Physics Faculty Use of Example Solutions in Teaching Introductory Physics

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This study investigates how physics faculty perceive and use features of example problem solutions. Thirty physics instructors from diverse institutions participated in semi-structured interviews. In addition to open-ended questions, three example problem solution artifacts were used to focus on specific solution features. Data were analyzed to identify instructors’ goals for the use of example solutions and whether their goals were consistent with the solution features that they valued and used. The study concludes that many faculty have three major goals: keeping students cognitively involved, helping students become better problem solvers, and supporting students in learning physics. The study also found that faculty recognize features from different parts of the problem solving process to varying degrees. Features related to the initial problem analysis are well recognized. Features related to solution construction are recognized by about half of the faculty. Features related to checking are recognized by few faculty. In comparison to a prior study of Teaching Assistants’ (TAs) use of example solutions, faculty and TAs are very similar in the features that they notice and their preference for particular features, suggesting that faculty do not naturally become more sophisticated in their sensitivity to or use of features of example problem solutions. Focused professional development is recommended to support faculty in using example problem solutions to meet their goal of helping students become better problem solvers.
PHYSICS FACULTY USE OF EXAMPLE SOLUTIONS IN TEACHING INTRODUCTORY PHYSICS

by

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*Out of the night that covers me,*  
Black as the pit from pole to pole,  
I thank whatever gods may be  
For my unconquerable soul.

*In the fell clutch of circumstance*  
I have not winced nor cried aloud.  
Under the bludgeonings of chance  
My head is bloody, but unbowed.

*Beyond this place of wrath and tears*  
Looms but the Horror of the shade,  
And yet the menace of the years  
Finds and shall find me unafraid.

*It matters not how strait the gate,*  
How charged with punishments the scroll.  
*I am the master of my fate:*  
*I am the captain of my soul.*

- William Ernest Henley- (1849–1903)

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CHAPTER I
INTRODUCTION

Two central goals that physics instructors have for using problems in introductory physics courses are (1) helping students construct physics knowledge (Bereiter & Scardamalia, 1989; Smith, Disessa, & Roschelle, 1993), and (2) helping students develop clear problem-solving skills (Reif, 1995). Since problem solving is often the main assessment tool, Yerushalmi et al. suggested that the form and content of those problems directly impact what students really learn in the course (Yerushalmi, Cohen, Heller, Heller, & Henderson, 2010).

Often, teachers will solve problems to demonstrate to the students how to solve problems of a similar nature. We define the term “example solutions” here as any problem solutions that students are exposed to during the class. For example, solutions that the instructor works on the board during class discussion, example solutions from the textbook and written solutions that the instructor distributes to the students (e.g., test or homework solutions). Example solutions are used by instructors in nearly all introductory physics courses. Example solutions are sometimes given different names in the research literature, such as worked examples (Atkinson, Atkinson, Derry, Renkl, & Wortham, 2000), worked-out examples (Renkl, 1997), instructor solutions (Henderson & Harper, 2009), and example problem solutions (Yerushalmi, Henderson, Heller, Heller, & Kuo, 2007).

In this thesis, we follow Reif’s description the expert problem solving process as a framework for thinking about the structure of example solutions (Reif, 1995). Example solutions have an important role in many research-based instructional
approaches that have been shown to promote clear problem solving as example solutions help students become better problem-solvers (Heller & Hollabaugh, 1992; Heller, Keith, & Anderson, 1992; Mestre, Dufresne, Gerace, Hardiman, & Touger, 1993; Reif & Scott, 1999; Van Heuvelen, 1991). Cognitive apprenticeship (Collins, Brown, & Holum, 1991) underlies many of these approaches. A central role of example solutions in these instructional strategies is “modeling” – explicating the problem solving processes of an expert in a way that students can understand it. Clear approaches to problem-solving have been shown to involve an initial problem analysis, planning of the solution, execution of the plan, as well as ongoing evaluation and refining of the solution process (Chi, Glaser, & Rees, 1982; Eylon & Reif, 1984; Larkin, 1979; Larkin, 1981; Larkin, McDermott, Simon, & Simon, 1980). Reif (Reif, 1995) suggested that expert problem solvers approach problems using a three-stage strategy which comprises: (1) initial problem analysis, (2) solution construction, and (3) checking solution.

The study in this thesis is a continuation of previous research conducted by Lin et al. (Lin, Henderson, Mamudi, Singh, & Yerushalmi, 2012). This previous work investigated the extent to which Teaching Assistants (TAs) value and know how to help students become better problem solvers through the design features in example solutions. This thesis examines how the goal of helping students become better problem solvers is manifested in the considerations of the faculty’s choices of example solutions. Further, we want to compare our findings with the results from the Lin et al. TAs study.

Lin et al.’s study provides a picture of how TAs approach example solutions, but did not investigate faculty. The current study will close this gap and give us information that supplements Lin’s findings. First, we investigated instructors’ goals
for providing example solutions in introductory physics courses. We want to understand the goals in a general context, where the faculty describe their main purposes for providing example solutions, and in a concrete context, where the faculty identify their considerations when comparing three example solutions that reflect different pedagogical views. Second, as Lin et al. had gathered data from TAs, some of who will later become faculty, this study will provide a second point on a possible learning trajectory of instructors’ abilities to successfully use example solutions in their teaching. Differences between the faculty and TAs will be discussed in order to describe possible progression of ideas throughout an instructor’s professional career.

The main research questions in this study are:

1. To what extent is helping students become better problem solvers a goal that faculty have for example solutions?

2. When considering example solutions for their students, to what extent do faculty notice and appreciate design features that the literature perceives as helping students become better problem solvers?

3. How do faculty compare to TAs in their beliefs on applying example solutions in their teaching?

The study in this thesis involves an analysis of interviews with 30 physics instructors who were asked to describe their goals in providing example solutions in several different situations, their beliefs about why it is useful to provide example solutions in a pedagogical sense, and what their actual practices are when they are giving the example solutions in their teaching. The instructors came from a variety of institutions: large state research universities, primarily undergraduate state universities, primarily undergraduate private colleges, and community colleges.
The data gathered from the interviews were analyzed by the author and then discussed with the research group. The analysis involves both top-down and bottom-up approaches. The author was responsible for coding the raw transcripts of faculty interviews using an analysis rubric, and then verifying his interpretation with fellow researcher (Lin). If there were disagreements or possibility of new findings between both researchers, the senior researchers (Henderson & Yerushalmi) were consulted. Discussions continued until consensus was reached. In that way, we fit the data collected from the faculty into the pre-existing analysis rubrics from our previous research on TAs, while still allowing new interpretation to be added into rubrics. Readers are encouraged to check the rubrics we have used in the attachment before proceeding to read the rest of this thesis.

At the time this study was conducted, the author was a graduate student in Physics and Science Education at Western Michigan University. In addition to his formal academic work in physics education, the author has had experiences teaching Physics and Mathematics to students from underdeveloped regions in Indonesia, and has been working with prospective elementary teachers in the United States for several years. He was a member of the research team for the Lin et al. TA study.

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

Charles Henderson: Charles Henderson is a Fulbright scholar and an associate professor of Physics and Science Education at Western Michigan University. His current work is mostly focused the development of theories and
strategies for promoting change in the teaching of STEM subjects. Dr. Henderson also currently serves as the senior editor for the journal, *Physical Review Special Topics - Physics Education Research*.

**Shih-Yin Lin**: Shih-Yin Lin is a PhD student at University of Pittsburgh. She has had extensive experiences with physics TA training and workshop at University of Pittsburgh Physics & Astronomy department. Shih-Yin Lin serves as a teaching assistant for a methods course for physics TAs at University of Pittsburgh Physics & Astronomy department, whose students serve as the population in an TA study that this project directly builds on.

**Chandralekha Singh**: Chandralekha Singh is a professor of Physics at the University of Pittsburgh. Her interest is to identify sources of student difficulties in learning physics both at the introductory and advanced levels, and to design, implement, and assess curricula/pedagogies that may significantly reduce these difficulties. Dr. Singh led a methods course for physics TAs at the University of Pittsburgh Physics & Astronomy department, whose students serve as one population in an accompanying study that this project directly builds on.

**Edit Yerushalmi**: Edit Yerushalmi is a senior scientist with the physics education group at the science teaching department, Weizmann Institute for Science in Israel. A central focus of Dr. Yerushalmi’s work is the development, implementation and research of professional development programs for high school physics teachers in Israel. While a post doctoral research associate with the University of Minnesota Physics Education Research and Development Group, she took part in a research project focused on faculty beliefs regarding the learning and teaching of physics problem solving, that this project directly builds on.

The following provides a brief guide to the remaining chapters in this thesis:
Chapter 2: Literature Review. This chapter provides a review of research relevant to this study.

Chapter 3: Methodology. This chapter presents a detailed description of the methods designed to collect and analyze data for this study.

Chapter 4: Results and Discussions. This chapter presents and describes the findings from both general situation and concrete artifact portions of this study.

Chapter 5: Conclusions and Implications for Practice. This chapter provides a brief summary of the study, relates the findings to prior research, and suggests possible directions for future studies.

Appendices.

Bibliography.
CHAPTER II
LITERATURE REVIEW

This chapter summarizes several lines of research that are relevant to this study. However, this chapter is not meant to be an exhaustive review of the literature. I intend to familiarize the reader with the basic assumptions about problem solving in physics that I take into account when my team and I designed this study and when we interpreted the results at the end.

In the first part of this review of the literature, I will describe the research relevant to helping students become better problem solvers. The second part of this literature review is about the research on learning from example solutions. The third part is a brief summary of the research in faculty beliefs and practices related to the role of problem solving in the teaching and learning of physics. This will include literature related to the development of these beliefs in faculty.

**Helping students become better problem solvers**

There has been substantial work in the context of physics problem solvings in order to help students become better problem solvers. In our study, the term “expert” refers to physics faculty and/or graduate students while "novice" refers to introductory physics students.

From this body of research, we can make several strong claims. The first one is that experts typically employ a systematic approach when solving a problem compared to novices (Heller, 2000; Polya, 1971; Reif, 1995; Van Heuvelen, 1991). For example, experts typically devote considerable time at the outset for re-description of the problem information and developing a representation of the problem (Chi et
al., 1982; Larkin & Reif, 1979; Larkin et al., 1980). This is true whether experts are presented with situations that are similar to problems they have already practiced with, or with novel situations (Singh, 2002). The second case that can be made is that based on this analysis of the problem, experts typically use the relevant information to plan the solution before executing it. (e.g., defining useful subgoals) (Larkin et al., 1980; Maloney, 1994; Polya, 1971). The third claim is that experts devote more time to assessing their solution process (such as implicitly or explicitly asking themselves: what am I doing? Why?), and evaluating their final answers (Larkin et al., 1980; Maloney, 1994; Schoenfeld, 1992).

Research indicates that when instructors explicitly model and encourage students to follow a set of problem solving procedures, students are likely to use it (Heller & Reif, 1984; Heller & Hollabaugh, 1992; Heller et al., 1992; Huffman, 1997; Reif & Scott, 1999; Van Weeren, de Mul, Peters, Kramers-Pal, & Roossink, 1982; Wright & Williams, 1986). Reif terms these procedures as prescriptive models of problem solving (Reif, 1995). One should note that these prescriptive models reflect only some aspects of the actual problem solving process that an expert goes through and leave out other aspects, such as back and force moves where the solver evaluates and corrects their approach to the solution. Instructional techniques that have been used include introducing problem-solving strategies that reflect the implicit problem-solving approaches used by experts, and using real problems (Heller & Hollabaugh, 1992; Van Heuvelen, 1991) that require a higher level of analysis and planning. Scaffolding can be provided to students through the use of a prescriptive problem solving-model (Heller & Reif, 1984; Reif & Heller, 1982; Reif, 1995), by cooperative learning groups (Heller et al., 1992), and by computer-based tutoring (Reif & Scott, 1999).
Most of these techniques using problem solving strategies contain components that can be thought of in terms of modeling, coaching, and fading phases in the cognitive apprenticeship framework (Collins et al., 1991). Based on this framework, in addition to explicitly introducing the problem-solving model to students, instructors should also demonstrate use of the model during the class. Then, the students can be provided with opportunities to practice applying the model (e.g. by working with the other students or with computers) under the assistance of the instructor. As students develop more independence and expertise, the support from the instructor can be gradually reduced. Various instructional activities may be used to support student learning through the different phases. Example problem solutions, for example, can be used to show students how to use a prescriptive problem-solving model if this model is made explicit in the example problem solutions that the instructors present to students.

