that they will adopt it or use it with fidelity. For curriculum developers, this knowledge can inform how problem solving is presented to students and even give a variety of problem-solving approaches that could help develop strong problem-solving skills. Understanding the population of physics instructors will allow curriculum developers to better bridge gaps between the curriculum and the instructors' beliefs. When presenting professional development to physics instructors, rather than trying to put people in categories and potentially trying to change the categories into which they fall, a continuum representation has a larger potential for small incremental change and overlap of beliefs. Rather than needing to change beliefs completely, which is very difficult, one can focus more on the positive tendencies of an instructor and support that with teaching strategies that align with research based instructional strategies.

As an example of how this could be used in adoption of research-based homework, the professional development could be created to emphasize the understanding and applying of physics principles which is a main goal for instructors giving homework. There could also be a comprehensive presentation of how this homework is presented throughout a full semester which could address concerns that students are being introduced to something too early without getting a chance to learn how to decipher physics problems or practice what some term "basic skills" such as using and solving equations, vectors, unit analysis, etc. Having this practical approach to introducing a new approach to homework that is responsive to the audience might address some fundamental problems that physics instructors feel are there but might not express.

8.5 Further Research

There are three areas where this research could be further developed—additional analysis of the interview and survey data that has been collected as part of this continuing study, additional data collection using a revised version of the survey, and further exploration of the results.

8.5.1 Additional Data Analysis

The demographic data collected by the survey, including gender, teaching experience, physics degree earned, and type of institution, provides several possibilities for aggregation and comparison among groups using existing data. Some potential research questions are:

1) How is gender correlated with an instructor's problem-solving framework? Are there differences between male and female instructors in the value and importance placed on activities and mindsets for problem solving?
2) How is and instructor's institution type correlated with the value and importance placed on activities and mindsets of problem solving?
3) How is years of teaching experience correlated with an instructor's problem-solving framework? Are there differences in the value and importance placed on activities and mindsets for problem solving based on teaching experience?

8.5.2 Further data collection with the survey

There are several groups of instructors that could be given the survey in order to investigate groups differences among instructors. Some of these groups include:

- High school teachers

- High school teachers of concurrent enrollment classes (i.e. Advanced Placement, International Baccalaureate, College in the Schools)
- Post-secondary instructors from other regions of the U.S.
- Instructors of algebra-based physics classes

Several questions that could be investigated with different populations of instructors are as follows:

1) What are the distinctions in views of homework between high school teachers of concurrent enrollment (college classes taken in high school for dual credit) physics courses and post-secondary instructors? Are there differences between concurrent enrollment teachers and "regular" teachers?
2) Are there regional differences among physics instructors?

8.5.3 Further exploration based on this study

The movement away from a category-based model of instructors to a continuum model still requires exploration for a better understanding of what the problem-solving frameworks incorporate and how they are practically used in a classroom. Having a study that solely focused on this aspect of the research would give greater insight into what are differences in beliefs in problem-solving frameworks. This is best studied by essentially starting the research cycle over with a small number of interviews that have a focus on the way that instructors conceptualize and present the problem-solving process to students. If possible, this could be triangulated with the instructors' lecture notes and observations of several classes with attention given to the problem-solving framework. This would provide more insight into how to create a measure that can be given to a larger population to see how instructors tend to fall on the continuum.

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Appendix A: Interview Protocol

Introduction

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

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

Situation #1 (Example Problem Solutions)

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

> Probing question, if necessary: "How does this work? Do you hand out the solutions, or is there something else that happens?"
>
> "What is your purpose in providing solved examples in these different situations?"

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

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

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

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

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

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

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

Situation #2 (Student Solutions)

Q4: "This situation will deal with written student solutions. We will first focus on grading of student solutions. I imagine you grade students on the final exam and quizzes. What is your purpose in grading the students?

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

Probing question, if necessary: "Why?"

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

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

Q5: "Here are student solutions to the problem that we have been looking at. These solutions are based on actual student solutions from an introductory calculus-based physics class at the University of Minnesota. To save time, we have indicated errors in each solution in the boxes on the page."

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

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

**Record the grades and ranking.

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

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

Q6: "Now I would like to use these student solutions to expand the discussion of aspects or components of problem solving that we started in the 1st situation. Here I'd like to focus on what students actually think or do while solving a problem."

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

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

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

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

Probing question, if necessary (make sure this is answered for all student solutions):

"What is your overall impression of each of these students approaches? What are the most important differences between them?"

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

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

Situation#3 (Problems)

Q7: "In the first two situations we dealt with one problem and talked a lot about what sorts of things a student might need to know or be able to do to solve it. In this situation, we will expand our view somewhat by looking at other ways of asking problems around the same physical situation. There are four new problems."

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

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

Q8: "Different ways of asking problems require different things from students. We would like to use these problems to capture aspects of problem solving that we might not have talked about yet."

"Comparing these problems to the problem that we have been using so far (the

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

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

Situation #4 (Grand finale)

Q9: "Now I would like to combine the things that we've talked about in the last 3 situations. I've written each of the things you thought students might go through when solving a problem on an individual card. I would like to have us talk about these in more detail, but to make it simpler I would first like you to categorize them."

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

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

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

**Write the name of each category on recording sheet.

Q10: "For students who had troubles with each of these categories at the beginning of the course, what do you think they could do to overcome them?"

Q11: "For a student who had trouble with each of these categories, what could you do to help him/her overcome it?"

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

Q12: "I would like to focus on how hard it is for students to improve in the things in each of these categories if they had trouble with them in the beginning of the course?

Please put the cards in order from easiest to hardest for students to improve. Please explain your ordering."

**Write ordering on recording sheet.

Q13: "Which of these things is it reasonable to expect most students to be able to do by the end of the introductory calculus-based physics course? Why?"

Q14: "Next, I'd like to find out where your students are regarding the things you mentioned. Think about a typical calculus based physics course at your school. For each category check the appropriate box that represents roughly what portion of the class can do these sorts of things at the beginning of the course and what portion of your class can do them at the end of the course?"

**Allow Interviewee to fill in appropriate section on recording sheet.

Q15: "I want you to focus on two kinds of students: those who improved things they had trouble with at the beginning, and those who did not. What makes these 2 kinds of students different?"

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

Q16: "Looking down the list of changes of your students during the course, are you happy with your course outcomes? What would need to be different in order for you to be happier?"

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

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

**Notes actions done by the researcher.

Appendix B: Survey correspondence

Initial Information Letter

Sent as an e-mail on April 4-5, 2018 to the physics department contact

Hello Prof. ______,

My name is Mandy Straub, and I am a PhD student working with the Physics Education Research Group at the University of Minnesota(http://groups.physics.umn.edu/physed/).

As part of our ongoing work studying the use of problem solving in teaching introductory physics, we are conducting a survey of postsecondary physics instructors and would love your help and input! Our goal is to provide a research basis for those designing educational materials that instructors will find useful.

