Does Solving Ill-Defined Physics Problems Elicit More Learning than Conventional Problem Solving? [*]

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Abstract. Students who complete an introductory physics course often do not have a good conceptual understanding of the principles taught. There have been various attempts at increasing conceptual learning, often with only modest improvements. One promising avenue is the use of ill-defined problems. However, it can be very difficult for students to solve these problems without proper support. If ill-defined problem solving can be supported using intelligent tutoring systems, then it will be possible to investigate the potential of ill-defined problems and their influence on conceptual learning.

Keywords: Intelligent Tutoring Systems, Ill-Defined Problems, Physics, Problem Solving.

1 Introduction

1.1 Problems with fostering conceptual understanding

One of the great challenges in physics education is that traditional physics teaching methods lead to shallow learning. Most physics students, regardless of their grades in class, have a poor understanding of the concepts being taught [1]. One possible source of this discrepancy between conceptual understanding and performance is that traditional teaching methods rely heavily on the use of well-defined physics problems as both the primary practice and assessment activity. While it is important for students of physics to be able to solve these well-defined problems, it is obviously not enough.

The homework and exam problems typically presented in a physics class are so constrained that students do not have to do any conceptual analysis of the problem in order to solve them. They tend to look at the quantities supplied in a problem description, match them with known equations, and simply use algebra to find the value of the variable requested in the problem[2]. Additionally,

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successful novices will match surface features of the problem (particular keywords, phrases, or quantities) to previously solved problems or worked examples to decide which equation to use [3]. These algebraic methods may be reliable methods of solving straight-forward physics problems, but require minimal conceptual knowledge of physics.

In contrast, experts in physics solve problems by conceptualizing the problem first, forming a qualitative solution, and then finally using the relevant given quantities to arrive at the numeric solution [4]. Performing more expert-like problem solving strategies can be important for fostering this conceptual knowledge. When novices are given the specific task of specifying which physics principles are needed to solve well-defined problems as part of homework and exams, which requires them to perform an intermediate step in the expert problem-solving strategy, their understanding of these concepts improves more than just solving problems[5]. Having a system that enforces the specification of principles before solving the problem and provides immediate feedback could increase the effectiveness of the task for novices[6].

A popular strategy for attempting to improve conceptual understanding in the classroom setting is the use of demonstrations. Classroom demonstrations are designed to capture student interest and provide a practical, real-world event to deepen understanding of the theoretical concepts taught in lecture. Despite the good intentions of the instructor, classroom demonstrations on a concept have little effect on the students' understanding of that concept. This is true even when students are given additional tasks to increase engagement with the demonstration[7]. Asking students to predict the outcome of the demonstration requires conceptual analysis, and this task does increase conceptual understanding. However, even the students who did this task ultimately did not perform well on the end-of-semester conceptual task of predicting outcomes (30% correct). Analysis of the errors demonstrated in the assessment show that students are more willing to rely on faulty "common sense" beliefs about how the universe behaves rather than work out the answer from the concepts that they have been taught. It may be that while this strategy is useful, students do not get enough practice with conceptual or qualitative analysis over the course of the semester to master the skill and benefit from it.

1.2 ITS and conceptual understanding

Intelligent tutoring systems have proven to be useful in improving conceptual understanding in physics students[8]. This experiment used the ITS system Andes as a framework for presenting physics problems to students. The normal Andes programming presents a series of "hints" if requested by the student. The experimental manipulation replaced some of these hints with detailed dialogues concerning the relevant physics concepts. If a specific error was identified, based on the problem and the student's partial solution, a dialogue targeting the conceptual knowledge associated with the error would be given. The dialogues were modeled after expert human tutors' instructional strategies, and were found to improve the students performance on a concept-based post-test.

This improvement was only seen on post-test questions associated with concepts that students had seen in the dialogues they received. This finding suggests that while this strategy is at least partly successful, it failed to find many problems in conceptual understanding. Because this approach can only address conceptual problems if they result in problem solving errors, the students who use shortcut strategies successfully, such as the algebraic method and interpreting surface features, cannot be helped by it. If the underlying conceptual misunderstandings could be revealed, then targeted dialogue might be applied successfully to those concepts as well.

1.3 Ill-defined problems and conceptual understanding

The use of ill-defined problems for increasing conceptual learning has been investigated in non-physics contexts. The term "ill-defined problems" cover a broad category of problem types, including problems where the problem specification is incomplete, there are multiple possible solutions that are not equivalent but equally valid, or there is no definitive solution that experts can agree upon [9].

For example, if a physics problem does not give numbers for all of the necessary variables, the algebraic method cannot be applied, and the problem is referred to as "ill-defined". These ill-defined problems can not simply be solved using algebraic shortcuts, they must first be qualitatively approached in order to determine what information is needed to solve the problem. To reach an understanding of this ill-defined problem, students must rely on their knowledge of concepts, rather than their skill at manipulating numbers in equations. This requires students to follow the concept-based problem solving strategy used by experts, rather than bypassing most of that strategy by relying on the novice algebraic shortcut.