Learning from example solutions

Example solutions are one of the central tools used in the teaching of introductory physics. Students typically encounter example solutions in at least three contexts: 1) written solutions in the textbook or other similar material, 2) solutions constructed by their instructor during lecture and recitation, and 3) solutions provided by their instructor after students have submitted solutions to homework or test problems (Lin et al., 2012; Tarmizi & Sweller, 1988; Wright & Williams, 1986). Research on the design of example solutions has shown that example solutions are more effective if multiple sources of information (e.g., diagram, text, and aural information) are integrated into a unified presentation to reduce cognitive overload on students (Atkinson et al., 2000). In addition, structuring the examples to emphasize the important chunks of steps or subgoals
(either by explicitly labeling them or simply isolating them visually) can guide students to discover the underlying deep structure of the solution and enhance learning (Atkinson et al., 2000; Catrambone, 1994, 1995; Catrambone & Holyoak, 1990). Research also indicates that at the initial stages of skill acquisition, learning from an example solution is more effective for improving problem solving performance compared to problem solving itself (Atkinson et al., 2000; Sweller et al., 1998). Because the cognitive overload is less when studying example solutions than actually solving problems, more short term memory capacity is available for students to extract useful strategies and to develop knowledge schemas. At this stage, process-oriented solutions (solutions which present the rationale behind solutions steps) are appropriate. On the other hand, when learners acquire more expertise, process-oriented examples are less effective (or in some cases may even start to hamper learning) because the redundant information presented, which is hard to ignore, takes up the limited working memory available for the students. Product-oriented solutions (in which rationale is not included) are therefore more appropriate at the later stage of learning when the learners possess more prior knowledge.

Research suggests that there is a difference between how good students and poor students study example solutions (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Ferguson-Hessler & de Jong, 1990). Good students typically engage in deeper processing than the poor students. Students who “self-explain” the example solutions more are able to benefit more from the example solution. Self-explanations refer to the content-relevant articulation (beyond what the text explicitly said) formulated by the students in order to fill in the gaps and to make sense of the example solutions. Chi proposed that self-explanation can involve two processes:
generating inferences and self-repairing one’s own imperfect mental model (Chi, 2000). Generating inferences corresponds to a situation in which a student’s mental model is isomorphic to the scientific model conveyed by the example solutions. While the students’ mental model is globally correct, it may involve gaps that correspond to the omissions in the solution. In this case, self-explaining the solution makes it possible to fill in these gaps. On the other hand, self-repairing corresponds to a situation where a student’s mental model is flawed. In this situation, self-explanation is generated to resolve the conflict between the student’s mental model and the solution. Such a process therefore allows students to self-repair their flawed mental model. Chi argued that high self-explainers are those who readily detect conflicts while learning from the example solution. It is recommended that instructors provide students with prompts that encourage them to detect conflict. Renkl reported that one style of the self-explanation that successful learners provide is principle-based self-explanations, in which there are some elaborations of a principle. For example, the multiplication rule can be explicitly elaborated by a statement: “It gets multiplied, because the events are independent from each other.” (Renkl, 1997). Atkinson, Renkl, and Merril have shown that principle-based prompts are effective for inducing principle based self-explanation (Atkinson, Renkl, & Merrill, 2003).

Faculty beliefs and practices

A number of researchers have investigated the general ideas of teaching and learning held by college instructors. These studies generally found that instructors’ views could be characterized on a continuum from a teacher-centered view, which emphasizes the transmission of knowledge, to a student-centered view, which emphasizes the construction of knowledge by the students (Biggs, 1989; Donald,
1993; Prosser, Prosser, Trigwell, & Taylor, 1994; Prosser & Trigwell, 1999; Samuelowicz & Bain, 1992). Instructors' beliefs about problem-solving have also been found to be correlated with their general ideas about teaching and learning (Lin et al., 2012). For example, instructors who conceived the meaning of the problem as obvious and unproblematic to students and thought of problem solving as an application of existing knowledge held more teacher-centered views on teaching. On the other hand, instructors who see that the meaning of the problem is not necessarily obvious to students and problem solving involves making sense of the problem held more student-centered views.

Although instructors' ideas about teaching and learning influence their decision making, studies have found that due to conflicting factors or constraints, instructors' practices may not be consistent with the general ideas that they hold about teaching and learning (Henderson & Dancy, 2007; Yerushalmi et al., 2010). For example, a prior study (Yerushalmi et al., 2010) investigated the goals of 30 physics faculty related to their use of problems in their introductory physics course and found that “developing students’ physics understanding” and “developing students’ ability to plan and explore solutions paths” are the two most mentioned learning goals influencing their preferences for different problem features. However, many of these instructors do not use the problem features they believe support these goals and even use features they believe hinder the goals. Yerushalmi et al. propose that a strong reason for this misalignment comes from a powerful set of values concerning the need for clarity in the presentation and reducing the stress on students. Similarly, in another study Yerushalmi et al. found that, although some faculty believe students would learn better from example solutions that contained more explanation of expert thought process, they refrained from constructing these
solutions for reasons including: (1) their physics values which direct them to not stifle student creativity in problem solving by providing example solutions that were too detailed, (2) their value of an effective solution which involves the shortest path to arrive at the result and/or which conforms to the way an expert physicist would write, (3) their considerations that students may be frightened by problem solutions showing too many steps, and (4) their constraint of lack of time to construct such solutions (Yerushalmi et al., 2007).

What remains unknown from this study is whether the faculty notice the goals of helping students become better problem solvers when they present their instructor solutions to their students, and whether they recognize and value the features from example solutions that explicate clear problem-solving process. One of the goals of this thesis is to answer this question.
CHAPTER III

METHODOLOGY

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

Goals of the study

This study is designed to find out whether college and university physics faculty have the goal of helping students become better problem solvers when they incorporate instructor solutions in their teaching, and whether they recognize and value example solution features that explicate clear problem solving process. We are also interested to see how faculty as expert instructors compare to TAs as novice instructors.

Data Collection Procedure

Sampling and participants

This study involved the analysis of existing interview transcripts. The interviews with physics instructors were developed and conducted as part of a prior study (Henderson, 2002). As the goal of this prior study was to understand how physics instructors make teaching decisions, the interview subjects were limited to those instructors who had taught the introductory calculus-based physics course for at least five years. The population was a convenience sample of college physics faculty in Minnesota; Henderson also assumed that there is no reason to expect physics instructors in Minnesota to be different from the physics instructors in other
parts of the United States. The sample consisted of 30 physics instructors roughly divided within the following group: 1) Community College Instructors; 2) State College Instructors; 3) Private College Instructors; 4) Research University Instructors – UMN Twin Cities Campus. The distribution of the sample is shown in Table 1. The sample was randomly selected from a pool of 107 tenured or tenure-track faculty in Minnesota who had taught an introductory calculus-based physics course within the last five years and could be visited by an interviewer in a single day trip from the University of Minnesota, Twin Cities Campus.

Table 1. Summary of background information for the 30 interview participants.

<table>
<thead>
<tr>
<th>Type of institution</th>
<th>Numbers of instructors interviewed</th>
<th>Gender (M)</th>
<th>Gender (F)</th>
<th>Range of teaching experience</th>
<th>Range of teaching experience in introductory calculus-based physics</th>
<th>Range of typical class size for introductory calculus-based physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community College</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>6-35 years</td>
<td>3-29 times</td>
<td>6-75 students</td>
</tr>
<tr>
<td>Primarily Undergraduate Private</td>
<td>9</td>
<td>9</td>
<td>0</td>
<td>6-30 years</td>
<td>1-20 times</td>
<td>10-50 students</td>
</tr>
<tr>
<td>Research Oriented State</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>2-43 years</td>
<td>1-79 times</td>
<td>50-300 students</td>
</tr>
<tr>
<td>Primarily Undergraduate State</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>4-32 years</td>
<td>2-60 times</td>
<td>40-140 students</td>
</tr>
</tbody>
</table>

In order to compare with TAs, we use the data collected from a convenience sample of 24 first year graduate students from the University of Pittsburgh who were enrolled in a semester-long training course (Lin, Henderson, Mamudi, Singh, & Yerushalmi, 2012). The TAs are almost evenly divided in their background
education, with 13 TAs as international students, most of whom had their former education in China or India, and 11 TAs earned their secondary and prior post-secondary education in America. The training course aimed to guide TAs to contemplate issues related to the teaching of physics and explore possible strategies to improve their teaching. Most of the TAs who were enrolled in this course were simultaneously doing their TA job, either leading recitations, lab sections, or being a grader. Also, the TAs interviewed in this study had just entered graduate school and started their TA positions.

As the complete methodology of the TAs analysis has been discussed in the previous paper by Lin et al., the following discussion will elaborate the methodology used in the faculty analysis.

The interview

Several days before the interview, Henderson et.al. sent the specific problem to faculty and asked them to solve it. All the faculty solved the problem. After making sure the instructors were familiar with the problem, Henderson et.al proceeded with the interview. During the interview, a tripod-mounted video camera made an audio record of the conversation and visually recorded any pointing at features of the artifacts.

The interview protocol (see Appendix) was designed to probe instructors’ beliefs across three instructional situations using both general and specific questions related to the elements that compose the instructional system. The interview

1 We designed the methodologies for both faculty and TAs to be as parallel as possible to ensure the consistency of data collected given the limitation of our sources of data. Readers are encouraged to read our complete arguments in our previous paper “The group administered interactive questionnaire: An alternative to individual interviews” (Yerushalmi, Henderson, Mamudi, Singh, & Lin, 2011).
protocol avoided, as much as possible, imposing any language on the interview by using artifacts to elicit the instructor's natural language. Once elicited and clarified, this language was then used by the interviewer. The use of a structured protocol reduces the likelihood that the conceptual frameworks of individual interviewers will bias interviewee responses. The interview protocol allowed Henderson et.al to complete the data collection for a single instructor in 1.5 hours.

The interview was broken into four distinct parts. The first three parts each dealt with one of the three types of instructional artifacts and focused primarily on how the artifacts might be used during the instructor's course. The intent of these parts of the interview was to probe both the perceived and desired interactions between the students and instructor within the learning system. The fourth part of the interview was intended to focus on the instructor's perceptions of the students' initial and final state of knowledge about problem solving, the instructor's beliefs about the nature of problem solving, and the instructor's satisfaction with their instruction. All of the interview questions fit into one of three basic categories: 1) general, open-ended questions designed to gather information about an instructor's ideas; (Argyris & Schon, 1992; Menges & Rando, 1989) 2) specific questions, often related to a specific artifact, to gather information about a simulated instructional decision— their ideas-in-use; (Argyris & Schon, 1992; Menges & Rando, 1989) and 3) questions about the problem-solving process to gather information about the instructor's beliefs regarding student problem solving. In this thesis, the analysis involve only the first part of interview that focuses on the Instructor Solution artifact.
The Artifacts comparison technique

The Instructor Solution artifact portion of the interview began with general questions about how and why the instructor used example problem solutions. The interviewer then gave the three Instructor Solutions to the instructor, who was asked to compare them to the materials they used in classes and to explain their reasons for making those choices. This part concluded by asking the instructor to reflect on the important parts of the problem-solving process either as represented in or missing from the artifacts.

The artifacts used in this thesis were adopted from previous work conducted at the University of Minnesota by Henderson (Henderson, 2002). When creating the artifacts, Henderson utilized three possible example solutions, based on his review on posted solution available online, for a single problem selected to be one that could reasonably given in most introductory physics courses. The problem was considered difficult enough by the instructors so that an average student could use an exploratory decision-making process as opposed to an algorithmic procedure. Please refer to appendix for the problem used in this thesis and the example solutions we provided.