Shortly, I will send out the survey link in another email. The survey is estimated to take 15-20 minutes. I am asking you both participate in the survey and to disseminate it among your department. If you have not taught introductory physics or do not wish to participate, please reply to this email with the appropriate comment and I will not send the survey.

If you have any questions about the survey or the study, please contact me at pihla008@umn.edu, Leon Hsu at lhsu@umn.edu, or Ken Heller at heller@umn.edu.

Thank you for your help,
Mandy

Initial Survey e-mail sent May 24, 2018

Dear Head of Physics Department,

Please forward the following to the physics instructors at your institution. Thank you.

Miranda Straub

****

Dear Physics Instructor,

In its continuing efforts to study ways of improving student physics problem-solving, the University of Minnesota Physics Education Research group needs to know your ideas about your student's physics problem solving in your course outside of class time. This entails students working on homework, studying, or any other outside of class activity where your students practice problem solving for your class. We have constructed a survey to elicit your ideas about this. To accurately reflect the span of experiences, we hope anyone who has taught calculus-based physics in the last ten years take the survey.

As you can imagine, the potential population of higher education physics instructors in Minnesota is quite small, so your input makes a difference. Please follow the survey link below and tell us about your student's problem solving outside of class time. The survey is estimated to take 12 minutes.

Homework Survey (link)

This data collection has been approved by the University of Minnesota Institutional Research Board and is part of my PhD research.

Thank you in advance for your help!

Miranda Straub, PhD student

Ken Heller, UMN Advisor

Leon Hsu, UMN Advisor

Homework survey- reminder 1 of 2 sent May 30, 2018

Hello again! Please forward to the physics instructors at your institution.

This is a friendly reminder that if you haven't taken the survey but intend to, now is a great time to do it!

Homework Survey (link)

Thank you to everyone who has already participated! I appreciate your contribution.

For those of you who'd like to know a little more about the study, participants, and questions, keep reading. If not, thanks again!

~Miranda Straub, PhD student

Why homework?

Homework is ubiquitous in physics courses, but there is not much research on why or how instructors give it. Some of the questions that this study addresses are

~ What are the goals for homework?

~ What do instructors expect students actually do when they do homework?

~ What are instructors' thoughts on how homework is best done (i.e. groups, alone, both, with a set procedure, etc.)?

Who is being surveyed?

For this study, we have chosen to only survey instructors who have taught calculus-based introductory physics in the last ten years. We needed to choose a particular class because the goals of homework could vary quite a bit among introductory courses and higher level courses. This survey is being sent to all post-secondary physics instructors in the state of Minnesota plus several institutions in other states. The intent is for this to be given on a larger scale, but we started small-ish for this first study. It's only a PhD right now.

How many instructors are eligible?

Well, that's a question I would love to answer, but might not be able to. From the institutional websites, I was able to determine that there are 43 institutions in the state that offer physics courses. There are about 254 instructors of physics at those institutions.

These are my extreme bounds on the survey population. I will be doing more work to determine how many of those instructors actually teach or have taught calculus-based physics in the allotted time.

Is there anything I can do to help?

Why, yes! The only way I can determine the size of my survey population is through self-reporting of the departments. If you can send me an estimate of how many instructors in your institution have taught the calculus-based introductory course, that would be so very helpful.

As always, let me know if you have questions, and thanks for your help!

Homework survey reminder 2 of 2 sent on June 7, 2018

Hello all!

This is my final appeal for anyone who has not done so to complete the Homework Survey. As long as the link works, the survey is open. It seems that the time to take the survey is running in the 30-minute range. I would say that you shouldn't spend too much time thinking about the questions, but I know my audience…

(Homework Link)

I deeply appreciate everyone who has taken time to share your thoughts and ideas regarding homework. I know you have been thoughtful in your responses, and I'm grateful for your time and effort in this study. I still need responses from all types of institutions (associate's, state, private, large, small, rural, urban, wherever you are). You are part of a unique group, so your thoughts count for a lot!

I would like to say a special thank you to the departments who have a high response rate (listed below).

Lastly, I need to know how many instructors in your department have taught calculus-based physics in order to determine accurate response rates (which is important in survey research). If you could even give me a lower-bound estimate based on your personal recollection, that would be helpful. If you only have one person teaching physics, I can figure it out.

Thanks, and have a happy and productive summer!

Mandy Straub

High-response rates schools*! Special thanks!

College of St. Ben's/St. John's University

Gustavus

Hibbing Community College

Central Lake College

Bethel University

Rochester Community and Technical College

South Central College

*Returned at least one survey and were within one response of full completion as determined by information given about the number of instructors who have taught calculus-based physics.

Appendix C: Survey

Homework survey

This survey asks about your practices and goals for your students while they work on problems outside of the classroom. This type of work is often called homework and can have many different forms. Not all possibilities may be represented on this survey. If you do not see your own practices represented in the responses, please include them in the space provided. The survey has five sections:
1) Defining homework
2) Student approaches to homework
3) Working alone or in groups
4) Your approach to helping students
5) Demographics
Thank you so much for sharing your ideas and practices!

Q1 Have you been the primary instructor of a calculus-based introductory physics course within the last 10 years?

○ Yes (1)

○ No (2)

****If the respondent answered "Yes," they moved on to Section 1. If they "No," they were brought to the last page of the survey.****

Section 1: Defining homework: This Section asks about your homework and the goals you have in giving homework. Here, homework means anything you expect your students to do related to your class outside of class time.

Q2
My homework is (choose all that apply):

- ▢ Required (1)
- ▢ Optional (2)
- ▢ Fully graded (3)
- ▢ Partially graded (4)
- ▢ Not graded (5)
- ▢ Graded for correctness (6)
- ▢ Graded on process (7)
- ▢ Graded on completeness (8)
- ▢ Counted in students' course grade (9)
- ▢ Left to my students to determine (I don't suggest or assign anything) (10)

Q3 Homework in my class consists of (choose all that apply):

- ☐ Problems from a book/text resource (1)
- ☐ Problems from an online source (2)
- ☐ Problems I write (3)
- ☐ Problems from other sources (4)
- ☐ Other (5)

Q4 Please describe any other homework resources you use.

____

Q5 The types of problems in my homework are

	All quantitative (1)	Mostly quantitative with some qualitative (2)	Equally quantitative and qualitative (3)	Mostly qualitative with some quantitative (4)	All qualitative (5)	I don't assign homework (6)
Homework (1)	○	○	○	○	○	○

Q6 The purpose of my homework is primarily to help students (choose up to 2):

- ☐ be successful on my tests/quizzes (1)
- ☐ practice applying physics principles in a variety of situations (2)
- ☐ gain an understanding of physics principles (3)
- ☐ practice general problem solving (4)
- ☐ I don't assign homework (5)

Q7 Other reasons I give homework:

____

Q8 Please rank the following statements according to how much or little you agree.