In a study involving computer database design, peer groups of novices were able to complete an ill-defined problem, but needed extra support to do so[10]. They were given prompts to direct them through each step of an expected problem-solving strategy. These prompts may have helped frame the task for participants who were not used to dealing with ill-defined problems by dividing the task into smaller, better-defined problems. While the prompts helped participants to arrive at better solutions to the ill-defined problems, conceptual understanding was not measured. This kind of prompting scheme may be useful in designing a dialogue system for use with ill-defined problems in an ITS.

Ill-defined problems have been used successfully in conjunction with peer group experiments. While the use of peer groups can be a powerful tool in education, their success in solving ill-defined problems depends on many factors. The size of the group, ability of individual members, personality of individual members, and gender composition all affect the outcome[11]. In addition, time and effort was expended by the researchers to assign task roles to each individual and to evaluate the group dynamics. Research that combines ill-defined problems with small group work, such as this study, Activity-Based Physics, and Project SCALE-UP, is unable to address which factor (ill-defined problems or group work) is most responsible for improvement in conceptual learning.

Presenting ill-defined problems to individuals has produced disappointing results. In the computer database design study discussed above, individuals performed badly on the ill-defined problem tasks despite receiving supportive prompts[10]. When ill-defined physics problems have been presented to individual physics students on a case-study basis[12], none of the students were able to solve the problems. While the task is daunting, it should not be impossible. If peer groups can solve this type of problem, then individuals should be able to solve ill-defined problems as well if given the proper support. Some differences in strategy have been observed in how peer groups solve ill-defined problems as opposed to individuals. Groups are more consistent in following a prescribed problem-solving strategy than individuals, and are more likely to state the physics concepts and principles being used[13]. An intelligent tutoring system could be designed to guide novices through this process and provide immediate corrective feedback as well as providing support for implementing the solution.

1.4 ITS and ill-defined problems

Intelligent tutoring systems can be successful in supporting individuals in solving ill-defined tasks in non-physics domains. For psychotherapists in-training, analysis of simulated psychotherapy sessions is an important learning tool, but the process is not procedurally well-defined. By providing feedback comparing the analysis of novices to those of experts, an intelligent tutoring system can foster improved performance on this task[14]. While professional psychotherapy has been referred to as "an art, rather than a science," this suggests that intelligent tutoring systems can be used with ill-defined tasks to support conceptual thought in science as well.

From previous research using peer groups to support solving ill-defined problems and intelligent tutoring system's success at improving conceptual knowledge, if given the chance; it should be possible to combine them in order to see if solving ill-defined problems is an appropriate and productive task for students. Additionally, if solving ill-defined problems proves to be beneficial, scaling up an intelligent tutoring system to very large classrooms or for distance learning is easier than specifying and maintaining cooperative groups.

In particular, this study is designed to show that if students are required to figure out what information is needed to solve ill-defined physics problems before solving them, then they will develop better conceptual understanding than if they had been presented with the same problems with all the necessary information provided.

It is expected that working on ill-defined problems will help conceptual understanding. Students will be required to analyze the problems in a conceptual way to decide which principles and equations to use in order to decide what quantities need to be specified to make the problem well-defined. This task should also encourage students to evaluate the principles on a deeper level as they realize the shortcomings of any shallow strategy.

2 Methodology

Approximately forty college students from the University of Pittsburgh who are taking or have taken an introductory college level physics course will be recruited to participate. It is important to have participants who already are familiar with physics as solving the physics problems used in this study would be beyond their capabilities without many hours of training. The study is to take place in computer labs under the direct supervision. The participants will be randomly split into two conditions. In the experimental condition, participants will be asked to solve a set of ten ill-defined physics problems. In the control condition, participants will solve the same number of equivalent well-defined problems.

In order to see if ill-defined problems encourage people to develop and use conceptual knowledge, it is important to define what type of ill-defined problems will be used in this study. Ill-defined problems can be defined as problems that either have missing information needed to solve the problem, unclear final goal, or multiple solution paths [15]. In this study, only problems with missing information will be used. One of the main reasons for this limitation is to keep the problems tractable for both the participants and the intelligent tutoring system. The more important reason is that, once the information is provided, the problem becomes well-defined. This is important because it sets up the comparison that is to be evaluated. If the only difference between the two conditions is if a participant solved the ill-defined or well-defined version of the set of problems, then it is easier to assume that the difference was in the nature of the tasks. For example, they will be present with problems like the following:

> Regina is practicing skateboard tricks. She grinds her board down a railing and lands on an old mattress she placed at the bottom of the railing. How far does the mattress compress after she lands on it?

Another important characteristic of the problems is that they have a minimal use of physics terminology ("momentum" and "energy," for example) or physics textbook problem conventions that could easily be used by novices to guess the principles used to solve the problem using these surface features. It is desirable that the problem has a single optimal solution but that it is not easily discerned from surface features of the problems statement. It is assumed that participants who solve the well-defined version of a given problem will focus not on the problem, but on the information provided and they will try to match that to known equations and use a general problem solving strategy to reach the goal. For participants who solve the ill-defined versions, they will not have this crutch and will be forced to decide which principles they will use before implementing a solution.