All three example solutions reflect various instructional styles, and so none of the solutions was designed to be flawless by Henderson. During the interview, Henderson showed the example solutions to the faculty all at once to minimize any possibility of having biased response from the faculty. Henderson then asked them to reflect on how those solutions are similar or different to the solutions they use, and then try to articulate their reasons for favoring particular solution feature.

The three example solutions are different from one another in several
important aspects. In a review of instructor solutions posted on the web, Henderson found that almost all solutions fell into one of two basic types. The first type is represented by example solution I is a ‘bare-bones’ solution that offers little descriptions or commentaries. It deliberately left many of the minor steps to be filled by the reader. The other common type of solution is represented by example solution II, which explicates many of the details of the solution process. In this type of solution, all of the details of the solution were explicitly written out. Both example solution I and II, although providing a good representation of the range of actual instructor solutions, were missing two aspects of instructor solutions that are recommended by some curriculum developers (Heller & Hollabaugh, 1992; Van Heuvelen, 1991) based on physics education research. First, both of the previously described solutions proceed from the given information to the desired information. Research (Maloney, 1994) has shown that problem solvers typically proceed from the desired information and attempt to relate it to the known information. Secondly, neither of the previously mentioned solutions described why particular steps were being done by describing an approach to the solution before starting with calculations. Based on these arguments, Henderson created example solution III that starts from the desired information and that describes the approach first before starting with calculations. It reflected a systematic decision-making process characteristic of expert problem solvers along the prescriptive problem solving models suggested by Reif (Reif, 1995). Reif suggested that experts begin the problem-solving process by having an overview that discusses the problem goal and then relate the goal to the known information. The reasoning behind each step is explicated. Then, a separate ‘execution’ section takes place to mathematically
execute the plan. At the end, there is an assessment of the solution, which does not exist in either example solution I nor II. There are other important differences between the solutions. For example, while example solution II starts ‘forward’ with the knowns and unknowns and invoke the conservation of mechanical energy principle to find the speed first, example solution III works ‘backward’ from the targeted variable and begins with the Newton 2nd law. This is also related to the fact that the problem given for the interview may favor a backward solution as it is gives the final state (mass goes up so many meters), while asking for the initial state (amount of force required).

### Data Analysis

We are interested in both the goals instructors have for providing the instructor solutions, and the solution features that the instructors recognized as explicating clear problem solving techniques in their solutions. We collected the data about their goals from the first part of the interview when we explicitly asked the faculty about their goals for providing the solutions in their teaching, and from the latter part of the interview when the instructors elaborated their features preferences and related their reasons to the goals they have mentioned earlier.

Table 2. The common and distinct elements of the three solutions.

<table>
<thead>
<tr>
<th>Explicit Features</th>
<th>Solution I</th>
<th>Solution II</th>
<th>Solution III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Symbolic solution</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>List of knowns &amp; unknowns</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Reasoning along the steps</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Overview</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Start from target variable</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Checking at the end</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The transcripts were categorized into two main categories: 1) Prior to viewing the artifacts (general situation), and 2) After viewing the artifacts (concrete artifacts). Figure 1. will show how we acquire the data from the transcripts.

**Figure 1. Acquiring the data from the transcripts**

The statements prior to viewing the artifacts are related to the situations when the instructors are using the example solutions and the explicit goals of using the example solutions in that situation.

We open the interview with general questions about situation and reasoning:

“So let me start out with a very general question about instructors' solutions. And that is, when you're teaching, and again, think about the calculus-based course, when you're teaching, in what situations do students see solved problems? And, you know, a lot of professors solve problems on the board or give solutions for homework or quizzes, or things like that. So just in what situations do your solutions see solved examples?”

*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?”

“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?”

The statements after viewing the artifacts consists of two main data. The first is when an instructor mentions a specific preference for a feature. The second one is when an instructor re-states the goal of using example solutions as related to features they recognize from either the artifacts or their own solutions, for example:

“Ok. Well, let me show you the solutions that I brought. I've got three solutions, and this is the problem that we had you solve earlier. And each of these three solutions is written in a somewhat different way based on things that we've seen in instructor's solutions. What I'd like you to do is look through them and tell me what parts of them are similar or different to the kinds of solutions that you would have your students look at.”

“Please explain your reasons for writing solutions the way you do.”

Each phase of the data analysis process is described in more detail in the following sections.

**Prior-viewing artifact analysis**

We examined the instructors' goals of providing instructor solutions that we found from the general situation and concrete artifacts, and the part of transcripts that represent those goals. In the general context, we asked instructors explicitly about the goals they have for providing solved examples in different situation. In the concrete context, right after the general one, we asked instructors to describe their
reasoning for preferring specific solution features in their own example solutions. The reasoning they mentioned were later used to elaborate they goals they mentioned earlier.

All of the goals mentioned existed in both the general and concrete contexts. As discussed earlier, when analyzing the instructors’ goals, the a priori categories that emerged from previous study by Lin et.al were used and refined for this research. The final set of categories for instructor goals that was used in this study is:

- **Keeping students emotionally involved:** In this goal, the instructors focus on maintaining students’ interest in and motivation on the material at hand. The emphasis is that the example solutions could be used to build students’ confidence in their own ability, while the solutions were also designed to prevent their sense of despair.

- **Keeping students cognitively involved:** In this goal, the instructors expect to engage students in cognitive processing, or that the example solutions should be clear and easy for students to understand with little difficulties. The instructors also want to prevent such overly complicated example solutions that may end up confusing students instead of helping them.

- **Setting standards for adequate solution:** In this goal, the instructors expect the students to see things they should put in their own solutions as elaborated in the example solutions. Some features should be included in the solutions so that it could be considered an adequate solution.

- **Supporting students in learning physics:** In this goal, instructors focus on using the example solutions as a mean for students to understand the specific
problem at hand. Instructors also expect students to develop an understanding of the physics concepts that are involved in the problem.

- **Helping students become better problem solvers:** In this goal, the instructors expect the students to acquire the problem-solving skills needed to solve similar problems or even different problems in the future.

- **Saving time:** In this goal, the instructors specifically stated how the example solutions should be able to save their own time in various situations.

- **Other considerations:** These are several minor goals that emerge from the transcripts that do not really fit into all the major goals mentioned above. For example, example solutions should be designed to save papers to print.

To answer research question 1, I identify goals by analyzing (i) the instructors’ answers in the early part of the interviews when they describe the specific situations and purposes for providing example solutions to students in a general context and (ii) their reasons for why they like or do not like the different solution features presented in the example solution artifacts in the concrete context. Readers are encouraged to see examples of interview transcripts in Appendix D and E. Before fitting the data into pre-existing rubric, I highlight the answers from the first questions with respect to situation and reasoning. If the answers from the interviewee are not explicit enough, I may need to paraphrase their answer or mark that part of transcripts to be further discussed with one of the research group member (Lin). For example, consider this part of the interview from instructor 13 (the complete interview is on Appendix D):

\begin{quote}
Q: And tell me what your reasons for using solutions in these situations are.

A: Well I think for homework and exams it’s pretty much, you pretty much
\end{quote}
have to. You know, students, well, let me think about it... One reason is to allow the students to see where they made mistakes, I guess that’s the main reason. And the second is to try to give examples of good problem solving techniques. So if when I do my solutions, I always make a drawing and I always keep track of my units, maybe those practices will somehow diffuse into the students.

Q: Ok. And that’s for the homework and exams. What about the in-class problems?

A: In the in-class problems, there the motivation is to, well, to give concrete examples of concepts that we’re working through. Also to show problem solving techniques that they can then use on homework. And of course also to give examples with problem solving techniques.

Based on this part of interview, I highlight the answers from the interviewee while looking at the table of goals category. In this example, there are four statements that could be related to their goals of providing example solutions:

1) “One reason is to allow the students to see where they made mistakes, I guess that’s the main reason.”

2) “And the second is to try to give examples of good problem solving techniques. So if when I do my solutions, I always make a drawing and I always keep track of my units, maybe those practices will somehow diffuse into the students.”

3) “In the in-class problems, there the motivation is to, well, to give concrete examples of concepts that we’re working through.”

4) “Also to show problem solving techniques that they can then use on
homework. And of course also to give examples with problem solving techniques.”

At this point, I check the list of the goal category we have been using from the previous study on TAs, and categorize the first and third statements that fits in the goal of “supporting students in learning physics” because the instructor is concerned about the specific concept applied on the problem. The second and fourth statements are categorized as “helping students become better problem solvers” as they concerned a problem-solving strategy that could be applied beyond one specific problem. Before finalizing these interpretations, I verified it with a second researcher (Lin) as the primary researcher from the previous study to maintain the consistency with the study from TAs. In case of there was disagreement between myself and Lin, we asked the senior research members (Henderson and Yerushalmi) for their opinions until a consensus was reached. Once consensus was reached with the entire research group member, I put our finalized interpretation into our

Table 3. Example of transcript coding

<table>
<thead>
<tr>
<th>Citation</th>
<th>Paraphrase</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>One reason is to allow the students to see where they made mistakes, I guess that’s the main reason.</td>
<td>to allow students to see where they made mistakes</td>
<td>Supporting students in learning physics</td>
</tr>
<tr>
<td>And the second is to try to give examples of good problem solving techniques. So if when I do my solutions, I always make a drawing and I always keep track of my units, maybe those practices will somehow diffuse into the students.</td>
<td>to give examples of good problem solving technique</td>
<td>Supporting students in learning physics</td>
</tr>
<tr>
<td>In the in-class problems, there the motivation is to, well, to give concrete examples of concepts that we’re working through.</td>
<td>to give concrete examples of concepts that students are working through</td>
<td>Helping students become better problem solvers</td>
</tr>
<tr>
<td>Also to show problem solving techniques that they can then use on homework. And of course also to give examples with problem solving techniques.</td>
<td>to give examples of problem solving technique</td>
<td>Helping students become better problem solvers</td>
</tr>
</tbody>
</table>
rubrics. The coding for the transcripts above is shown on Table 3.

**Post-viewing artifact analysis**

This part of the analysis invokes instructor statements related to the three concrete artifacts. To identify the features that faculty talked about in the example problem solutions, we first categorized the episodes into the list of *a priori* features as used in the previous study by Lin et.al. We then grouped the features into several major clusters based on a theoretical view of the problem-solving process. Table 4 will show the clusters we use in this analysis.

Parallel to the previous study by Lin et.al (Lin et al., 2012), we categorized the features into several clusters based on an expert view of the problem solving process. In this thesis, we focus on the first three clusters (C1 – Initial problem analysis, C2 – Solution construction, and C3 – Checking of solution) which relate to the key stages in a prescriptive problem solving model described by Reif (Reif, 1995). Additionally, we also have the final two clusters C4 – Extended details and C5 – Organization and clarity which relate to communicating the solution to students. Each is briefly described in the following paragraphs.

The first cluster (C1: Initial problem analysis) relates to the initial problem analysis as described by Reif:

The purpose of the initial problem analysis is to bring the problem into a form facilitating its subsequent solution. To this end, one must first clearly specify the problem by describing the situation (with the aid of diagrams and useful symbols) and by summarizing the problem goals.