	Agree (1)	Somewhat agree (2)	Somewhat disagree (3)	Disagree (4)
For most students, it is necessary to do the homework to be successful in my class. (1)	○	○	○	○
If a student seriously attempts all of the assigned/suggested homework, they will gain the understanding of the concepts I expect for my class (2)	○	○	○	○

Q9 Move the slider to the approximate percentage of your students that <u>need</u> to do the homework in order to be successful in your class.

	0 10 20 30 40 50 60 70 80 90 100
(1)	

Section 2: Student approach to homework: This section addresses how useful you think different student behaviors are while working on homework.

Q10

I think that most of my students usually have a useful approach to doing homework.

- ◯ Agree (1)
- ◯ Disagree (2)

Q11 Please rank the usefulness of the following student behaviors:

	Not at all useful (1)	Somewhat useful (2)	Useful (3)	Very useful (4)
Looking for equations that relate known quantities to unknown quantities (1)	○	○	○	○
Deciding on a useful physics principle (2)	○	○	○	○
Using any numbers right away (3)	○	○	○	○
Working with other people (4)	○	○	○	○
Working Independently (5)	○	○	○	○
Following a set procedure given in class or the book (6)	○	○	○	○
Reading the book (7)	○	○	○	○
Solving more than the assigned/suggested problems (8)	○	○	○	○
Spending a significant amount of time on problems even when they are stuck (9)	○	○	○	○
Trying anything that seems related to the problem (10)	○	○	○	○
Thinking about the reason for what they are doing (11)	○	○	○	○

Asking for help if they are confused (12)	○	○	○	○
Comparing their answers with answers available to them (13)	○	○	○	○
Stopping work when they are stuck (14)	○	○	○	○
Spending time learning how to apply the physics principles (15)	○	○	○	○
Reading example problems in the book or other resource (16)	○	○	○	○
Looking for worked-out solutions to similar problems to use as a guide (17)	○	○	○	○

Q12 Given the same list of student behaviors, which do you think are <u>essential</u> for successful physics problem solving (choose up to 5)?

☐ Looking for equations that relate known quantities to unknown quantities (1)

☐ Deciding on a useful physics principle (2)

☐ Using any numbers right away (3)

☐ Working with other people (4)

☐ Working independently (5)

☐ Following a procedure given in class or the book (6)

☐ Reading the book (7)

☐ Solving more than the assigned/suggested problems (8)

☐ Spending a significant amount of time on problems even when they are stuck (9)

☐ Trying anything that seems related to the problem (10)

☐ Thinking about the reason for what they are doing (11)

☐ Asking for help if they are confused (12)

☐ Comparing their answers with answers available to them (13)

☐ Stopping work when they are stuck (14)

☐ Spending time learning how to apply the principles (15)

☐ Reading example problems in the book or other resource (16)

☐ Looking for worked-out solutions to similar problems to use as a guide
(17)

Section 3: Working alone or in groups

This section contains questions about students working on their homework alone or in groups.

Q13

Choose whether you think the following are more likely to happen while working in a group, working alone, equally likely, or unlikely in either case.

	Working in a group (1)	Working alone (2)	Equally likely (3)	Unlikely to happen in either case (4)
The time they devote to doing homework will be spent productively. (1)	○	○	○	○
They think more while doing the homework. (2)	○	○	○	○
They try something before asking questions. (3)	○	○	○	○
They tell other students their own ideas (either immediately or later). (4)	○	○	○	○
They do not get stuck on problems. (5)	○	○	○	○
They are confident in their understanding of the solution process. (6)	○	○	○	○
They know what they did on the homework. (7)	○	○	○	○
They complete their homework. (8)	○	○	○	○
They look for external resources if they are stuck. (9)	○	○	○	○
They seek out other students' ideas (either immediately or later). (10)	○	○	○	○

They discuss the solution process with other students (either immediately or later). (11)	○	○	○	○
They think about the physics principles used in the homework. (12)	○	○	○	○

Q14 Choose which statement you think is more true of your students when they work together on their homework.

	1 (1)	2 (2)	3 (3)	4 (4)	
They discuss the solution process with each other. (1)	○	○	○	○	They only compare final answers.
Everyone contributes when the group is stuck. (2)	○	○	○	○	Only a few students do the work while others watch.
Everyone has a better understanding of physics after the working session. (3)	○	○	○	○	Only a few students understand what is going on.
They spend less time in unproductive struggling to solve problems. (4)	○	○	○	○	They don’t have the chance to struggle productively with the problems.
They don't wait until the last minute to do the homework. (5)	○	○	○	○	They wait until the last minute to do the homework.
They explain the solutions process with each other (6)	○	○	○	○	They just tell each other answers.

Q15 Other benefits you see for working on homework <u>alone:</u>

____

Q16 Other **drawbacks** you see for working on homework <u>alone:</u>

____

Q17 Other **benefits** you see for working on homework in groups:

____

Q18 Other **drawbacks** you see for working on homework in groups:

____

Q19 I think that most students benefit from working in groups.

- ◯ Agree (1)
- ◯ Disagree (2)
- ◯ I have no opinion (3)

Section 4: Your approach to helping students

This section asks about how you as an instructor help students when they are struggling and what you expect them to do while solving physics problems.

Q20

When helping students I advise them to:

	Always (1)	Usually (2)	Not often (3)	Never (4)
Follow the steps of my problem-solving procedure. (1)	○	○	○	○
Try something and see if it works. (2)	○	○	○	○
Have the same strategy to begin every problem. (3)	○	○	○	○
Think about the physics principles involved in the problem. (4)	○	○	○	○
Keep organized. (5)	○	○	○	○
Be okay with starting over. (6)	○	○	○	○
Write down their solution plan before spending much time on the details. (7)	○	○	○	○

Q21 Given the same list of advice, which do you think are the most important (choose up to 3)?

- ☐ Follow the steps of a problem-solving procedure. (1)
- ☐ Try something and see if it works. (2)
- ☐ Have an initial strategy to every problem. (3)
- ☐ Think about the physics principles involved in the problem. (4)
- ☐ Keep organized. (5)
- ☐ Be okay with starting over. (6)
- ☐ Write down their solution plan before spending much time on the details. (7)

Q22 How necessary are each of the following tasks for an average students when solving a physics problem?

