Using cognitive apprenticeship framework and multiple-possibility problems to enhance epistemic cognition

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Abstract. Epistemic cognition can occur when a person is solving a problem that does not have one correct answer (a multiple-possibility problem). The solver is engaged in epistemic cognition if she/he examines different possibilities, assumptions, and evaluates the outcomes. Epistemic cognition is an important part of real life problem-solving. Physicists routinely engage in epistemic cognition when they solve problems. But in educational settings, we polish problems and make them single-possibility problems. Thus students rarely get a chance to engage in epistemic cognition while working on problem-solving tasks. We introduced multiple-possibility physics problems in recitation sections of an algebra-based introductory physics course at Rutgers University. We describe here how we have incorporated the cognitive apprenticeship framework in the course and evaluated its effectiveness as a method of enhancing students' epistemic cognition level.

Keywords: Problem solving, Epistemic cognition, Ill-structured problems, Cognitive apprenticeship.
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INTRODUCTION & MOTIVATION

One important aspect of physics instruction is helping students develop better problem solving expertise. Besides enhancing the content knowledge, solving problems help students develop different cognitive abilities and skills (e. g., [1]). Our research is focused on multiple-possibility problems (MPPs). They are also called ill-structured or ill-defined problems. We prefer to call those problems "multiple-possibility problems" to avoid the negative psychological affect of the prefix "ill". MPPs are different from traditional "end-of-chapter" single-possibility problems (also called well-structured or well-defined 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 [2]. It is an important part of real life problem-solving. Physicists routinely use epistemic cognition when they solve problems.

There are several different ways to construct MPPs. In physics education research some examples are context-rich problems, experimental problems, jeopardy problems, and problem posing tasks [3]. In addition, students can be engaged in MPP solving through science research projects ([4] & [5]) as well as through non-traditional laboratory sessions in physics courses [6]. An example of MPP used in the study described in this paper is in the Appendix. It is an MPP because it has vagueness that allows more than one correct solution (the E-field could be zero either to the left or to the right of charge A).

Surprisingly very little research has been done in analyzing physics MPP solving [7] and its impact on students' epistemic cognition [8]. In the study reported in this paper we examine whether students who were specifically trained to identify assumptions in their solutions of MPP problems with the help of special prompts and rubrics retain this ability when the prompts and rubrics are removed.

EPISTEMIC COGNITION

Kitchener [2] proposed a three-level model of cognitive processing to categorize the reasoning steps one makes when faced with a MPP (cognition, metacognition, epistemic cognition). At the first cognition level, individuals read, understand the problem, perform calculations, etc. At the second metacognitive level, individuals monitor their progress and problem-solving steps performed at 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.

COGNITIVE APPRENTICESHIP

Cognitive apprenticeship theory is based upon constructivist approach to education [9]. It draws an analogy from the old-style way of teaching, the apprenticeship. The main role of a master was to demonstrate the skill, to coach the apprentice and to facilitate the efforts of the apprentice as she/he was trying to use the skill in small but real settings. Slowly, the help of the master faded, and the apprentice was given complete tasks to perform.

The difference between real apprenticeship and cognitive apprenticeship is that in the former the skill that needs to be learned is clear and visible when the master uses it. In the latter the skill is invisible; therefore the master has to make a special effort to make it visible and to help the apprentice notice it. There are many ways to accomplish this goal and here we will only focus on the features of cognitive apprenticeship relevant to the study. In addition to explicitly demonstrating the skill to the learners, and to providing support (scaffolding) through guiding questions that slowly fade as students improve, cognitive apprenticeship theory suggests that students work in teams on projects or problems with a close scaffolding by the instructor. Work in teams allows more prepared students to help less prepared students, extending their "zone of proximal development" [10] so the latter can perform tasks that are slightly more difficult than students can manage independently.