(Reif, 1995, p. 28)
Table 4. Feature list. Features related to the key stages in a prescriptive problem solving model are grouped into clusters C1 to C3. Features related to the communication of the solution are grouped into clusters C4 and C5.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
<th>Cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Provides a schematic visualization of the problem (a diagram)</td>
<td>C1 - Initial problem analysis</td>
</tr>
<tr>
<td>F2</td>
<td>Provides a list of knowns/unknowns</td>
<td>C1 - Initial problem analysis</td>
</tr>
<tr>
<td>F3</td>
<td>Provides a &quot;separate&quot; overview of how the problem will be tackled (explains premise and concepts - big picture - prior to presenting solution details)</td>
<td>C2 - Solution Construction</td>
</tr>
<tr>
<td>F4</td>
<td>Explicit sub-problems are identified (Explicitly identifies intermediate variables and procedures to solve for them)</td>
<td>C2 - Solution Construction</td>
</tr>
<tr>
<td>F5</td>
<td>Reasoning is explained in explicit words (Description/justification of why principles and/or sub-problems are appropriate/useful in this situation)</td>
<td>C2 - Solution Construction</td>
</tr>
<tr>
<td>F6</td>
<td>The principles/concepts used are explicitly written using words and/or basic mathematical representations (e.g., F=ma or Newton’s 2nd Law)</td>
<td>C2 - Solution Construction</td>
</tr>
<tr>
<td>F10</td>
<td>Provides alternative approach</td>
<td>C2 - Solution Construction</td>
</tr>
<tr>
<td>F12</td>
<td>Direction for the progress of the solution progress: Backward vs. Forward</td>
<td>C2 - Solution Construction</td>
</tr>
<tr>
<td>F18</td>
<td>Approach a problem from general principles and only later focus on the specific case</td>
<td>C2 - Solution Construction</td>
</tr>
<tr>
<td>F19</td>
<td>Exploration of problem space (by trial and error)</td>
<td>C2 - Solution Construction</td>
</tr>
<tr>
<td>F13</td>
<td>Symbolic solution (numbers are plugged-in only at the end)</td>
<td>C3 - Checking of solution</td>
</tr>
<tr>
<td>F14</td>
<td>Provides a check of the final result (e.g. if the unit is correct, or if the answer makes sense by examining the limits, or whether it is reasonable)</td>
<td>C3 - Checking of solution</td>
</tr>
<tr>
<td>F7</td>
<td>Thorough derivation (Detailed/verbose vs. Concise/short/simplified/skips lots of derivation)</td>
<td>C4 - Extended Details</td>
</tr>
<tr>
<td>F8</td>
<td>Long physical length (Long/verbose vs. Short/concise vs. Balanced/not too long, not to short)</td>
<td>C4 - Extended Details</td>
</tr>
<tr>
<td>F9</td>
<td>Includes more than the minimal set of intermediated variables required to solve the problem/more physics considerations accompanying the solution than needed for an adequate solution</td>
<td>C4 - Extended Details</td>
</tr>
<tr>
<td>F16</td>
<td>Explains the meaning of symbols</td>
<td>C4 - Extended Details</td>
</tr>
<tr>
<td>F11</td>
<td>Solution is presented in an organized and clear manner</td>
<td>C5 - Organization &amp; Clarity</td>
</tr>
<tr>
<td>F15</td>
<td>Solution boxed</td>
<td>C5 - Organization &amp; Clarity</td>
</tr>
<tr>
<td>F17</td>
<td>In first person narrative</td>
<td>C5 - Organization &amp; Clarity</td>
</tr>
</tbody>
</table>
The initial analysis are typically done by putting the known information more transparently in visual form via feature 1 (schematic visualization of the problem), or by explicitly written it down via feature 2 (a list of known and unknown).

The second cluster (C2: Solution construction) relates to the core of the solution construction stage as described by Reif.:

A search strategy... helps to identify the kinds of choices that need to be made. A well-structured hierarchical knowledge organization facilitates these choices by reducing greatly the number of options that need to be considered. [And,] implementation of any such choice is facilitated by precisely acquired interpretation and description of knowledge [via initial problem analysis].

(Reif, 1995, p. 28)

The problem decomposition that takes place in this stage is materialized via feature 4 (explicit sub-problems are identified). Feature 6 (principles/concepts used are explicitly written) makes explicit the relations used in each sub-problem to eliminate unknowns. The rationale underlying the problem decomposition is described in feature 3 (providing separate overview) and feature 5 (reasoning is explained in explicit words). A written solution cannot easily demonstrate the recursive nature of the search process, yet feature 10 (providing alternative approach) reminds us that there are alternative solution paths. Finally, feature 12 (backward vs. forward solution) reflects possible directions of the search process. There is acceptance that experts in fact do it both ways, forwards and backwards, and this also depends on the nature of the problem. In this study, the problem we choose incline towards backward approach and so we expect the solutions preferred
by the instructors will begin with the targeted variable explicitly mentioned at the beginning of the solution.

The third cluster (C3: Checking) relates to checking the solution as described by Reif:

It is essential to check any solution to assess whether it is correct and satisfactory – and to revise it appropriately if any deficiencies are detected.

(Reif, 1995, p. 27)

For example, a symbolic solution (F13) allows one to check that the different stages in the solution are self-consistent. Performing a check of the final result by examining the unit or the limiting cases (F14) allows one to contemplate whether the final answer makes sense.

The fourth cluster (C4) and fifth cluster (C5) are both related to the presentation of the solution. Features in the C4 clusters are all related to the “long/detailed” aspect of a solution. F7 (thorough derivation) and F9 (details without which the solution is still technically) represents two example components in a solution content that can lead to a long physical length (F8). On the other hand, the single feature in cluster C5 focuses whether the solution is presented in a clear and organized way (F11).

To answer research question 2, we focus on feature clusters C1 to C3 which relate to the goal of helping students become better problem solvers. For each cluster, we identified whether each instructor (i) recognized these features in the solution artifacts provided and (ii) liked/disliked these features in their own solutions. Most of the time, the instructors are explicit about their preferences, whether they like or dislike certain features. When the instructors are not explicit
about their preferences, we assumed (unless contrary evidence existed) that whenever the instructors said that they use a specific feature, they do that because they like the feature. In this part, we also analyze the interviewees’ reasoning when they elaborate their preferences on features to further understand their goals in providing example solutions.

For example, consider this part of interview from instructor 8 (more complete interview is on Appendix E):

A: My approach is similar to number 3. The number 1 and the number 2, they talk about conservation and mechanical energy first, then they talk about the force.

Q: Right.

A: The number 3 talks about force first, and then talk about the energy. My approach is similar to this.

Q: And why?

A: Why? Because their question is to ask the force.

Q: So you start from what the student is asked to find and then go.

A: Yeah, then we, because they need to determine the force of people [unintelligible] on the street, right.

Q: Right.

A: In order to determine that you need to determine the centripetal force. The weight is given. So in order to determine centripetal force, you need to know the velocity. And the velocity is related to kinetic energy.

Q: So you want them to start always with what they are looking at, and go back and find what they need.
A: Yeah, that’s my approach.

Q: I see.

In this part of transcript, there are two statements that refer to a specific feature:

1) The number 1 and the number 2, they talk about conservation and mechanical energy first, then they talk about the force.

2) The number 3 talks about force first, and then talk about the energy. My approach is similar to this.

These two statements suggest this instructor’s preference about the direction of solution. This instructor favors a backward solution that begins with target variable first. The next step in the analysis is to understand this instructor’s reasoning about why he has this specific preference. I highlight several more statements that describe his reasoning:

1) Their question is to ask the force. [So you start from what the student is asked to find and then go].

2) In order to determine that you need to determine the centripetal force. The weight is given. So in order to determine centripetal force, you need to know the velocity. And the velocity is related to kinetic energy. [So you want them to start always with what they are looking at, and go back and find what they need.]

This part describes an elaborated strategy of this instructor as an expert to solve physics problem. Further, the instructor also confirms the interviewer’s clarification about always solving a physics problem from the target variable.

Just like what I did with the part of the interview prior to viewing the
artifact, I discussed my interpretation in this part of interview with a second researcher (Lin) and the rest of the research group before finalizing it into the rubric. As we reach consensus, I put my interpretation into our rubric.

The coding for this part of interview above is shown in table 5:

Table 5. Example of transcript coding

<table>
<thead>
<tr>
<th>Citation</th>
<th>Feature &amp; Cluster</th>
<th>Solution</th>
<th>Preferences &amp; Reasons</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>My approach is similar to number 3. The number 1 and the number 2, they talk about conservation and mechanical energy first, then they talk about the force. <strong>Right.</strong> The number 3 talks about force first, and then talk about the energy. My approach is similar to this. <strong>And why?</strong> Why? Because their question is to ask the force. <strong>So you start from what the student is asked to find and then go.</strong> Yeah, then we, because they need to determine the force of people [unintelligible] on the street, right. <strong>Right.</strong> In order to determine that you need to determine the centripetal force. The weight is given. So in order to determine centripetal force, you need to know the velocity. And the velocity is related to kinetic energy. <strong>So you want them to start always with what they are looking at, and go back and find what they need.</strong> Yeah, that’s my approach. <strong>I see.</strong></td>
<td>F12 &gt;&gt; Backward solution C2 &gt;&gt; Solution constructio n</td>
<td>artifact 3, not 1, not 2</td>
<td>Like this feature. The instructor states that he starts from what is asked to find and then go solve it. Working backwards is necessary in order to determine intermediate variables needed to solve the problem.</td>
<td>Goal 5 &gt;&gt; Helping students become better problem solvers</td>
</tr>
</tbody>
</table>
Comparison to TAs

To answer research question 3, we used the previous results from the TA study as published in the Lin et al. (Lin et al., 2012) and compared it directly with the parallel results from the faculty analysis as discussed above. The interpretation was done with the full research group. It is important to note that not all of the faculty results have a parallel in the TA results.

Data Validation

The first stage of analysis was primarily done by the author himself. Raw transcripts were coded into pre-existing rubrics for both goals and features, which were later verified by another researcher (Lin) to ensure the consistency of data interpretation with the previous study of TAs. Most of the data interpretation of the overall results was agreed in this stage, with about 1/3 of the codes further checked by the senior researchers (Henderson & Yerushalmi) to resolve any disagreements or possibility of new findings until full agreement with the whole research group was established.

One important consensus was about the features included in our result. In the beginning, the author coded the transcripts using the original 14 features as listed from the previous TAs study. Readers are encouraged to review table 4 to see the list of the features. After finishing his interpretation, the author and the research group identified 5 additional features ("solution boxed", "meaning of symbols", "in first person narrative", "approach a problem from general principles and only later focus on the specific case", and "exploration of problem space") that the faculty noticed. Because these additional features were only mentioned by 1 or 2 faculty, we decided to focus only on the 14 pre-defined features in the discussion of
the results.

**Limitation of the Study**

There are several limitations on this study. The first is that the methodology of the study may lead to possible under-reporting of features noticed/valued. For example, if we had asked faculty how many of them think it is important for instructor solutions to have an explicit evaluation of the answer, we might have different results than in our methodology. These stem from the fact that some of the features are not explicit, and there is always possibility that while the faculty implicitly like certain features in their solution, they still fail to mention it or only give us vague answers during the interview.

Also, there is possibility that we may overlook some emergent features that were noted by one of two faculty. Although we choose not to include these emergent features as they have no counterpart features from the TAs, we suggest that a future study with larger samples of data could raise the number of instructors who notice these emergent features and give us more information about their preferences.

We also acknowledge that the methodologies used to get the data from faculty and TAs are different and, thus, there are weaknesses in comparing the two groups. While we have done our best to ensure that the data were gathered using parallel questions in both individual interviews and questionnaire, a study in the future for both faculty and TAs with the same methodologies will have stronger validity and it could also verify the findings from this study.

Finally, the sample size used in both the faculty and TA study are rather small, and may not be large enough to be representative of instructors in general.
Also, while the faculty chosen in this interview were randomly chosen from a pool of faculty with at least 5 years teaching experiences, we note that lumping faculty from different types of institutions together may have impacted the results. A future study with larger number of samples for both faculty and TAs with a specific type of institution background may be done to reduce the limitation in this study.
CHAPTER IV
RESULTS AND DISCUSSION

This chapter will present detailed results to the research questions, one at a time. The next chapter will summarize these results and discuss implications.

1. **When presenting instructor solutions, to what extent do faculty have the goal of helping students become better problem solvers?**

   When asked in the interview, why they use example problem solutions in their teaching, most faculty (22 out of 30, or 73%) explicitly or implicitly indicated that they had the goal of helping students become better problem solvers. For example:

   “I want to try to give examples of good problem solving techniques. So if when I do my solutions, I always make a drawing and I always keep track of my units, maybe those practices will somehow diffuse into the students.”

   “Some students learn it after the exam, you know, and I try to help them at least so they can learn basic problem solving techniques.”

   Table 6 shows the actual coding for these transcripts, and figure 2 shows the results of this goal along with the other goals that were identified from the interviews.

