Introducing Ill-Structured Problems in Introductory Physics Recitations

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Abstract. One important aspect of physics instruction is helping students develop better problem solving expertise. Besides enhancing the content knowledge, problems help students develop different cognitive abilities and skills. This paper focuses on ill-structured problems. These problems are different from traditional "end of chapter" well-structured problems. They do not have one right answer and thus the student has to examine different possibilities, assumptions and evaluate the outcomes. To solve such problems one has to engage in a cognitive monitoring called epistemic cognition. It is an important part of thinking in real life. Physicists routinely use epistemic cognition when they solve problems. We present a scaffolding technique for introducing ill-structured problems in introductory physics recitations and describe preliminary results of an exploratory study of student problem solving of ill-structured problems.

Keywords: Student problem solving, Ill-structured problems, Cognition, Epistemic cognition, Metacognition.
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INTRODUCTION & MOTIVATION

Studies of workplace needs indicate that problem solving is one of the most important abilities students need to acquire. [1] Are the types of problems one encounters in the workplace similar to problems that students solve in a traditional educational setting? Do they invoke the same cognitive abilities and problem solving skills?

Most of real-life and professional problems are ill structured. However, in educational settings we polish problems and make them well-structured problems. [2] Shin *et al.* [3] compared the problem skills required for solving well-structured and ill-structured problems in the context of open-ended, multimedia environment in astronomy. They found that ill-structured problem-solving scores were significantly predicted by domain knowledge, justification skills, science attitudes, and regulation of cognition, whereas only the first two categories were significant predictors for well-structured problem-solving scores. So, a wider range of skills and cognitive abilities are required for being a good problem solver.

It is equally important to consider the benefits of using ill-structured problems for improving students' content knowledge of physics. Kim and Pak [4] found that there is little correlation between the number of traditional well-structured problems solved and conceptual understanding. Is it possible that solving ill-structured problems helps understand physics better?

Ill-structured problems have been used in different instructional settings in physics education research. Heller et al. [5] have designed context-rich problems (which can be considered as a subcategory of the ill-structured problem domain) and used them in recitations. Students can be engaged in ill-structured problem solving through science research projects [3, 6], as well as in non-traditional laboratory sessions in physics courses. [7] In this paper we describe a scaffolding technique for introducing ill-structured problems in general (not only context-rich problems) in physics recitations and focus specifically on their implications on students' epistemic cognitive skills.

EPISTEMIC COGNITION

There are several identifying characteristics of ill-structured problems. Typically, they fail to present one or more of problem elements, have vaguely defined goals and unstated constraints, possess multiple solutions and solution paths, posses multiple criteria for evaluating solutions, and represent uncertainty about which concepts, rules and principles are necessary for successful solution. [3] Examples of ill-structured problems are found in Appendix(# 1and 3).

Kitchener [8] proposed a three-level model of cognitive processing to categorize the thinking steps one makes when faced with an ill-structured problem (cognition, metacognition, epistemic cognition). At the first cognition level, individuals read, perceive the problem, perform calculations, etc. At the second metacognitive level, individuals monitor their progress and problem-solving steps performed in the first level. At the third epistemic cognition level, individuals reflect on the limits of knowing, the certainty of knowing, and the underlying assumptions they make. Epistemic cognition influences how individuals understand the nature of problems and decide what kinds of strategies are appropriate for solving them.

An example of first-level cognitive activity in solving a simple mechanics problem can be reading the problem, writing down Newton's equations, and solving for an unknown. An example of metacognitive level activity is monitoring first-level cognitive tasks, such as checking the math, making appropriate notations, choosing productive representations (e.g., drawing a free-body diagram), making time management decisions, etc. An example of epistemic cognitive activity is reflecting on the limits of knowing, the criteria of knowing, the assumptions, the types of strategies that should be chosen, limiting cases, reasonableness of the answer, etc.

ILL-STRUCTURED PROBLEMS IN AN INTRODUCTORY PHYSICS COURSE

We introduce ill-structured physics problems in cooperative group solving activities in recitations [5] using a scaffolding technique described below.

Heller et al. [5] have shown the effectiveness of group solving of context-rich problems (they usually are ill-structured). Working in groups helps students acquire complex problem-solving skills while easing the frustration students might have due to the difficulty of finding the correct approach to the problem.