	Frequently necessary (1)	Sometimes necessary (2)	Seldom necessary (3)	Never necessary (4)
Drawing pictures or diagrams (1)	○	○	○	○
Writing down all information given in the problem (2)	○	○	○	○
Picking a coordinate system (3)	○	○	○	○
Thinking of multiple approaches (4)	○	○	○	○
Writing down all the steps before doing them (5)	○	○	○	○
Identifying the quantity to be determined (6)	○	○	○	○
Writing down the applicable physics principles in words (7)	○	○	○	○
Deciding which physics principles apply (8)	○	○	○	○
Writing down any applicable equations (9)	○	○	○	○
Being willing to start over with a different approach (10)	○	○	○	○
Relating selected equations to the target quantity (11)	○	○	○	○
Writing down the reasons for major steps in the solution (12)	○	○	○	○

Solving equations symbolically before putting in numbers (13)	○	○	○	○
Being systematic (14)	○	○	○	○
Doing a dimensional analysis of the final answer (15)	○	○	○	○
Checking the reasonableness of an answer (16)	○	○	○	○
Reflecting on the major parts of the solution (17)	○	○	○	○
Thinking about the next steps (18)	○	○	○	○

Q23 Given the same list of tasks, which do you think are essential for an average student solving a physics problem (choose up to 5)?

- ☐ Drawing a picture or diagram (1)
- ☐ Writing down all information given in the problem (2)
- ☐ Picking a coordinate system (3)
- ☐ Thinking of multiple approaches (4)
- ☐ Writing down all the steps before doing them (5)
- ☐ Identifying the quantity to be determined (6)
- ☐ Writing down the applicable physics principles in words (7)
- ☐ Deciding which physics principles apply (8)
- ☐ Writing down any applicable equations (9)
- ☐ Being willing to start over with a different approach (10)
- ☐ Relating selected equations to the target quantity (11)
- ☐ Writing down the reasons for major steps in the solution (12)
- ☐ Solving equations symbolically before putting in numbers (13)
- ☐ Being systematic (14)
- ☐ Doing a dimensional analysis of the final answer (15)
- ☐ Checking the reasonableness of an answer (16)

☐ Reflecting on the major parts of the solution (17)

☐ Thinking about the next steps (18)

Q24 Other tasks I think are necessary for solving quantitative physics problems:

____

____

Q25 Which <u>one</u> of the following do you think is the most useful to give to students in terms of helping them learn from doing homework?

○ A general procedure for solving quantitative problems (1)

○ General tools for solving quantitative problems (2)

○ Questions students should ask themselves as the solve quantitative problems (3)

○ Specific procedures for solving specific types of problems (4)

○ Students should develop their own approach from solving problems (5)

Q26 Are there any other ideas that you would like to share with us about students solving problems?

____

____

Section 5: Demographics

This section contains questions about you, your teaching experience, your department, and your institution.

Q27 Please answer the following questions about you and your institution.

	0-5 (1)	5-10 (2)	10-15 (3)	> 15 (4)
How many times have you been the **primary instructor** of an introductory physics courses? (1)	○	○	○	○
How many times have you taught **calculus-based** introductory physics as the primary instructor? (2)	○	○	○	○
How many times have you taught **algebra-based** introductory physics as the primary instructor? (3)	○	○	○	○
How many times (years) have you been teaching physics in **any capacity** (e.g. TA, other courses, high school, etc)? (4)	○	○	○	○

Q28 At what type of institution are or were you most recently teaching?

- ☐ State (1)
- ☐ Research (2)
- ☐ Private (3)
- ☐ Associate's (4)

Q29 Name of institution

____

Q30 What is the highest physics degree your department awards?

- ○ PhD (1)
- ○ Master's (2)
- ○ B.S/B.A. (3)
- ○ Minor (4)
- ○ None (5)

Q31 What is your gender?

- ○ Male (1)
- ○ Female (2)
- ○ Other (3)

Q32 What is the highest physics degree you earned?

- ○ PhD (1)
- ○ MS (2)
- ○ B.S./B.A. (3)
- ○ Minor (4)
- ○ None (5)

Q33 In which state do you teach (e.g. MN, CA, MO, etc.)?

____

Thank you so much for sharing your ideas and practices with us! We greatly appreciate your time!
Any questions or comments about the survey can be sent to Miranda Straub at pihla008@umn.edu or Leon Hsu at lhsu@umn.edu or Ken Heller at helle001@umn.edu

Appendix D: Survey data

Q1 Instructor in last 10 years (calc-based)	Yes	75
	No	9
Q2 Homework	Required	64 (90%)
	Optional	10 (14%)
	Fully graded	45 (61%)
	Partially graded	21 (28%)
	Not graded	11 (15%)
	Graded for correctness	49 (66%)
	Graded on process	33 (45%)
	Graded on completeness	36 (49%)
	Counted in grade	53 (72%)
	Student determined	1 (1%)
Q3 Homework source	Book/text	61 (82%)
	Online	36 (49%)
	Instructor written	43 (58%)
	Other sources	18 (24%)
	Other	5 (7%)
Q4 Other sources (open-ended)	Comments	23
Q5 Homework type	All quantitative	4 (6%)
	Most quantitative some qualitative	57 (79%)
	Equally quantitative and qualitative	11 (15%)
Q6 Purpose of homework	Success on assessments	15 (21%)
	Practice applying physics principles	54 (79%)
	Understanding physics principles	39 (54%)
	Practice problem solving	36 (50%)
Q7 Other reasons (open-ended)	Comments	31

Q8 Homework is	Agree	Somewhat agree	Somewhat disagree	Disagree
1 Necessary	55 (77%)	15 (21%)	1 (1%)	0 (0%)
2 Sufficient	29 (41%)	34 (48%)	8 (11%)	0 (0%)

Q9 Percentage of students who need to do homework for success		Average	Standard deviation	Lowest	Highest
		85.2%	13.3%	20%	100%
Q10 Students have a useful approach		Agree	Disagree		
		40 (57%)	30 (43%)		
Q11 Usefulness of behaviors		Not at all	Somewhat	Useful	Very
	Look for equations	7 (10%)	34 (51%)	20 (30%)	6 (9%)
	Pick physics principle	0 (0%)	4 (6%)	13 (19%)	50 (75%)
	Numbers first	45 (67%)	20 (30%)	1 (1%)	1(1%)
	Group work	0 (0%)	12 (18%)	36 (54%)	19 (28%)
	Work alone	0 (0%)	18 (27%)	38 (57%)	11 (16%)
	Follow procedure	3 (4%)	36 (54%)	25 (37%)	3 (4%)
	Read book	1 (1%)	19 (28%)	26 (39%)	9 (13%)
	More problems	0 (0%)	9 (13%)	29 (43%)	29 (43%)
	Spend time	13 (19%)	19 (28%)	26 (39%)	9 (13%)
	Try anything	29 (43%)	30 (45%)	8 (12%)	0 (0%)
	Think about reasons	1 (1%)	3 (4%)	19 (28%)	44 (66%)
	Ask for help	0 (0%)	1 (1%)	22 (33%)	44 (66%)
	Compare with other sources	1 (1%)	25 (37%)	34 (51%)	7 (10%)
	Stop when stuck	21 (31%)	38 (57%)	7 (10%)	1 (1%)
	Learn to apply principles	0 (0%)	3 (4%)	29 (43%)	35 (52%)
	Read examples	0 (0%)	16 (24%)	33 (49%)	18 (27%)
	Look at example problems	7 (10%)	35 (52%)	22 (32%)	4 (6%)
Q12 Choose 5 most usefulness behaviors		Number of selections			
	Look for equations	13 (19%)			