   In addition to the goal of helping students become better problem solvers, we also found two other goals that are at least as prominent. One of the goals is to support students in learning physics. In this goal, the instructors emphasize conceptual understanding by focusing on using the example solutions as a mean for students to understand the specific problem at hand.
Table 6. Example of coding for helping students become better problem solvers

<table>
<thead>
<tr>
<th>Citation, Line number (in parenthesis)</th>
<th>Paraphrase + P, M</th>
<th>Situation</th>
<th>Purpose</th>
<th>Inten</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>And the first one is just when do students see worked out solutions when they’re taking your class?</em></td>
<td>(P) to give examples of good problem solving technique</td>
<td>Inside the classroom. Post HW, Inside the classroom. Post Test.</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Well, they see them for homework and exam, they’ll have problems. That’s the main place. And then they see them in class. <em>And tell me what your reasons for using solutions in these situations are.</em> To try to give examples of good problem solving techniques. So if when I do my solutions, I always make a drawing and I always keep track of my units, maybe those practices will somehow diffuse into the students. <em>Ok. And that’s for the homework and exams.</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(39-45)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| *Now after a quiz or exam, do they find the solution to those problems at some point?* | (P5) students should learn PS techniques from (M1b) watching and comparing the instructor solutions to their own | Outside the classroom Post Test. | 5 | 1b |
| I think, yeah they do. Some students learn it after the exam, you know, and I try to help them at least so they can learn basic problem solving techniques. *And is that in class that you talk about the exam solutions, or do you put them somewhere?* I usually, I always include a solution with their exam. So each one has their personal solution. | | | | |
| (119-140) | | | |

38
Figure 2. Faculty goals of using example solutions

More interestingly, the goal mentioned by the largest number of faculty during the interview is actually not related to either conceptual understanding or becoming better problem solvers. The faculty instead emphasized the importance of cognitive involvement with the students when they are using the instructor solutions. In other words, the instructors want the example solutions to be clear and easy for students to understand with little difficulties, and to prevent such overly complicated example solutions that may end up confusing students. A statement was coded as cognitive involvement when an instructor expressed the idea that an example problem solution should be written in a manner such that a student can follow it without confusing them in that process. For example:

“I want the diagram to be clear and don’t want to confuse students.”

“Backward solution is in wrong order, making it harder for students to follow.”

Table 7 shows the actual coding for these transcripts.
Nearly all (90%) of the faculty we interviewed expressed this goal. The main concern of this goal is that faculty want students to be able to follow the solution or to avoid the situation where the example solution -or at least some features in the solution- could confuse the students.

Summary for research question 1

The results suggest that indeed helping students become better problem solvers is a goal that most faculty have. However, we also found that there are two other goals that faculty also considered important. For example, nearly all faculty (27 out of 30) identified the goal of keeping students cognitively involved.

Later we will discuss our finding that some faculty differ in their preferences of which way to present solutions to students. Their preferences seem to be related with between the goal of cognitive involvement and the goal of helping students become better problem solvers when it comes to solution construction. This

Table 7. Example of coding for cognitive involvement

<table>
<thead>
<tr>
<th>Citation</th>
<th>Reasons</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>This person has a problem that I often have in my drawings is that, for example you do want to indicate velocity, you do want to indicate the acceleration, and you don't want students to confuse those with forces in any way whatsoever, if I'm doing it on the board I might use colored chalk or something. (315)</td>
<td>Want the diagram to be clear and don't want to confuse students</td>
<td>2</td>
</tr>
<tr>
<td>And this [3rd] one is probably related to that but it just looks more, well, I find harder to follow and in the wrong order. Because it’s starting with things that you don't need to worry about yet. (159-161)</td>
<td>Backward solution is in wrong order, making it harder for students to follow</td>
<td>2</td>
</tr>
</tbody>
</table>

Nearly all (90%) of the faculty we interviewed expressed this goal. The main concern of this goal is that faculty want students to be able to follow the solution or to avoid the situation where the example solution -or at least some features in the solution- could confuse the students.

Summary for research question 1

The results suggest that indeed helping students become better problem solvers is a goal that most faculty have. However, we also found that there are two other goals that faculty also considered important. For example, nearly all faculty (27 out of 30) identified the goal of keeping students cognitively involved.

Later we will discuss our finding that some faculty differ in their preferences of which way to present solutions to students. Their preferences seem to be related with between the goal of cognitive involvement and the goal of helping students become better problem solvers when it comes to solution construction. This
difference in preferences will be discussed in more detail in the discussion of research question 2.

2. When considering example solutions for their students, to what extent do faculty notice and appreciate design features that the literature perceives as helping students become better problem solvers?

To answer this question, we focus on the three clusters of example solution features introduced earlier. The three main clusters represent Reif’s organization of an expert-like problem solving strategy: C1 - initial problem analysis, C2 - solution construction, and C3 - checking solution.

**C1 - Initial Problem Analysis**

We identify two important features related to the initial problem analysis from the artifacts we presented to the instructors. The features are the F1 - drawing and F2 - the list of knowns and unknowns. Drawings were present in all three solution artifacts with varying details (see Figure 3 below), while the list of knowns and unknowns are present only in the second artifact (see Figure 4 below).

![Instructor Solution 1](image1.png)  ![Instructor Solution 2](image2.png)  ![Instructor Solution 3](image3.png)

**Figure 3. Variation of drawing as presented in the artifacts**
The instructors recognize the importance of the initial problem analysis, but not in the same proportion for both features. Most (70%) of faculty mentioned and said that they like the feature of drawings in an instructor solution. However, faculty also have various ideas about the details that should or should not be put within the drawings. For example:

“The diminishing vector helps show the concept.”

“Having a diagram could direct the students about what to find.”

**Table 8. Example of coding for drawing**

<table>
<thead>
<tr>
<th>Citation</th>
<th>Feature</th>
<th>Feature #</th>
<th>Solution</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>I like the way the vectors are diminishing up here. It helps show that concept nicely. (365 – 366)</td>
<td>quality of visualization (vectors are diminishing)</td>
<td>2</td>
<td>3</td>
<td>+</td>
</tr>
<tr>
<td>and I think the diagram is fine, that's all really good because it states kind of what it is that you're trying to find (204 – 205)</td>
<td>diagram</td>
<td>1</td>
<td>3</td>
<td>+</td>
</tr>
</tbody>
</table>

On the other hand, the list of knowns and unknowns feature is mentioned by fewer faculty. Only 33% of the faculty identified this feature. While most liked it, 1 of the faculty disliked it as it does not show the motivation (explicit elaboration of strategy) to solve the problem.
C2 - Solution Construction

We identify six important features related to reasons to choices made for constructing the solution. They are the F3 - separate overview, F4 - explicit sub-problem is identified, F5 - explicit reasoning, F6 - principles explicitly written, F10 - alternate approach, and F12 - backward solution. The Figures 6 - 11 will show how these features are represented by the solution artifacts.

<table>
<thead>
<tr>
<th>Instructor Solution 1</th>
<th>Instructor Solution 2</th>
<th>Instructor Solution 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Approach:

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

2. $A$) For a massless string $F_w = T_s$ ($T_s$-Tension at bottom)

3. $B$) I can relate $T_s$ to $v_t$ (velocity at bottom) using the radial component of $\sum \vec{F} = m\vec{a}$, and radial acceleration $\frac{v_t^2}{R}$, since stone is in circular path

---

Figure 6. Variation of separate overview as presented in the artifacts

<table>
<thead>
<tr>
<th>Instructor Solution 1</th>
<th>Instructor Solution 2</th>
<th>Instructor Solution 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

$B$) Relate $T_s$ to $v_t$

---

Figure 7. Variation of explicit sub-problem as presented in the artifacts
As shown in Figure 12, explicit reasoning is the feature most frequently mentioned by the faculty. We found that 60% of faculty recognize it and the majority of these would like to have it in their solutions. Separate overview comes in a close second with 57% faculty mentioning this feature, and the majority of the faculty also
like to have this feature in their own instructor solution. Alternative approach comes the third with 30% of faculty recognize this feature with 90% of these explicitly stating that they would like to have it in their own solution. Backward solution is also mentioned by 30% of faculty. But, while 30% of faculty recognize this feature, faculty are almost evenly divided about whether they like or dislike this specific feature. In short, there is difference in preferences when it comes to the direction of solution construction. Last but not least, both explicit sub-problem identified principles explicitly written are the least recognized by the faculty, with only 17% of them notice and like it.

Figure 12. Percentage of faculty mentioning and their preferences towards features in solution construction

We are interested in the finding on the direction of solution preferences and investigated the transcript in more detail to better understand this apparent difference in preference. We found out that there are indeed some patterns when the faculty elaborate their reasoning on the direction of solution construction. Of all five faculty who like backward solutions (a solution that starts with the target variable) they consistently mention the importance of helping students become better problem solvers. On the other hand, the four faculty who dislike backward solutions raise
their concerns about engaging cognitively with their students, where the solutions should be easy to follow and not end up confusing students. Table 9 on the following page shows the actual quotes from the faculty when they elaborate their reasoning on the direction of solution construction.

We note that these two goals (cognitive engagement and helping students become better problem solvers) are two important goals that faculty express related to the presentation of instructor solutions to their students, and that these goals were manifested differently by different faculty. In terms of forward vs. backward solution approaches, forward approaches are preferred by those who place a higher value on not wanting to confuse students with the ‘wrong’ order of solutions, while backward approaches (starting with target variable) are preferred by those faculty who place a higher value on wanting to help students become better problem solvers themselves. While the number of faculty in this study is rather small and this finding may not be strong enough to suggest a connection between the instructors’ preference in their goals of providing example solution and their preferences in choosing the direction of solution, we suggest that this possible connection could be explored in more details in the future study.

**C3 - Checking Solution**

After getting the solution to the problem, an expert will check their answer (Reif, 1995). We identify two important features related to checking from the artifacts we presented to the instructors. The features are the F13 – symbolic solution and F14 – providing a check of the final result. Symbolic solution is a feature of all 3 artifacts. In each case, numbers are plugged in at the very end after
Table 9. Faculty preferences on the direction of solution

<table>
<thead>
<tr>
<th>Actual quotes</th>
<th>Direction</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>So I guess I sort of feel like let’s start with what you want and see what we need... [otherwise] there is no motivation [the clear objectives to accomplish].</td>
<td>backward</td>
<td>helping students become better problem solvers</td>
</tr>
<tr>
<td>I start from what is asked to find and then go solve it. Working backwards is necessary in order to determine intermediate variables needed to solve the problem.</td>
<td>backward</td>
<td>helping students become better problem solvers</td>
</tr>
<tr>
<td>I always teach them that the first equation they write down should contain the target variable... [as] it is most like what I do.</td>
<td>backward</td>
<td>helping students become better problem solvers</td>
</tr>
<tr>
<td>I would probably attack it from Newton's second law, so students will try to get at the tension that way.... [in that way,] since the problem asks about tension, most students will attack it thinking about tension first.</td>
<td>backward</td>
<td>helping students become better problem solvers</td>
</tr>
<tr>
<td>So my approach would be more like this one [start from target variable]. I need to find fm. That's true, I would abbreviate that somewhat and just say fm=?.</td>
<td>backward</td>
<td>helping students become better problem solvers</td>
</tr>
<tr>
<td>I find harder to follow and in the wrong order [to begin with the target variable]...so to speak, with the force equation, and that's far down the pipe rather than worrying about the kinematics of the free flight, in my view of things. Because it's starting with things that you don't need to worry about yet.</td>
<td>forward</td>
<td>cognitive engagement</td>
</tr>
<tr>
<td>I probably would start with this [formula] and then try to get everyone to see, basically get everyone to decide we're going to use energy conservation first [so they see it will be easier to solve that way].</td>
<td>forward</td>
<td>cognitive engagement</td>
</tr>
<tr>
<td>The first one [where we plug the formula] looks pretty much like what I did. [I want them to see that there are] sort of looks like something that might be more appropriate for a lower level class, where you're really trying to write everything out that they might need to know, or maybe even some things they don't need to know.</td>
<td>forward</td>
<td>cognitive engagement</td>
</tr>
<tr>
<td>Because I tell them what the thing to do to solve problems is to read the problem... the way you solve it is going this way. And so that's why this... is the order of thought. [Instead of starting from the very beginning with the variable we're looking for,] we're looking for a relationship that involves what you're looking for.</td>
<td>forward</td>
<td>cognitive engagement</td>
</tr>
</tbody>
</table>
manipulating equations in variable form (see Figure 13). Providing a check is explicitly and prominently shown in the third solution artifact (see Figure 14).