SCAFFOLDING EPISTEMIC COGNITION

Epistemic questioning: Based on the analysis of MPP structure [8], we have developed a set of questions, called epistemic questions, that a problem solver should constantly ask herself or himself during the solution process in order to engage in epistemic cognitive thinking and to successfully solve a MPP problem. These are the epistemic questions:

1) How do I know this?
2) Am I making any assumptions?
3) Are the assumptions valid?
4) Are there alternative reasonable assumptions?
5) Are there other possible outcomes?

If a person is continuously asking herself/himself these epistemic questions, then she/he should be able to identify different possibilities (different sequence of events based on the given initial conditions) along with the assumptions that make each possibility valid.

When students are assigned MPPs in recitations, instructors can prompt students to ask themselves the above-mentioned epistemic questions during problem solving. As the students gain more experience, the scaffolding can be gradually removed.

MPP solving Rubric: We designed a special rubric for formative assessment of solutions to MPPs (Table 1). A rubric contains descriptors of different levels of performance relevant to the task. The rubric is based on the rubric design approach developed by the Rutgers PER group. This approach was found to be effective in helping students acquire various scientific abilities [11]. According to this approach, the rubric describes four levels of student performance.

Students' solutions to MPPs are graded based on the rubric. Initially when students solve MPPs in recitations, we label them as such and provide the rubric. As the students progress through the semester, the scaffolding is slowly removed by discontinuing labeling MPPs and the rubric attachment altogether.

DESCRIPTION OF THE STUDY

Setup: We conducted a study in the second semester of a two-semester large-enrollment (188 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 [12]. During recitations students worked in groups of three. At the end of each recitation students handed in their group work which was graded for effort and clarity. There were fourteen recitation sessions during the semester; in eight of them students had to solve a MPP. Eight out of fourteen homework assignments had a MPP assignment. Two midterm exams and the final also contained a MPP. All MPPs were graded based on the MPP solving rubric. Solutions to recitation and homework assignments, as

TABLE 1. The self-assessment rubric for solving MPPs

	Missing	Inadequate	Needs some improvement	Adequate
Is able to correctly identify different possibilities (or sequence of events) in the situation	Only one relevant possibility is discussed. No determination of underlying assumptions or criteria that make it valid.	Only one relevant possibility is discussed. Underlying assumptions or criteria that make it valid are determined.	More than one relevant possibility is discussed. There is no determination of underlying assumptions or criteria that make each possibility valid.	More than one relevant possibility is discussed. Underlying assumptions or criteria that make each possibility valid are determined.

well as exam problems were being posted on the course website throughout the semester.

Scaffolding and its removal: During the first six weeks, each MPP used in recitations or as part of homework was labeled as such. In addition to the rubric, a special document with guidelines was attached to the MPP problems. The purpose of the guidelines was to insure that students knew what type problems were called MPPs, and why learning to develop MPP solving abilities was important. The guidelines also explained the MPP solving rubric.

After the first six weeks the label was removed from recitation MPPs as well as the rubric and the guidelines. Students were not told whether there was an MPP problem in recitation problems. The homework assignments retained the MPP label and rubric.

Data collection: We copied students' solutions to the midterm and final exam MPPs. We also made copies of students' in-class recitation work from three recitation sections (about 63 students out of 188).

PRE-POST TREATMENT ANALYSIS

How effective was our scaffolding approach in triggering students to engage in epistemic questioning, and identifying multiple possibilities? To measure epistemic questioning, we collected students' recitation work and counted the number of groups (students were working in collaborative groups) whose solutions contained a consideration of more than one possibility for the assigned MPPs.

Figure 1 shows that we had more than 70% success rate during the scaffolding. More importantly it also shows that after the scaffolding was removed, students continued to identify the MPPs in recitation assignments, although at a lower rate. The big drop that occurred in recitation 10 is an exception. The problem that was used in that recitation (problem 26, p. 167 [13]) was exceptionally difficult and seeing two possibilities required much deeper insight than the other MPPs we had been using. So it is quite likely that students did ask themselves epistemic questions and looked for other outcomes, but did not have enough physics knowledge to find answers to their questions. Thus we can say that after scaffolding removal, students' engagement level in epistemic cognition didn't drop drastically.