	Pick physics principle	57 (84%)			
	Numbers first	0			
	Group work	22 (32%)			
	Work alone	9 (13%)			
	Follow procedure	16 (24%)			
	Read book	12 (18%)			
	More problems	10 (15%)			
	Spend time	18 (26%)			
	Try anything	0			
	Think about reasons	49 (72%)			
	Ask for help	42 (62%)			
	Compare with other sources	7 10%)			
	Stop when stuck	0			
	Learn to apply principles	42 (62%)			
	Read examples	12 (18%)			
	Look at example problems	6 (9%)			
Q13 Positive Outcomes	Outcome	Group	Alone	Either	Neither
	Try something before asking	16 (24%)	40 (60%)	11 (16%)	0 (0%)
	External resources	10 (15%)	34 (51%)	22 (33%)	1 (1%)
	Know homework	12 (18%)	21 (31%)	31 (46%)	3 (4%)
	Think about homework	14 (21%)	18 (27%)	35 (52%)	0 (0%)
	Confident	23 (34%)	15 (22%)	24 (36%)	5 (7%)
	Productive time	14 (21%)	7 (10%)	45 (67%)	1 (1%)
	Think about principles	14 (21%)	5 (7%)	43 (64%)	5 (7%)
	Do not get stuck	37 (55%)	3 (4%)	21 (31%)	6 (9%)
	Complete homework	32 (48%)	2 (3%)	33 (49%)	0 (0%)
	Discuss ideas	61 (91%)	1 (1%)	6 (9%)	0 (0%)
	Seek out ideas	60 (90%)	1 (1%)	6 (9%)	0 (0%)
	Discuss process	62 (93%)	0 (0%)	4 (6%)	1 (1%)
	Positive				Negative

Q14 Positive/ Negative group dynamics	Discuss process	24 (36%)	26 (39%)	17 (25%)	0 (0%)	Compare answers
	Everyone contributes	5 (7%)	16 (24%)	37 (55%)	9 (13%)	Few students work
	Everyone understands better	12 (18%)	40 (60%)	13 (19%)	2 (3%)	Few students understand
	Less unproductive time	9 (13%)	41 (61%)	15 (22%)	2 (3%)	Don't struggle productively
	Don't wait until last minute	14 (21%)	34 (51%)	13 (19%)	6 (9%)	Wait until last minute
	Explain process	18 (27%)	35 (53%)	13 (20%)	0 (0%)	Tell each other answers
Q 15 Benefits- alone (open-ended)	Comments	41				
Q16 Drawbacks- alone (open-ended)	Comments	38				
Q17 Benefits- group (open-ended)	Comments	38				
Q18 Drawbacks- group (open-ended)	Comments	41				
Q19 Group work is beneficial to most	Agree	59 (88%)				
	Disagree	0 (0%)				
	No Opinion	8 (12%)				

Q20 Advise students to do when working on homework		Always	Usually	Not Often	Never
	Follow steps of my procedure	17 (26%)	35 (53%)	12 (18%)	2 (3%)
	Try something	4 (6%)	33 (50%)	22 (33%)	7 (5%)
	Have same beginning strategy	12 (18%)	27 (41%)	24 (36%)	3 (5%)
	Think about principles	56 (85%)	9 (14%)	1 (2%)	0 (0%)

	Keep organized	33 (50%)	25 (38%)	7 (11%)	1 (2%)
	Willing to start over	33 (50%)	26 (39%)	7 (11%)	0 (0%)
	Write down solution plan	9 (14%)	26 (39%)	28 (42%)	3 (5%)
Q21 Pick 3 most important		Count			
	Follow steps of my procedure	27 (41%)			
	Try something	6 (9%)			
	Have same beginning strategy	27 (41%)			
	Think about principles	61 (92%)			
	Keep organized	30 (45%)			
	Willing to start over	27 (41%)			
	Write down solution plan	9 (14%)			
Q22 Necessity of tasks	Task	Frequently	Sometimes	Seldom	Never
	Draw pictures	95 (91%)	6 (9%)	0 (0%)	0 (0%)
	Writing down all information	36 (55%)	28 (43%)	1 (2%)	0 (0%)
	Pick coordinate system	36 (55%)	28 (43%)	1 (2%)	0 (0%)
	Multiple approaches	5 (8%)	48 (74%)	12 (18%)	0 (0%)
	Write down all steps	3 (5%)	34 (52%)	25 (38%)	3 (5%)
	Identify target quantity	56 (86%)	9 (14%)	0 (0%)	0 (0%)
	Write principles in words	10 (15%)	29 (45%)	25 (38%)	1 (2%)

	Decide which principles apply	56 (86%)	8 (12%)	1 (2%)	0 (0%)
	Write any applicable equations	35 (54%)	27 (42%)	3 (5%)	0 (0%)
	Being willing to start over	14 (22%)	50 (77%)	1 (2%)	0 (0%)
	Relate equations to target quantity	38 (58%)	23 (35%)	4 (6%)	0 (0%)
	Write down reasons for steps	14 (22%)	33 (51%)	18 (28%)	0 (0%)
	Solve symbolically before numbers	32 (49%)	26 (40%)	7 (11%)	0 (0%)
	Being systematic	46 (71%)	18 (28%)	1 (2%)	0 (0%)
	Dimensional analysis	31 (48%)	27 (42%)	7 (11%)	0 (0%)
	Check reasonableness	52 (80%)	11 (17%)	2 (3%)	0 (0%)
	Reflect on solution	28 (43%)	29 (45%)	7 (11%)	1 (2%)
	Thinking about next steps	24 (37%)	34 (52%)	7 (11%)	0 (0%)

Q23 Choose 5 most essential tasks	Task	Count
	Draw pictures	57 (88%)
	Writing down all information	19 (29%)
	Pick coordinate system	15 (23%)
	Multiple approaches	1 (2%)
	Write down all steps	0 (0%)
	Identify target quantity	47 (72%)
	Write principles in words	3 (5%)
	Decide which principles apply	51 (78%)
	Write any applicable equations	22 (34%)
	Being willing to start over	10 (15%)
	Relate equations to target quantity	14 (22%)