In order to help participants solve ill-defined problem, the intelligent tutoring system will require that the participant first specify what quantities they need to solve the problem; for example, the spring constant of the mattress. This will be supported with short, scripted dialogues that will help guide the participant to select relevant principles and determine what information is needed in order to use it. After an appropriate list of requested information is specified, then the system will provide the necessary information. For example, the system will start out by asking "What quantities would you need to solve this problem?" If the answer is incorrect or incomplete, it will ask "What main principle would you use to solve this problem?" If they have problems with this question, various targeted dialogues about candidate principles and their appropriateness would take place.

Once the participants have the necessary information, they will produce a solution using Andes [16], a model tracing tutor for solving well-defined physics problems. Andes will be used because it has a proven record of helping people solve physics problems and it removes any bias in instruction a human would have while tutoring the participants through the task of producing a solution. It is also noted that Andes is a great help in improving problem solving ability in students, but not necessarily in conceptual knowledge [8]. Andes records copious data concerning problem solving actions and can provide uniformly scaled scoring for solutions, both of which can be analyzed for differences in problem solving ability. It is also an accepted tool in several college physics courses, including the Physics LearnLab which is part of the Pittsburgh Science of Learning Center and is a planned site for additional experiments. These future experiments will investigate if this manipulation can accelerate future learning as measured by better performance on traditional homework problems and exams as well as affective measures of confidence in physics.

As for assessment measures, multiple choice problem from a test of conceptual knowledge of energy and momentum will be used as both a pretest and posttest measure [17]. It is designed to measure conceptual learning, particularly in introductory physics course. To reduce the possible effects of test-retest bias, a problem matching task will also be used as a posttest measure. In the problem matching task, participants are presented a target problem statement and then asked which of two additional problem statements would be solved most similarly to the target problem without solving any of the problems [18]. This task is useful because it can easily measures problem solving expertise without complicated rubrics for grading individual solutions and it factors out mathematical ability as a source of variance. It is very useful in differentiating between people who rely on surface features to solve problems verses those who conceptually analyze the problem, a noted difference in novice versus expert problem solvers[2].

3 Conclusion

Given the hypothesis, it is expected that participants who solve ill-defined problems will demonstrate better conceptual understanding by performing better on the assessments of conceptual understanding. If they become better problem solvers in that they are able to conceptually analyze problems, then they should get more of the problem matching task items correct as well as increased gains in the conceptual multiple-choice task.

Training students to conceptually analyze problems before attempting to solve them should lead to increased performance in several areas, in particular with solving physics problems in general. Analyzing the logfiles from the Andes problem solving sessions are expected to show differences between the two conditions. If the ill-defined problem solvers are conceptually analyzing the problem, then they will likely request less help. In particular, Andes can respond to "What's next?" help requests with hints about what principle to apply next. If the participant already has an idea of what principle they are going to apply, then they are less likely to use this functionality.

Additionally, if the participant has a general idea of the solution, then they are less likely to exhibit signs of floundering, such as help abuse. Some help abuse that has been found in Andes is trial-and-error (corrective feedback abuse) and repeated requests for help so that the next step is explicitly given (hint abuse). If performing the conceptual analysis before solving the problem is a key component to producing expert problem solvers, it should be reflected in their use of the help system. If they rely on it less and are still producing sufficient solutions, then that can be seen as evidence for it.

4 Perspectives

If this study has positive results, then the next step would be to introduce these ill-defined problems to a classroom. It would be important to integrate the problems into the normal curriculum and have them included in appropriate homework assignments. The ill-defined problems would come after the relevant principles have been practiced using traditional well-defined problems (normal homework and textbook problems). It is important that students are familiar with the concepts and equations used, even if they do not fully understand them, before they are asked to perform the more difficult task of solving these ill-defined problems.

One important reason to integrate this task into classrooms is to investigate if students find the task worthwhile. Some gross measurements of interest would be completion rates of assigned ill-defined problems. Most introductory classes put little grading weight on homework problems, so if students find ill-defined problems not worthwhile, then they are more likely to skip doing them. Checking this would be a simple, but crude measure of the acceptance of the task.

The main reason for including this task in a classroom is to investigate if it is beneficial for the student in other parts of the curriculum. If students who solve ill-defined problems rely less on shallow problem solving methods, then this should be detectable in other parts of the course. For example, it could show up as better performance on homework and exam problems concerning concepts not used in the ill-defined problems.

It has also been suggested that measures of the student's affect towards physics may be influenced by these problems. Solving ill-defined physics problems may increase their confidence in being able to "do physics." It may also increase there self-assessed understanding of physics concepts. It might also provide an important cognitive bridge for students in connecting what they learn in physics to their understanding of the real world by demonstrating a broader range of problems that they are able to solve (e.g. physics is not just for Atwood's machines).

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