![Table](image)

**Figure 13. Variation of symbolic solutions as presented in the artifacts**

![Table](image)

**Figure 14. Variation of solution checking as presented in the artifacts**

Only 13% of the faculty identify a symbolic solution as an important feature of example solutions. Those who like this feature explain that it is better from a theoretical standpoint, and it will enable the students to spot errors. For example:

“Symbolic form till the end will certainly enable the students to spot errors, if something doesn’t make sense, they can spot the symbolic forms of these things and for example look at the dimensions and see whether they make sense.”

Similarly, only 20% of the faculty recognize the feature of solution checking. Most of the reasons suggest that the faculty wants the students to see the reasonableness of the solution and that the solution should make sense. For example:
“This [checking] could be beneficial to engineering students... as the final answer should be reasonable, and makes sense in context.”

These are the smallest percentages of all the features that constitute expert-

Table 10. Example of coding for symbolic solution and checking

<table>
<thead>
<tr>
<th>Citation</th>
<th>Feature</th>
<th>Feature #</th>
<th>Solution</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>And quantities are left in symbolic form until the end. And that will certainly enable the students to spot errors, if something doesn’t make sense, they can spot the symbolic forms of these things and for example look at the dimensions and see whether they make sense. (228 – 231)</td>
<td>Symbolic solution</td>
<td>14</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>Could I actually hold something at that point with that kind of force steady at the center? That would be hard. So you would look for the reality of it? The reasonableness. Whether it’s something that you can actually do. Or could the elevation that you reach be 230 just as easily as 23? That kind of questions I think are important to introduce constantly, especially for engineering students, so that they get a feel for what things can be. (218-231)</td>
<td>Provides a check of the final result (in this case, by interpreting whether the final answer makes sense / reasonable)</td>
<td>15</td>
<td>unclear</td>
<td>unclear</td>
</tr>
</tbody>
</table>
like problem thinking in instructor solution. The findings suggest that these features are underrated or ignored by most instructors.

![Graph showing percentages of faculty mentioning and their preferences towards features in checking solution.]

**Figure 15. Percentage of faculty mentioning and their preferences towards features in checking solution**

**Summary for research question 2**

In general, we found out that faculty recognize features from different clusters of the problem solving process to varying degrees. The most prominent cluster of features that faculty recognize is cluster C1 – initial problem analysis, with the highest percentage of faculty recognize and like the first feature of schematic visualization by 70%.

The second cluster C2 – solution construction is the medium cluster of features in terms of being recognized by the faculty. Out of the 6 features in this cluster, features that exemplify the solvers’ reasoning underlying their choices (F3 – providing a separate overview and F5 – explaining reasoning in explicit words) are the ones that the faculty recognized most (57% and 60%, respectively). We also notice that faculty differ in their preferences of which way to present solutions to students (F12 – backward approach has 17% of faculty like it vs 13% who prefer...
forward approach). A more thorough investigation reveals that this difference in preferences is related to two major goals, the goal of keeping students cognitively involved where faculty do not want the example solution to end up confusing students and the goal of helping students become better problem solvers. A further investigation to explore about this possible connection between the goals and preferences in the direction of solution could be done in future study.

Lastly, the third cluster C3 is the least recognized by the faculty. Design features in this cluster include F13 - symbolic solution, and F14 – providing a check of final result (13% and 20%, respectively).

3. How do faculty compare to TAs?

In the previous section, we examined the extent to which faculty recognize features that the literature suggests as supportive to the goal of helping students become better problem solvers. Here, will compare our findings from faculty data with the ones from a previous study of TAs (Lin et al., 2012). We will compare the data cluster-by-cluster. Note that the TA analysis did not include all features analyzed for the faculty.

C1 - Initial Problem Analysis

The first cluster is about the initial problem analysis. The clusters included in this comparison consist of the feature of drawing and the feature and list of known and unknown.

Figure 16 compares the faculty and TA results for this cluster. This figure suggests that faculty and TAs are very similar in their views on this cluster of features. Faculty notice and like the feature of drawing and, to a lesser extent, the feature of listing knowns and unknowns. The TAs also have similar preferences.
Figure 16. Comparison between Faculty (left) and TAs (right) for C1 - Initial problem analysis

C2 - Solution Construction

The second cluster for the comparison consists of four different features: separate overview, explaining reasoning, alternative approach, and backward solution.

Figure 17. Comparison between Faculty (up) and TAs (down) for C2 - Solution construction

Figure 17 compares the faculty and TA results for this cluster. Here, more faculty than TAs notice these features. We also notice that TAs appear to lack the
difference in preferences that are prevalent in the faculty. For example, faculty are almost evenly divided about their preferences of which way to present solutions to students (17% like backward vs 13% dislike it), while few TAs even notice this feature (4% like vs 0% dislike). It is possible that as so few TAs noticed this feature, TAs may not be sophisticated enough as instructors to have noticed it.

C3 - Checking Solution

The last comparison is about checking solution. This cluster consists of two features, symbolic solution and checking solution.

Figure 18. Comparison between Faculty (left) and TAs (right) for C3 - Checking solution

Figure 18 compares the faculty and TA results for this cluster. We found that few faculty and TAs notice this feature. This finding implies that checking is an aspect of the expert problem solving process that is mostly underrated or even ignored by both faculty and TAs.

Summary for research question 3

In general, we found that faculty and TAs are very similar in the features that they notice and their preference for particular features. In all three clusters, faculty seem to notice the features somewhat more than TAs with very few exceptions (for example, 30% faculty like the list of knowns and unknowns, as opposed to 33% TAs who like it).
Another potentially important finding is the apparent difference in preferences of which way to present solutions to students. This difference between backward vs forward solution construction seems to only be prevalent among faculty. While in the second cluster the faculty preferences are split almost evenly, the data from TAs only show very little indication that a similar preferential difference exists. A further analysis on the data from faculty indeed reveals how this difference is related to two major goals of providing example solutions, while there is no evidence that similar situation arises among TAs.
CHAPTER V
CONCLUSIONS AND IMPLICATIONS FOR PRACTICE

The objective of this study was to find out whether college and university physics faculty have the goal of helping students become better problem solvers when they use instructor solutions in their teaching, and whether they recognize and value example solution features that the literature perceives as helping students become better problem solvers. We were also interested in comparing how faculty as expert instructors compare to TAs as novice instructors. This will help us understand how instructional skills develop through experience.

As the goal of this study is to understand how physics instructors make teaching decisions, the interview subjects were limited to those instructors who had taught the introductory calculus-based physics course with at least five years of teaching experience. In order to compare with TAs, we use the data collected from 24 first year graduate students from the University of Pittsburgh who were enrolled in a semester-long training course. Most of the TAs were simultaneously doing their TA job, either leading recitations, lab sections, or being a grader. Also, the TAs interviewed in this study had just entered graduate school and started their TA positions.

The faculty interviews were conducted previously through direct interviews with the instructors. Each interview began with general questions about how and why the instructor used example problem solutions. The interviewer then gave the three Instructor Solutions to the instructor, who was asked to compare them to the materials they used in classes and to explain their reasons for making those choices. This part was concluded by
asking the instructor to reflect on the important parts of the problem-solving process either as represented in or missing from the artifacts.

We are interested in both the goals instructors have for providing the instructor solutions and the solution features that the instructors recognized in their solutions. We collected the data about their goals from the first part of the interview when we explicitly asked the faculty about their goals in providing the solutions in their teaching, and from the latter part of the interview when the instructors elaborated their features preferences and related their reasons to the goals they have mentioned earlier.

The transcripts were categorized into two main categories: 1) Prior to viewing the artifacts (general situation), and 2) After viewing the artifacts (concrete artifacts). The statements prior to viewing the artifacts are related to the situations when instructors are using the example solutions and the explicit goals of using the example solutions in that situation. The statements after viewing the artifacts consist of two main types of data. The first one is when the instructors mention their specific preferences about features they like/dislike on the instructor solutions, and the second one is where the instructors discuss their goals of using example solutions as related to the certain features they recognize from either the artifacts or their own solutions.

Our finding suggests that helping students become better problem solvers—a goal that is aligned with the recommendation from education research—is indeed a prominent learning goal that most of the faculty expressed when contemplating the use of example solutions. Explicitly 73% of the faculty interviewed recognized this goal as important. However, we found that this is not the most frequently mentioned goal for providing example solutions, as 90% of the interviewed faculty emphasized the importance of cognitive involvement where the example solutions should not end up confusing.
Although most faculty expect example problem solutions to help students develop problem solving skills, many faculty do not notice the features of problem solutions even though the solution artifacts used in the study were designed to highlight these features. We found that faculty recognize features from different clusters of the problem solving process to varying degrees. The most prominent cluster of features that faculty recognize is cluster C1 – initial problem analysis, with the highest percentage of faculty (70%) recognizing and liking the first feature of schematic visualization. The second cluster C2 – solution construction is the medium cluster of features in terms of being recognized by the faculty. Out of the 6 features in this cluster, features that exemplify the solvers’ reasoning underlying their choices (F3 – providing a separate overview and F5 – explaining reasoning in explicit words) are the ones that the faculty recognized most (57% and 60%, respectively). We also notice the preferential difference in choosing the direction of solution as represented in feature F12 - backward approach (17% of faculty like it vs 13% who prefer forward approach). A more thorough investigation reveals that these feature are related to two major goals, to either keeping students cognitively involved by choosing an approach that is clear and not confusing students, or helping students become better problem solvers by showing the target variable at the very beginning of the solution. We suggest that this possible connection can be explored in more details in future studies. Lastly, the third cluster C3 is the least recognized by the faculty. Design features in this cluster include F13 - symbolic solution, and F14 – providing a check of final result (13% and 20%, respectively).

When we compare our findings in faculty to the TAs, we find that faculty and TAs are very similar in the features that they notice and their preference for particular features. In all three clusters, faculty seem to notice the features somewhat more than
TAs with very few exceptions (for example, 30% of faculty like the list of knowns and unknowns, as opposed to 33% TAs who like it). Another potentially important finding is that the difference in preferences of solution direction seems to only be prevalent among faculty. While in the second cluster the faculty preferences between forward and backward solutions are split almost evenly, the data from TAs only show very little indication that the difference even exist. The fact that very few TAs noticed this feature, and that those that did expressed liking for it, implies a lack of recognition as only a handful of people even noticing it. A further analysis on the data from faculty reveals how these differences are related to different major goals while there is no evidence that similar situation arises among TAs.