	Write down reasons for steps	3 (5%)			
	Solve symbolically before numbers	20 (31%)			
	Being systematic	20 (31%)			
	Dimensional analysis	9 (14%)			
	Check reasonableness	22 (34%)			
	Reflect on solution	4 (6%)			
	Thinking about next steps	1 (2%)			
Q24 Other necessary tasks (open-ended)	Comments	11			
Q25 Most useful for students learning physics	Approach	Response			
	A general procedure	25 (38%)			
	General tools	22 (34%)			
	Questions to ask themselves	15 (23%)			
	Specific procedure	3 (5%)			
	Develop own approach	1 (2%)			
Q26 Other ideas about problem-solving	Comments	14			
Q27 Demographics-Teaching experience (*years)	Course	0-5	5-10	10-15	>15
	Intro (any)	8 (12%)	11 (17%)	10 (15%)	36 (55%)
	Calculus	15 (23%)	18 (28%)	12 (18%)	20 (31%)
	Algebra	34 (52%)	12 (18%)	9 (14%)	10 (15%)
	Any Physics*	4 (6%)	8 (12%)	7 (11%)	46 (71%)
Q29 (skipped numbering) Name of institution (open-ended)	Comments (give a break down of listed schools)	60			
Q30 Highest physics degree at institution	Degree	Count			
	PhD	17 (26%)			
	Master's	9 (14%)			
	B.S./B.A.	27 (42%)			
	Minor	2 (3%)			

	None	10 (15%)		
Q31 Gender	Male	49 (77%)		
	Female	15 (23%)		
Q32 Highest Physics degree earned	Degree	Count		
	PhD	57 (88%)		
	MS	7 (11%)		
	B.S./B.A.	1 (2%)		
Q33 State	State	Count		
	MN	60		
	MO	1		
	WI	3		

Survey Responses-Open-ended items

Q4 Other sources of homework

Keep a reading journal answering simple questions based on assigned reading.
Mastering Physics
University of Minnesota Computer Coaches
Mastering physics
I have used MasteringPhysics in conjunction with turn in homework, but prefer to have them have all hand written work, problems I write, problems from our book, problems from other books
Mastering Physics
none
We use the MAtter and Interactions curriculum, with Webassign homework.
Mastering Physics
Old textbooks. Current textbook. Old courses, make up myself.
none
Mastering Physics is REQUIRED
Colorado Physics Material
Journal writing where they observe and analyze physics
Pearson's Mastering Physics

Physics in the News, Materials lookups (engineering toolbox, e.g.), Physlet/PHET exploration
only the textbook problems
Problems developed by the senior faculty over time, and shared with the Deaprtment
UMN Context Rich Problems
Webassign
Other books, question banks.
Problems written by colleagues who have taught the course previously
openstax problems via lon-capa (which is FREE!)

Q7 Other reasons for giving homework

Understanding principles through practice is another application
To keep them thinking about ideas, distributed over time, so they can work though the ideas and remember better
practice problem solving
Keeps the brain active in out-of-class time (exercises cognitive functions).
encourage students to form study groups
All 4 of the above purposes are important
In order to have them interact with each other and with the tutors and with the assigned reading
Provide a basis for students to identify their challenges to enrich office hours
Really all of the above (more than 2)
Challenge students in the hope that they will work together and complete the homework more efficiently.
Reflect on impact of physics in life
Gain an understanding of physics principles and practice problem solving.
The other two choices above are also reasons, as is the idea that students need practice translating a written description of a situation into a quantitative model.
we know that practice is important in learning how to solve problems
get feedback on what students are understaning
"time on task"
expose students to new and interesting applications
So that students don't freeze when taking exams
To apply principles in a variety of situations.
to bring the process into focus in our class discussions
Practice is important. Problem solving can only be learned by practice.
Learning by doing is essential for these classes.
Because all four for Q6 should be able to be chosen
to prompt students to read the book

To learn strategies for problem solving applicable to future coursework and real world problems.
Students don't comprehend if they can't model mathematically.
For homework, I want student to actually work on problems (not the straightforward exercises in typical textbooks) and practice writing up strong solutions to these less straightforward problems. The straightforward practice exercises are optional homework that student can get credit for towards their homework grade as homework padding.
To gain an understanding of physics principles (I would have chosen 3 items from the list)
I would have also chosen "gain an understanding of physics principles" if I could choose three from the above list
remind students of mathematical techniques
Force students to practice

Q15 Other benefits to working alone

Avoids scheduling problems
Working along gives better signals to the student on topics they may be struggling with for exams.
They are responsible for themselves. They learn how to overcome obstacles.
Move at their own pace, don't rely on others, have to think through the steps
develop independence and self reliance
Develops more self-efficacy.
none
If everyone is doing the SAME homework, then they first work on it alone and when they get stuck, then they go to tutors or to each other. Best is to have a similar problem in a group, then work on homework alone, but then have a group that has already done the homework discuss together what they are stuck on and how they all did the problem.
A middle of the pack student is more likely to understand what he/she has done IF they succeed while alone or finish the problem alone after talking to others.
Develop patience and self-discipline.
Mimics a test situation
Indepent work builds confidence
Confidence that they can work problem, practice for the exams
Can focus on the material more than socializing.
The individual student has a better understanding when finished.
Some problems are constructed more like practicing free-throws and multiplication tables, and don't benefit as much from group work. Students can try problems on their own and work with a group on those that merit further work.
For more introverted students, working alone, especially when first attempting the homework, is likely to be more productive. A good strategy for such students might be working independently on the problems, then setting up a group meeting where they can discuss their work.
pace is appropriate to their learning
Building confidence and self-reliance that they understand physics principles and can solve problems, responsibility for their own work (ownership)
those who do well, do well more efficiently alone
They will need to take exams alone, so working alone is good "practice."

Learning how to choose a path to start on without someone else's suggestion.
Gives students confidence in their knowledge of principles
Strengthens independent learning, reduces temptation to use study-buddies as a "crutch".
owning the process, logical connection
Confidence in successful work. Own thoughts form own paths.
Self-confidence and self-reliance. Prepares the students for tests and future classes.
Some students will do better on their own: people work differently.
Students take ownership of their work.
Digesting the ideas at a student's own pace instead of the pace of the fastest person in the group.
Best to have both alone and group time.
Students don't convince each other of different wrong ways of thinking about the problem or applicable concepts.
Some students get flustered when working in groups. They feel rushed, and maybe intimidated, and as a result they shut down, or just go along with what someone else in the group is telling them. Some students just need quiet alone time to ponder and dwell on their thoughts at their own pace.
There is a time for working alone and a time to work with others. It's best to work alone until one either thinks they know how to solve the problem, or gets stuck. Then it's useful to talk with others.
They can't rely on the group - they have to do it themselves. Also, this is like the test environment.
They remember what they did
gain independence, self-confidence
Many of our students work 20+ hours/week. Working alone is better than nothing when scheduling is difficult.
An individual knows what they did on the problem, and is less likely to follow someone else work mindlessly.
Better practice for individual exams.
Working at your own pace rather than feeling rushed