We believe that one of the important features of scaffolding ill-structured problems is prompting students to ask themselves the following epistemic questions during every step of problem solving: "How do I know this? Am I making any assumption while doing these steps?" Schoenfeld used a similar technique to help students develop metacognitive skills in mathematical problem solving. [9] He asked students metacognitive questions during classroom problem solving: "What exactly are you doing?" "Why are you doing this?" "How does it help?"

One of the first steps of problem solving is constructing the problem space of the task. [10] The problem space consists of all possible actions the problem solver can take. Experts not only construct richer problem spaces, but also more productive and meaningful ones. Novices are not able to recognize problem spaces as well as experts, as they pay more attention to surface characteristics of problems.

Once the problem space is constructed, the problem solver needs to reflect upon the alternative steps she/he can make. For ill-structured physics problems this often means reflecting upon what assumption to make and how reasonable the assumption is. Depending on the problem context, she/he can also try several of the possible solutions.

Then the problem solver should assess the validity of the different solutions by constructing arguments, justifications, and by improving domain knowledge.

The next step is monitoring the problem space and solution options. Although monitoring the problem-solving plan is a useful metacognitive ability for all problems, it becomes especially important when one is solving an ill-structured problem. In such an activity, one should monitor the validity of the different solutions in addition to the metacognitive comprehension monitoring used for well-structured problems. One should constantly ask oneself: "How do I know this?"

The last step of ill-structured problem solving is the adoption of a solution or solutions. If other solutions are identified, one can try them out and thus engage in an iterative process of monitoring and adapting the chosen solution based on feedback. [11]

Instructors can scaffold student work by prompting students to ask epistemic questions during the problem solving steps described above. [12]

DESCRIPTION OF THE STUDY

Setup: We conducted a pilot study in the second semester of a two-semester large-enrollment (225 students) algebra-based introductory physics course for science majors at Rutgers University. There were two 55-min lectures, one 80-min recitation and one 3-hr laboratory per week. The course followed the Investigative Science Learning Environment (*ISLE*) format [13]. During recitations (8 sections) students worked in groups of four (an optimal size for cooperative group problem solving [5]). At the end of each recitation students handed in their work which was graded for effort and clarity.

Intervention: After the first midterm, one of the recitation instructors (V. Shekoyan) replaced some of the assigned problems with ill-structured problems that covered the same content. He did this in two of his recitation sections while other sections (two taught by him and four by other instructors) were doing problems from the Physics Active Learning Guide. [14] Overall, his students worked on five ill-structured physics problems during the five weeks between the first and second midterms. As these problems replaced some of the recitation problems, experimental students solved fewer well-structured problems than their counterparts. During this period the course was covering waves and vibrations, magnetism, electromagnetic induction and mirrors. After the second midterm students did not solve ill-structured problems.

The instructor provided scaffolding while students were working on the ill-structured problems. The level of scaffolding depended on the difficulty of the problem. An example of such scaffolding for problem #3 in the Appendix is provided below. For example, a student solved the problem assuming that the negatively charged ball stays on the table and he did not mention that this was true only for a ball which was heavy enough, so that the gravitational force exerted on the ball was bigger than the Coulomb's attractive force due to the other charged ball. Then the instructor could ask him to write the condition under which the outcome would be true. Once the student wrote the condition, the instructor would ask for a solution when the condition he wrote was violated. Alternatively, the instructor could just ask the student why he thought the ball stays on the table. Basically the instructor devised prompts to help students learn to ask themselves: How do I know this? Am I making any assumption while doing these steps?

Student sample: The experimental and control groups had 55 and 155 students respectively. On the first midterm prior to the intervention, the experimental and control groups were indistinguishable based on the exam grades. There was no pre-test in the course.

Data collection: The midterms consisted of 10 multiple-choice and 2 open-ended questions; the final exam had 18 multiple choice and 6 open-ended questions. On the second midterm and on the final one of the open-ended problems was ill-structured.

We collected exam data for three problems. Two were ill-structured problems: on the second midterm exam and on the final. These problems were based on the content of the recitations where ill structured problems replaced five of the well-structured problems in the experimental sections. The third problem was a second midterm open-ended problem that was not ill structured but was based on the above content.

We graded these exam problems based on the evidence of content knowledge and correctness of chosen solutions. *Thus, students who did not consider multiple possibilities for ill-structured problems, but gave correct answers for one of the possibilities, still received high grades.* For example, if a student solved problem #3 in the Appendix only for the case of the charge staying motionless on the table without writing any constraints on the unknown mass of the charge, she/he still received full credit.