We conclude that the comparison between faculty and TAs reveal that faculty are quite similar to TAs and, thus, their sensitivity to these features does not appear to increase substantially via their teaching experience. This implies that that faculty do not make much progress spontaneously throughout their career. Thus, professional development is necessary to improve faculty and TA sensitivity to features of expert-like problem solving. Such professional development may be more feasibly done at the beginning of faculty career when they start as TAs themselves.
Appendix A

Human Subjects Institutional Review Board Approvals
Date: October 12, 2011

To: Charles Henderson, Principal Investigator
   William Mamudi, Student Investigator for thesis

From: Victoria Janson, Interim Chair

Re: HSIRB Project Number 11-10-12

This letter will serve as confirmation that your research project titled “Investigating Physics Faculty Practices to Improve Faculty Teaching for Physics Education” has been approved under the exempt category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: October 12, 2012
Date: April 4, 2011

To: Charles Henderson, Principal Investigator
   William Mamudi, Student Investigator for thesis

From: Christopher Cheatham, Ph.D., Vice Chair

Re: HSIRB Project Number: 11-03-29

This letter will serve as confirmation that your research project titled “Investigating Physics Teaching Assistant’s (TA) Practices to Improve Teaching Assistant Training for Physics Education” has been approved under the exempt category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: April 4, 2012
Appendix B

Interview Artifacts
**Homework Problem**

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

The correct answer is 1292 N
Instructor solution I

The tension does no work

Conservation of energy between point A and B

\[ \frac{Mv_A^2}{2} = mgh \]

\[ v_A^2 = 2gh \]

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

\[ \vec{T} - \vec{w} = ma \]

\[ T - w = mv_A^2/R \]

\[ T = 18N + 2\cdot18\cdot23m/0.65m = 1292N \]
Instructor solution II

Known
\[ \begin{align*}
    w &= 18N = \text{weight of stone} \\
    R &= 0.65m \\
    h &= 23m \\
    v_t &= 0 = \text{velocity at top} \\
    v_i &= ? = \text{velocity at release} \\
    v_b &= ? = \text{velocity at bottom} \\
    \text{force my hand exerts} &= F = ?
\end{align*} \]

Unknown

Step 1) Find \( v_i \) needed to reach \( h \)

\[ \begin{align*}
    E_i &= E_f \\
    E_{\text{release}} &= E_{\text{top}} \\
    \text{KE}_{\text{release}} + \text{PE}_{\text{release}} &= \text{KE}_{\text{top}} + \text{PE}_{\text{top}} \\
    mgh + \frac{mv_i^2}{2} &= \frac{mv_t^2}{2} + mgR \\
    v_i^2 &= 2g(h - R) \]

Step 2) Find \( v_b \) needed to have \( v_i \) at release

\[ \begin{align*}
    E_{\text{bottom}} &= E_{\text{release}} \\
    \text{PE}_{\text{bottom}} + \text{KE}_{\text{bottom}} &= \text{PE}_{\text{release}} + \text{KE}_{\text{release}} \\
    mgR + \frac{mv_b^2}{2} &= mgO + \frac{mv_i^2}{2} \\
    \text{Using } v_i \text{ from above:} \\
    v_b &= \left[2gh\right]^{\frac{1}{2}} \]

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

\[ \begin{align*}
    \sum F &= ma \\
    \sum F &= ma_k \\
    T_b - w &= m v_b^2/R \\
    \text{Using } v_b \text{ from above:} \\
    T_b &= w + 2mgh/R \\
    T_b &= w + 2mgh/R = 18 + 2 \times 2 \times 23/0.65 = 1292N
\]

\( T_b \) equals \( F \), the force my hand exerts, for a massless string.
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 $\sum F = ma$, 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
   i) Meeby since forces/accelerations change through the circular path
   ii) I can apply work-energy theorem 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 $\Rightarrow T \perp v \Rightarrow T$ does no work.

Execution:

B) Relate $T_b$ to $v_b$

\[
\sum F = ma
\]
\[
\sum F_R = ma_R
\]
\[
T_b - w = m \frac{v_b^2}{R}
\]

C) Relate $v_b$ to $v_t$

Work = $\Delta KE$

For constant force

\[
\vec{F} \cdot \Delta \vec{t} = KE_t - KE_i
\]
\[
F \cdot \Delta t = KE_{top} - KE_{bottom}
\]
\[-w \cdot h = m \frac{v_t^2}{2} - m \frac{v_b^2}{2}
\]

Substituting C) into B)

\[
T_b - w = 2 \frac{w \cdot h}{R}
\]

\[
F_m = T_b = w + 2 \frac{w \cdot h}{R}
\]

\[
= 18 + 2 \cdot 18 = 23\frac{1}{2}
\]

\[
= 1292N
\]

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

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

Interview Protocol
Introduction: “Please think about your experience teaching introductory calculus-based physics as you answer the interview questions. I’ll start with examples of solved problems.”

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: “Ok. Well, let me show you the solutions that I brought. I’ve got three solutions, and this is the problem that we had you solve earlier. And each of these three solutions is written in a somewhat different way based on things that we’ve seen in instructor's solutions. What I’d like you to do is look through them and tell me what parts of them are similar or different to the kinds of solutions that you would have your students look at.”

Q4: “Please explain your reasons for writing solutions the way you do.”
Appendix D

Example of Interview Transcript 1

(Instructor 13)
So let me get started. I wanted to talk about instructor’s solutions first, and again, these are times when you would solve a problem on the board during class, or post a solution to a homework or quiz, or anytime that a student sees a solution worked out for them during a class. And I’ve got some solutions that I’ve brought with me. I’d like to ask you just a couple of general questions about how you use instructor’s solution. And the first one is just when do students see worked out solutions when they’re taking your class?

Well, they see them for homework and exam, they’ll have problems. That’s the main place. And then they see them in class.

And tell me what your reasons for using solutions in these situations are.

Well I think for homework and exams it’s pretty much, you pretty much have to. You know, students, well, let me think about it... One reason is to allow the students to see where they made mistakes, I guess that’s the main reason. And the second is to try to give examples of good problem solving techniques. So if when I do my solutions, I always make a drawing and I always keep track of my units, maybe those practices will somehow diffuse into the students.

Ok. And that’s for the homework and exams. What about the in-class problems?

In the in-class problems, there the motivation is to, well, to give concrete examples of concepts that we’re working through. Also to show problem solving techniques that they can then use on homework. And of course also to give examples with problem solving techniques.

Ok. And then when you use these, in both of these situations I guess you’re sort of talking about the homework and the exams together, and then the in-class as maybe being something a little bit different. What kind of things do you, would you like the students to be doing when they deal with these solutions? Either when they’re looking at the homework or quiz solutions or when they’re in class watching you?

Ok, well first for the homework and quiz solutions, what I’d like them to do is to look at their homework and my solution together and go through them to see where their mistakes are and to see how I solve the problems. The same with the exams. I’d like them to go through these. And then these should also form study guides for future exams. In other words, I recommend that students go through their homework problems as a way to prepare for upcoming exams. And so then of course it helps them if they have solutions.

Now when you say ‘go through their problems’, what does that mean?

Well ideally it means that they go through and redo all the problems. And they’d use their old problem sets or my solutions when they get stuck, or to check their answers.

Ok.
That’s what I recommend that they do. I’m not sure how many actually do that.

*Ok. And then when they’re, you said when they first look at them you’d like them to compare their solution for your solution. Is that something that you think they commonly do?*

Actually I don’t. I don’t have much direct evidence that tells me what they do. But I suspect that many students never look at the solutions unless they come to an unusual circumstance where they need to. And that just comes because, well, frequently maybe I’ll give an exam question that’s very similar to a homework problem that everyone had trouble with but was worked out in the solutions. And they have the same problems. Anyway, there are a number of things which have shown me that in fact, I think, many students frequently don’t look at the solutions, unless there’s some unusual circumstance.

*Ok. What about in-class problems? Are there things you expect students to do while you work on a problem in class?*

Yeah. I expect that, well, they should be following along. So ideally they should be taking notes, and they should be following along, which should mean that they’re on the same step of the solution as I’m on.

*When you say taking notes, what kind of things should they note?*

They should note, when we’re solving problems, they should basically reproduce the solution to the problem, I think.

*So whatever you write on the board they would write down in their notebooks. Is that what you mean?*

Yeah, something like that, some representation of it.

*And then again, you thought that a lot of the people for the quiz and homework didn’t do what you hoped they would do. Do you think that’s true for the class as well, or…*

Here I think it’s, so the homework I have almost no real evidence about. Here, I mean I have some students’ notes, and many of them take beautiful notes which are actually better than my lecture notes. And then many don’t. I, you know, I feel like this is one of the areas, I’m not going to teach them how to take notes. I can’t tell a student whether note taking is useful or not useful to them. I can tell them that I found it useful when I was a student. If they don’t take notes they should be following along with what I’m doing in their mind. And if that’s enough for them…

*So it sounds like you don’t really care what they’re doing with the material, what’s important is that they follow along while you’re solving it in class, but you don’t really care whether they write it down or not, as long as they get something out of it.*
Yeah, that’s right. Except that I know when I was a student, it was important that I write things down. Even if I never referred to the notes later, somehow the act of writing it down made it concrete.

Ok. Well, let me show you the solutions that I brought. I’ve got three solutions, and this is the problem that we had you solve earlier. And each of these three solutions is written in a somewhat different way based on things that we’ve seen in instructor’s solutions. What I’d like you to do is look through them and tell me what parts of them are similar or different to the kinds of solutions that you would have your students look at.

Ok. So, this solution is fine. It’s very terse. There’s not much explanation.

Is that something common in solutions that you give out?

I’m usually more verbose. I mean this has the, the students can check their answers from this, that’s fine. And I guess probably most of them can see what you’ve done. But for students who didn’t know how to solve the problem the first time, this probably won’t help. So I’m usually more wordy. [pause]

Ok, this is a very well worked out solution. I mean, every single step is here and there are notes that describe every single step. I probably wouldn’t be this verbose. Normally I won’t, for two reasons. First of all, I don’t want to overwhelm students. They might look at this and just not read it. And secondly, I just don’t have the time to work out such beautiful, thoughtful solutions.

And then what things that are here that you probably would not have if yours would be somewhat less dense?

Well, lets see, at the top of course I’d have the drawing. That’s important. Here, I wouldn’t have this, I imagine. I probably would break it up into steps like this. But I might not show all the intermediate steps. So here, I might say the first line, e initial = e final, then this line, and then the last line. Something like that.

So skip some of the intermediate steps.

Right. And then from here, well...oh, I see. Lets take a close look at this. I actually did this a little bit differently in my solution. Well, so now looking not just at the style but also at the way this was done, I didn’t have this intermediate step of e release = e top, and then e bottom = e release. Although the first time I went through the problem myself before I wrote down my solutions, I did have this intermediate step.

So if you were writing it up for students, is it important to do it one way or the other, or does it matter?

I probably would, well, if I was writing this up for students, I would probably use e final = e bottom. Because I don’t think there’s anything to be gained with this
intermediate step. Maybe a note about it, that’s all. And then in this last part, yeah, again, I might have this line here and then the next line, and then the last line here. So, I don’t have any... yeah.

Ok, well what about the third one?

Ok, actually I like this solution the best because it describes the approach first, and then it does the execution.

And is that something that you do when you’re writing them.

I do although I typically make this part much, much shorter. Mainly because of my own laziness. But when I’m describing a problem in class, then I try to do this as well, to diagram the approach, to talk about the approach first for the class, and then go through the execution.

Ok. And when you talked about it in class, you would say this kind of thing, or would it be something different?

It would be something like this. I probably would start with this and then try to get everyone to see, basically get everyone to decide we’re going to use energy conservation first. And then basically try to get everyone to agree that, well, if we know the initial velocity of the stone, then we’ll be able to figure out the forces. And then first find the velocity and then do the second part and figure out the force from the velocity. So, you know, the same thing but I would probably first break the problem down into those two parts, solve one, and then solve the other.

Ok, rather than explaining how to solve both of them...

Everything...

Ok, that makes sense. And you would, it sounds like you would do it in the reverse order that we did it in here?

Um, I guess I probably would. I don’t know if that’s meaningful, but...

Ok, so it sounds like it’s not something that you think has to be done that way, it’s just your personal preference for doing it that way.

Yeah.
Appendix E

Example of Interview Transcript 2

(Instructor 8)
My first question is in what situation, I mean lecture, after test, after homework, do you give students solved solutions, examples of solved problems?

Like this? Basically in classroom. In lecture.

In lecture?

Yeah. I spend part of the lecture.

Solving on the blackboard.

Yeah. After giving the principles, the concepts, the ideas, then sometimes I use the simple problems in the book. But most of the time, I ask the student to read the sample problems as their reading part.

So they have to read the textbook sample problems after you...

Yes. So, I usually don’t go through the sample problems in the book. So usually that’s relatively simple for students to understand the concept. So I usually pick up some of the homework problems, which I think can best represent the concept, the idea, or the theories or principles. And I explain this.

And you explain the whole solution?

Yeah, as the application of these principles, or theories and so on.

And after tests, they get posted solutions? You give them solutions after the quiz or the test?

You mean which solution?

For the test?

Oh, the test. You mean mine right. I give three tests.

No, my question is, do you give them solutions for the test after the test?

Yeah, I’m answering your question.

I see.

I give 3 tests besides the final. Each test, after each test, I usually don’t give the solution but I pick out the students who did well in this problem, and another student who did well in other problems. So usually, which is almost 100% of the time, all of the test problem solutions are given by my students.

On the board?
On the board.