COMPARATIVE STUDY

Background: McMillan, et al. [14] conducted individual interview sessions with six students (five were majoring in physics, and one in engineering) to examine students' qualitative and quantitative problem-solving behavior. The problem they gave to the students was an electrostatics problem (see the Appendix).

It was a MPP, since the problem text did not specify whether the zero electric field-point is to the right or to the left of charge A (or whether the charge on B is negative or positive). If it is positioned to the left of charge A, then the charge on B should be negative (possibility 1). If E-field is zero to the right of charge A, then the charge on B should be positive (possibility 2). The students in McMillan's study

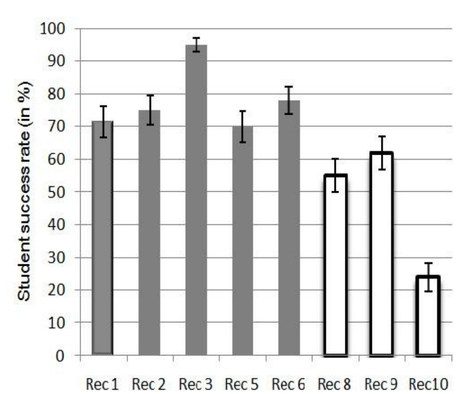

Figure 1: The percentage of collaborative groups in recitations who were considering multiple-possibilities for the assigned MPPs in recitation assignments. The white columns show the percentage of the number of successful groups after the scaffolding removal (rec. 8, 9 and 10). The bars represent the sampling errors.

were taking a second-semester introductory calculus-based college physics course at the time. The projected grades of the students were A-s or B-s for five of them and a D for one student.

The D student was not able to solve the problem at all, whereas the other five students solved the problem for only one possibility (the possibility 1) and didn't show awareness of the other possibility (as revealed from the interview questions). So, even physics major A or B students did not engage in epistemic cognition.

The comparative study: Would our students be more successful in engaging in epistemic cognition? To answer that question we included the same problem in the final exam of the course. It wasn't labeled as an MPP problem, and students were not told that they should be looking for a MPP in the final. We added the following sentence at the end of the problem: "Explain your reasoning." to encourage students to write down their thoughts.

Forty-six students were not able to solve or make any reasonable arguments about the problem. They represent the floor effect (as was the D student in McMillan's study). Out of remaining 142 students 39% (55 students) showed evidence of engaging in epistemic cognition. They either identified the other possibility directly or tried to discuss the possibility of more than one point satisfying zero E-field condition.

To understand the importance of these results we have to take into account that 1) the time lag was very large for Rutgers students. They dealt with electrical fields sometime in early mid semester. The professor did not spend much time on electrical fields. On the contrary, the students in McMillan's study just finished those topics. 2) The Rutgers class was an algebra-based class, whereas theirs was a calculus-based class. 3) The Rutgers students encountered the problem during the final exam. The exam was time-constrained, and therefore, there was a pressure on students to finish on time. The interviews were not time-constrained.

DISCUSSION

The two analyses showed that our method was successful in helping students retain "the habit" of epistemic questioning. Enhancing students' epistemic cognition is very important. Our studies reported elsewhere [13] indicate that using MPPs with epistemic questioning scaffolding not only does not affect students' abilities to solve regular problems, but helps them construct a better conceptual understanding of physics. Since the main difference between regular and multiple-possibility problem solving cognitive activities is the epistemic cognition, we believe that it plays the major role here.

In the future we would like to analyze student's epistemic cognitive engagement throughout the semester using midterm exam data. We also plan to do a fine-grained analysis of students' epistemic cognition levels via multi-level epistemic cognition coding.

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APPENDIX

MPP: Two point charges **A** and **B** at rest are separated by a distance of seven (7) meters. The electric field one (1) meter from charge **A** is zero (0). What is the charge on **B**, if the charge on **A** is 1×10^{-5} coulombs?

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