Q16 Other drawbacks to working alone

isolating
Students spend time more inefficiently. While working alone identifies knowledge gaps, group work has a better chance filling the gaps.
They likely don't get as much perspective, they get stuck more often, it takes longer and they can't necessarily complete as many problems as well as they could.
No one to talk to or ask questions of, no one to bounce ideas off of, easy to give up
If students are not sufficient on top of the materials and problem solving and if they don't know how to use resources available to them well, they won't be able to go further
Probably induces more frustration. Also, does not develop communication skills.
"right" answer for wrong reason
getting stuck and not seeing other possible approaches to the problem
Getting stuck or using a scattershot approach to trying to solve
Good students who never work with others miss things and/or never have the experience of explaining something to make sure they really understand it.
More likely to become distracted from the task.
Discouragement occurs when they can't solve the problem
Sometimes they get really stuck and cannot get unstuck themselves.
Needing help or input from other students.
Easier to get stuck on a problem
I suppose the complement of above; i.e., that more extroverted students would probably find working in a group first more useful than starting by attempting homework alone.
not enough resources around to solve the problem
More likely to punk out when stuck, don't see alternate routes to solutions, harder to achieve motivation to get lots of homework done at once
those who do not do well, will struggle mightily alone
Easy to get stuck; can be an inefficient use of time if student isn't able to move on to another problem.
Isolation, boredom.
May be able to solve problems, but may not be able to explain the underlying principles
May be less likely to reach out for help, not know when to distinguish productive struggling from unproductive struggling
time consuming, no immediate feedback

If clueless, then it is difficult to move forward.
Discussing problems helps everyone become more familiar with the material.
Students can become frustrated.
No verbalization of the ideas and hearing other people's understanding of ideas.
Students can get stuck, spinning their wheels on something that could be cleared up in just a few minutes after discussing with someone else.
Working alone is good unless one gets stuck and has no idea how to proceed. Then some interaction outside of one's own head is needed.
Get stuck more easily; get frustrated more quickly; don't get the benefit of explaining with others.
Especially for intro students, understanding how other students solve problems can help broaden one's problem solving toolkit
It takes more time
lose any sense of communitarian responsibility
Easier to get frustrated. Talking with people is generally better tan looking for random nonsense on the internet.
It is easier to get stuck, and once they do they might either give up or find solutions online.
Students might feel lost, lacking support.
No immediate reference when "stuck".

Q17 Other benefits to working in a group

deeper understanding
If done correctly, group work will help students (at all levels) learn more and develop skills more.
Ideas get challenged and perhaps updated, perspective is gained, a sense of belonging to the class develops
Discussion, different ideas, brings them back to the principles of the questions
can draw on others' resources, forced to articulate one's ideas
Develop comradery, communication skills.
various approaches to problems
If a group is managed, so that everyone participates, then you get a richer view of the different ways people approach the same problem
A properly moderated group of strong students can solve problems the individuals could not solve by themselves.
Develop teamwork skills.
Can generate rich discussion
Much more enjoyable. Builds commraderie. Solve harder problems successfully
They can work on problems that are much more interesting/challenging.
Everyone can input their own perspective on the problem.
Most members of the group truly work together rather than one person doing it for the group.
These students will work in groups for most of their careers.
These are well covered in the choices and in my answers to 15 and 16.
Industrial feedback consistently suggests employers value team members above loners, seeing alternate paths or thinking towards a solution, reduces frustration upon getting stuck
students can share knowledge, enthusiasm, frustration, and techniques with each other
Peer teaching, seeing other paths for solving a problem
Opportunity to solidify understanding by attempting to explain reasoning to others; comraderie.
Gives students a chance to explain their understanding
immediate feedback, time spent for solving
Sometimes helpful in initial discussion to find the key to a problem. Mutual encouragement through similar confusion.

Reduces the chances that everyone is stuck on a problem.
Students can form social connections.
Hear ideas expressed in words of peers.
Best to have both.
Have the opportunity to explain concepts to their peers to articulate their own understanding
Exchange of ideas, less time stuck on one thing, multiple perspectives for explaining something.
Builds community; more like the work world (teams)
See my response to Q16
They make friends
learn to be articulate about METHOD and not just ANSWERS
Training for future life.
Students can get help, when they get stuck. It is more likelyt that some in the group will find a way to solve the problems.
Students learn how to communicate and organize their thoughts.
Higher self-efficacy.

Q18 Other drawbacks to working in a group

scheduling problems
Bad group dynamics (working separately then compare) are the default state for too many students which leads to bad skill development. A good group model must be provided to students to avoid this behavior.
They don't form all of the skills you need to overcome problems independently.
Easy to get lost, can just copy an answer without understanding, some people do all the work
self involvement can be minimal
Some will always sit back and let others do the work.
if they just copy from others
Some people might think they understand the problems, but they are just being carried along with the group and they never think it through for themselves
My biggest reservation: they reinforce bad habits. Also, the weakest students often lose out, even with careful moderation.
Prisoner's dilemma.
Can marginalize populations
Loss of confidence when stuck working on a test
There are some free riders, but it doesn't seem like too much of a problem.
Not everyone participates.
It's too easy for a single student to just copy procedures rather than understand it.
As above.
some students are really fast (had physics before) and get frustrated at the slow pace of others
Worker vs. slacker dynamics, potential for distraction by social/professional imbalance, if they ONLY work in groups, seems to create a lack of confidence to work independently
students can sometimes get a false sense of preparation and understanding
Easy to sit back and another student do the heavy lifting...
Perhaps difficult to "go against" what others in the group have decided is the right answer.
Some students may be passive observers and copy answers without any understanding
The benefits and drawbacks *really* depend on the people in the group. Some are really good about sharing ideas and strategies and building each other up. Others are more likely to see working together as a shortcut, and can use others as a crutch. So, the list in Q14 depends a lot on the group dynamics.

unfocused discussions, presence of dominant influencer
reliance on others. Different paces of thinking. Different approaches of solutions, can be distracting. Can build false confidence.
Over-reliance on others
Some students will be carried by their group and not contribute. I suspect these students are also likely to not do well on their own, either.
Academic dishonesty and plagiarism could be more likely to occur.
Skipping to an answer so that the group can move forward.
Delays students urgency to understand if others give answers, and gives a false sense of competence
Inadvertently think they understand because someone else's explanation made sense.
Crowding out, or rushing the quiet kids. Constant pressure to interact socially can turn off introverted kids who would otherwise make excellent scientists or engineers.
For Q19, agree when they do it the right way.
Can get off track; sometimes have free riders
Might be easy for "freeloaders" to get by without really contributing/learning
They are less clear on the thought process involved
follow the leader syndrome
You can coast along on other peoples understanding.
It is easy for students to piggyback on someone else's work and not understand the problems.
Weaker students just might copy solutions, not being force to work through problems individually.
Students are more likely to go with the consensus rather than doing something on their own.