*Interesting.* *Ok.*

So when, usually after the test, I give the test back to students, then I have a list of the person, if they’re there. Sometimes they’re not there; I usually have 2 or 3 candidates for one problem. So I ask you, can you do the first problem for us on the board? *Sure.* And they do it. And usually that’s the thing.

*I see.*

And then this student will ask the class the questions that he tries to answer. If he needs help, I help answer.

*The students that made it good...*  

He, after he finish the problem on the board, he will ask if they have any questions. So some students ask questions.

*And he has to answer?*  

He has to answer.

*Oh, interesting.*  

If he didn’t do well in answer the questions, because sometimes they did well but didn’t explain themselves very well, so I’ll help. Or if there’s no questions, I give a summarize.

*Of the main things that you want to make clear.*  

Yeah. And I mention what are the most common mistakes made, why people made some mistakes and so on.

*I see.*  

It’s to talk about 20, 25 minutes, half hour lecture to go through the test.

*I see, so three questions, or...*  

Yeah, usually I give 3 test problems.

*I see. Now what is your main purpose in giving tests and grading them?*  

Firstly you have to judge whether the student understands or not. And they know the topic or they don’t. And their ability to solve the problem, as a proof that they really studied and met the require of the course. If you don’t give tests, how can you...
So the main thing is evaluation for the institution?

Yeah.

Ok. Now what would you like your students to do when they look at the solved examples? What do you want them to go through, to do when they look at the solved examples?

You mean the board, the example problems?

Yeah, or the book. You said they look at the book at the sample problems, and they look at the board. These are the 2 main situations. What do you want them to do when they look at it?

They should study the concept.

So they should find out what are the main concepts?

Yeah, the concept first. They shouldn’t just look at the problem, they should understand the concept or the theories or the formulas before they look at the problems.

Before. And when they look you want them to see how this formula or this principle is applied?

Yes.

I see. And do you think this is what they actually do?

I think so. All of my tests are open-book tests. I always give open-book tests.

Open-book?

Yeah. So I never ask a student to memorize any formula. I only say, you don’t need to memorize any formula, just understand the formula. And also of course, you need to know where this formula is in the book when you need it in the test.

Ok. Now I will show you several instructors’ solutions, and these are solutions that are not like board solutions, they’re solutions that are posted on the web. We found them, we found some types of solutions and we wrote the solutions for the problem that you looked at based on them. So what I would like you to do is first, look at these 3 solutions, and tell me how they are similar or different to the way you would write a solution. And explain to me why you write solutions the way you do.

My approach is similar to number 3. The number 1 and the number 2, they talk about conservation and mechanical energy first, then they talk about the force.
Right.

The number 3 talks about force first, and then talk about the energy. My approach is similar to this.

And why?

Why? Because their question is to ask the force.

So you start from what the student is asked to find and then go.

Yeah, then we, because they need to determine the force of people [unintelligible] on the street, right.

Right.

In order to determine that you need to determine the centripetal force. The weight is given. So in order to determine centripetal force, you need to know the velocity. And the velocity is related to kinetic energy.

So you want them to start always with what they are looking at, and go back and find what they need.

Yeah, that’s my approach.

I see. And are there other features that would resemble...

Yeah, this person did the energy first. He determined the initial velocity. Then he determined the centripetal force. That’s, of course it’s the same, but the thinking is a little bit different.

I see. And in other ways, were your solution would resemble more each one of them or more different...

This is similar to mine.

This is similar, this is also the way you will go through—first you’ll do that, and then you’ll...

Yes. The only difference between this and mine is that I have vector formula first. He didn’t give a vector formula. He gave this, f=ma. Newton’s second law. That’s true. But this force, sigma f = t + w.

Ok, he wrote this in the formula then you...

Then I used this positive direction. So my equation would be t – w = f...

So you would show a coordinate system which is not shown here.
Yes. That’s the difference. But actually he gives $t$ in the same direction as $a$, so he used $tw - w$. Mine is just 1 extra explanation, $yt-w$.

*And usually you give more explanation?*

Yeah, I use, I always use the vector form first, then change the vector form into [unintelligible] form, which is this.

*And why do you do more steps?*

Some people, that’s always the students problem. They know Newton’s law, $f=ma$. Then when there are two or more forces involved, there is acceleration, the most common mistake made was, which subtract which.

*I see. So they don’t know how to use coordinates.*

The directions.

*The directions.*

Then of course in a lecture, I always tell them that usually you choose the force which is in the same direction as acceleration as positive, and the others in the other direction as negative. But when I solve the problem, I always tell them, you decide your positive direction. So, for example, in this problem, I chose going up as positive direction.

*But you could choose it also down.*

Yeah, you can choose down. It’s up to you. But this problem, you choose up it’s easier because acceleration is up.

*Right. Ok. Now I would like to, is there other similarities or differences by the way you write problems and these problems are written?*

This is what I did. This is extra step.

*With the unit vectors.*

Yeah. Then I changed this from vector form to scaled (?) form. That’s what I did. And they didn’t do that. It’s the same, but just you spend one more minute.

*And what is the intent?*

Because here I didn’t put the centripetal force. I just put the $fc$.

*I see, so now you explain them what the centripetal...*
Yeah, what the centripetal force is. The centripetal force is $mv^2 / r$.

So you would do all the explanations?

Yeah, I usually do.

And why do you do so?

This is community college, and the students background is widespread. So some students are very fast. They don’t need this. But a large portion of the class, if you omit some steps, if you go too fast, they couldn’t follow.

So this is for them to follow...

If I’m in MIT I might not do this. I might go a step and everybody might understand.

So you will never do something like this guy did, which is very short?

This is my goal for the students at MIT, I think.

In MIT. But in community college it will look more like this?

I will do it step by step. That’s what I do. Yeah, I have the experience if you do it too fast, then the students complain, they don’t understand. They couldn’t follow.
Appendix E

Interview Rubric
<table>
<thead>
<tr>
<th>Where</th>
<th>Interaction (not really important)</th>
<th>Relation to P solved by students</th>
</tr>
</thead>
<tbody>
<tr>
<td>I- In class, O-Out of class</td>
<td>From ins.(one-way interaction) dialogue with students (2-way)</td>
<td>Post P - trying to solve some problem on their own (not on test), Pre P, Post T (Test), Pre T, N – None that we know</td>
</tr>
</tbody>
</table>

**Purpose column:** category (from list)
**Intended column:** mechanism category (from list, positive or negative)
**Actual column:** LEFT= explain in words, RIGHT: (similar (most): +, partially similar (some): ~, not similar (few): -, unclear: no information)

<table>
<thead>
<tr>
<th>Purpose category list (PS=Problem solving; C= concept)</th>
<th>Mechanism category list</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Keeping students emotionally involved</td>
<td>1. reflect on their own solution using instructor solution a) first solve the problem on their own; b) compare; c) analyze&quot;) compare=&quot;identify specific/local mistakes&quot; and that &quot;analyze = generalize&quot; also, b) implies a), and c) implies b) and a)</td>
</tr>
<tr>
<td>2. Keeping students cognitively involved</td>
<td>2. Observe and extract how one could approach the problem (either when the student have already tackled it or not) 2’ - physics conceptual knowledge 2” - problem solving strategies</td>
</tr>
<tr>
<td>3. Setting the standard for an adequate solution</td>
<td>3. Other: i.e. Students redo examples (&amp; think on concepts; Copy solutions for review when needed…</td>
</tr>
<tr>
<td>4. Promoting students ability to apply concepts and principles to solve THE problem 4a) focused on promoting conceptual understanding 4b) focus on the approach to solve some SIMILAR problem: promoting students ability to retrieve a solution plan for a specific problem 4c) attaching a concrete meaning for quantities that play in typical problems</td>
<td></td>
</tr>
<tr>
<td>Citation, Line number (in parenthesis)</td>
<td>Situation: Where (I, O); 1, 2way; Relation Post P, Pre P, Post T, Pre T, N)</td>
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</table>
**Citation column:** Enter the citation analyzed, and line number. Enter F if citation relates to feature and R if relates to reason

**Feature column:** In each row enter a title for a feature you identify that the instructor noticed

**Feature Number column:** Try, if possible, to fit one or more feature from the following list.

<table>
<thead>
<tr>
<th>Feature Number</th>
<th>Feature Description</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Provides a schematic visualization of the problem (a diagram)</td>
</tr>
<tr>
<td>2</td>
<td>Quality of visualization</td>
</tr>
<tr>
<td>3</td>
<td>Provides a list of known/unknowns (even when it’s written on the FIGURE)</td>
</tr>
<tr>
<td>4</td>
<td>Provides a “separate” overview of how the problem will be tackled (explain premise and concepts — big picture — prior to presenting solution details)</td>
</tr>
<tr>
<td>5</td>
<td>Explicit sub-problems are identified (Explicitly identifies intermediate variables and procedures to solve them)</td>
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<tr>
<td>6</td>
<td>Reasoning is explained in explicit words (Description/justification of why principles and/or sub-problems are appropriate/useful in this situation)</td>
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<tr>
<td>7</td>
<td>The principles/concepts used are explicitly written using words and/or basic mathematical representations (e.g., F = ma or Newton’s 2nd Law)</td>
</tr>
<tr>
<td>8</td>
<td>Thorough derivation (Detailed/verbose vs. Concise/short/simplified/short lots of derivation)</td>
</tr>
<tr>
<td>9</td>
<td>Long physical length (Long/verbose vs. Short/concise vs. Balanced/not too long, not too short)</td>
</tr>
<tr>
<td>10</td>
<td>A includes more than the minimal set of intermediate variables required to solve the problem</td>
</tr>
<tr>
<td></td>
<td>B includes more physics considerations accompanying the solution than needed for an adequate solution</td>
</tr>
<tr>
<td>11</td>
<td>Provides alternative approach</td>
</tr>
<tr>
<td>12</td>
<td>Solution is presented in an organized and clear manner</td>
</tr>
<tr>
<td>13</td>
<td>Direction for the progress of the solution process: Forward vs. Backward</td>
</tr>
<tr>
<td>14</td>
<td>Symbolic solution (numbers are plugged-in only at the end)</td>
</tr>
<tr>
<td>15</td>
<td>Provides a check of the final result (e.g., if the unit is correct, or if the answer makes sense by examining the limits, or whether it is reasonable)</td>
</tr>
<tr>
<td>16</td>
<td>Solution boxed</td>
</tr>
<tr>
<td>17</td>
<td>Explain the meaning of symbols</td>
</tr>
<tr>
<td>18</td>
<td>In first person narrative</td>
</tr>
<tr>
<td>19</td>
<td>Approach a problem from general principles and only later focus on the specific case</td>
</tr>
<tr>
<td>20</td>
<td>Exploration of problem space (by trial and error)</td>
</tr>
</tbody>
</table>

**Solution column:** enter the solutions that the instructor believe best represent this feature

**Preference column:** Enter + if the instructor like, - if dislike this feature. Y if s/he uses and X if s/he does not use this feature, ~

**Reason column:** Explain the reason in our words - Why does the instructor like/dislike, use/not use this feature?

**Category of Reason column:** Sort the reasons to the following categories:

<table>
<thead>
<tr>
<th>Categories</th>
<th>Specific Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Keeping students emotionally involved</td>
<td>5. Modeling expert-like PS, Develop a repertoire of PS strategies that can be applied to NEW problems</td>
</tr>
<tr>
<td>2. Keeping students cognitively involved</td>
<td>6. Saving time</td>
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<tr>
<td>3. Setting the standard for an adequate solution</td>
<td>7. Other…</td>
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<tr>
<td>4. Promoting students ability to apply concepts and principles to solve THE problem</td>
<td>8. Unclear</td>
</tr>
<tr>
<td>4a) focused on promoting conceptual understanding</td>
<td></td>
</tr>
<tr>
<td>4b) focus on the approach to solve some SIMILAR problem: promoting students ability to retrieve a solution plan for a specific problem</td>
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</tr>
<tr>
<td>Citation</td>
<td>Feature</td>
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Henderson, Charles. (2002). *Faculty Conception About the Teaching and Learning of Problem Solving in Introductory Calculus-Based Physics.*


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