PRELIMINARY RESULTS AND DISCUSSION

Our general research hypothesis was that engaging students in solving ill-structured physics problems through the classroom and instructional settings described above should help students develop epistemic cognition and master the physics concepts that were covered by the problems.

We performed two-tailed unequal-variance t-test on the grades of the second midterm problems. Tables 1 and 2 show that at the confidence level p = 0.05, the difference in the grades is statistically significant.

TABLE 1. Ill-structured problem (second midterm)

T-test -> 0.01	**Control grp**	**Exp. grp**
Effect size = 0.4	N = 155	N = 55
Average grade	12/20	13.6/20
St. deviation	4.4	3.8

TABLE 2. Open-ended problem (second midterm)

T-test -> 0.04	**Control grp**	**Exp. grp**
Effect size = 0.3	N=155	N=55
Average grade	14.6/20	16/20
St. deviation	5.4	3.6

Students' grades on the final exam ill-structured problem were indistinguishable (16 and 15.8 for the experimental and control groups respectively). As the grades reflected only the understanding of physics, we can say that students who spent time solving ill-structured problems in recitation mastered the content at the same level or better than those who worked on well defined problems.

Additionally, after the end of the semester, we coded students' written solutions for the two ill-structured problems for evidence of epistemic cognition and noted the students who considered multiple possibilities in their solutions. We found that students in the experimental group considered multiple possibilities much more often than in control group, although the total numbers were small in both groups. For the midterm problem, 11% of students from the experimental group considered multiple possibilities, as opposed to 1.3% in control group. For the final exam problem, 24% of the experimental group and 18% of the control group considered multiple possibilities. Chi-square test showed that the differences between two groups were statistically significant (p=0.01 and p=0.03 respectively).

We believe that these preliminary results show a positive trend and warrant further investigation. It is likely that the difference would have been greater if students solved more ill-structured problems in recitations.

This was an exploratory pilot study. We plan to increase the number of ill-structured problems in recitations this year and closely monitor student progress. Also, we would like to explore how our approach might affect students' inclination towards building more globally coherent knowledge structures. [15]

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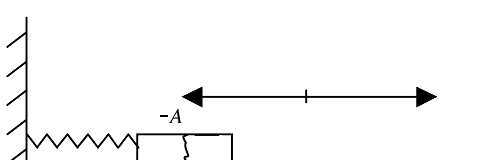
APPENDIX

Problem #1 The ill-structured problem for the second mid-term examination: A uniform block with a significant fracture through its middle is attached to a spring that is initially compressed to the left to position –*A* (see the figure below). When released, the block starts moving right toward the equilibrium position as it begins to vibrate horizontally on a frictionless surface. The vibration frequency with the complete block and spring is 2.0 Hz. Sometime during the first period of vibration, one half of the block breaks loose at the fracture and leaves the remaining half attached to the spring, which continues to vibrate.

a) What is the frequency of vibration of the system with the half block? *Explain.*

b) What could happen to the amplitude of vibration for the half block system after the other half falls off? *Explain* your reasoning.

Hint: Think about the energy of the vibrating system as well as the frequency of that vibration. Remember that the energy when the block passes equilibrium is all kinetic energy and when at the extreme positions farthest from equilibrium is all elastic potential energy.



Problem #2 The open-ended problem for the second mid-term The following description is included in an electric gadget catalog: *"Squeeze No Battery Flashlight":* No batteries or power plug will ever be needed!! An environmental-friendly flashlight, it saves energy without producing pollution to the environment. As long as you continually squeeze the handle in and out, the light works.

a) Devise an explanation for how this flashlight might work. Your explanation should allow someone else to build a model of this device.

b) Describe how you would test your explanation about how the flashlight works—without opening it.

Problem # 3 The final exam ill-structured problem*:* A positively charged small object with mass m = 10 g and charge q_1= +3 x 10^{-6} C hangs from a nylon string attached to the ceiling. The object's distance from the surface of a table is h = 20 cm. Imagine that you place another small object 2 with a small unknown mass and with negative charge q_2 = -3 x 10^{-6} C on the surface of the table.

a) Determine the force that the string exerts on the hanging object 1 immediately after you place object 2 on the table and before you remove your hand.

b) Does the force that the string exerts on object 1 stay the same after you place object 2 on the table and shortly after you remove your hand? If it does not stay the same, how qualitatively would the magnitude of the force that the string exerts on object 1 change a short time after you remove your hand from object 2? What assumptions did you make? Explain.

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