Q24 Other tasks that are necessary for solving quantitative problems

Understanding the limitations of each physical model. This is more important than being willing to start over, it actually helps the student to know when the model is not applicable due to complications or missing information.
Explaining why the answer is reasonable, through a comparison or test case.
Categorize your problem as an instance of a class of problems already solved in your book or in class. Same as deciding which physics principle applies, but more practical.
From the above list, I view the ability to identify "equations" (e.g. approach) that one to the quantity to be determined as well as "reflecting on the major parts of the solution" to be very important.
Solving the equations symbolically first.
Being willing to start over if needed. I used up my five choices above.
I assumed that "solving problems" meant "solving them while gaining an understanding of physics," because, as I frequently tell my students, while the final answer is important, at this stage, I'm most interested in seeing their thought process/approach to the problem. In light of that, I actually think that *all* of the tasks listed above are necessary. Perhaps they aren't necessary for every single problem, but, collectively, they are all necessary tasks that students need practice with in order to understand physics.
Reading the directions. I have had more problems with students ignoring the directions over the past two years than anything else.
making sure a consistent set of units are used for each given quantity
Checking the reasonableness of an answer (Picking just 5 was hard...I have 7 in my usual "how to analyze physics scenarios" guidelines).
Compare to a trip: Find where you are on a map (what do you know, sketch), Find where you are going (target quantity), Find a vehicle to travel (what principles apply, equations), go (do math), check if you arrived. Do not just race out of the house and run (chuck numbers into a calculator)!

Q26 Any other ideas to share about student solving problems

None
I feel the usefulness of various things depends on the students wildly, and the details on how they are used. So it's very difficult to answer many of your questions above.
Well, I would like to say that progress is fairly slow. Even after having students for a year in physics class, they struggle. With physics majors in upper-division classes, they pretty much have the diagram, equations thing down, but still want to skip evaluating their answer. By last semester of their senior year, most (80%) are competent at general solution of any quantitative problem. Perhaps this can be attributed to the way texts are written, even at the upper level. Each problem is treated like something "new", and shows up in its own little chapter on a particular topic, so it s hard to convince students there is a general approach that works.
Practice is essential
Practicing similar problems.
I think it's important to let students know that they will be confused at times, that they will move in and out of an understanding of the material, and that this is totally normal. I like to think that this helps at least some students persist when they're struggling (although I haven't collected any real data to support this... ;-)
I am low on the "choose a physics principle" because the problems always relate to the topic being covered. I don't do cumulative tests, so it's not something I emphasize.
It is important for students to recognize that fundamental physical principles and mathematical tools are used to solve seemingly different problems (e.g., conservation of energy applies to problems in mechanics, E&M, quantum, and stat mech).
I emphasize that it's totally OK to not know exactly where they're going at the start of a problem. A lot of students struggle with the idea of "just" starting with a diagram, list of knowns/unknowns, and applicable equations involving those knowns/unknowns, and determining a mathematical plan *after* having those pieces in front of them. Also, I like to talk about "analyzing physical scenarios/situations" as much as "solving problems", to (hopefully) help them move toward thinking about physics as an analytical tool used for open-ended questions.
A conceptual diagram/map that shows steps/processes/stages of problem solving
I don't know where else to put this, but I felt that too many of the answer required an all or nothing type response, where my opinions are more nuanced. I think working in groups can be great, but most students don't know how to do it well. They use it more as a means of getting their work done faster and checking their answer, rather than as an opportunity to develop their understanding of physics. So their approach is much more practical as an efficiency to get the assignment done rather than improving their understanding of physics. So my responses sound more pessimistic than they are, but that is because I work much more intently with my students to use the textbook, group work, etc, more effectively. For example with the doing the samples in the textbook I tell my students that reading the sample problems isn't useful, rather covering up the answer and trying to do the problem on their own, then looking at the book solution after they have tried to do it on their own is a better approach. You options didn't allow me to indicate that.

I think students need to be reminded that physics (especially problem solving) is an intrinsically hard task. It does not come naturally to any of us. It takes a lot of effort, patience, and critical thinking. It is normal to get frustrated and have a hard time of it. A non-negligible part of problem solving is emotion management (keeping your cool, trying multiple things, being willing to swallow your pride and admit when you were wrong, etc).

They do need a certain amount of modeling of the problem-solving process, especially early on.

Problem solving strategies should not be recipes, as very specific recipes might not apply to many types of problems. A general problem solving strategy should be employed. Often, students will find their own strategies that work for them after starting with something generic.

Appendix E: Exploratory Factor Analysis

Factor MR 5- The principle factor

Question	Loading	Topic
Q 8_1	-0.593	Homework-necessary
Q 9_1	0.607	Percent of students-homework
Q 11_2	0.831	Decide on physics principle
Q 11_11	0.720	Think about reason for doing things
Q 11_15	0.440	Spend time learning how to apply physics principles
Q 20_4	-0.591	Think about physics principles involved
Q 22_8	-0.412	Deciding on which physics principles apply

Factor MR 6 Approach factor

Question	Loading	Topic
Q 11_14	0.400	Stop work with they are stuck
Q 22_3	0.514	Pick coordinate system
Q 22_4	0.642	Think of multiple approaches
Q 22_10	0.583	Be willing to start over with new approach
Q 22_16	0.498	Check reasonableness of answer

Factor MR 2 The Resource factor

Question	Loading	Topic
Q 11_7	0.523	Reading the book
Q 11_13	0.408	Compare answers with answers available
Q 11_16	0.733	Reading example problems in book or other resource
Q 11_17	0.688	Look for worked-out solutions to use as a guide
Q 22_1	0.459	Draw picture or diagram

Factor MR7 The Write Down factor

Question	Loading	Topic
Q 11_12	0.562	Ask for help when confused
Q 20_7	0.428	Write down their solution plan before spending much time on the details
Q 22_5	0.585	Write down all the steps before doing them
Q 22_7	0.524	Write down applicable physics principles in words
Q 22_12	0.530	Write down the reason for major steps in the solution
Q 22_17	0.603	Reflect on major parts of the solutions

Factor MR4

Question	Loading	Topic
Q 11_9	0.431	Spend significant amount of time on problems even when stuck
Q 11_10	0.455	Try anything that seems related to the problem
Q 20_3	0.568	Have the same strategy to begin every problem
Q 22_14	0.581	Being systematic

Factor MR 3 The Equation factor

Question	Loading	Topic
Q 11_1	-0.492	Look for equations that relate known quantities to unknown quantities
Q 22_2*	0.575	Writing down all the information given in the problem
Q 22_9	0.706	Writing down all the applicable equations
Q 22_11	0.562	Relating selected equation to the target quantity