Using Reflection with Peers to Help Students Learn Effective Problem Solving Strategies

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Abstract. We describe a study in which introductory physics students engage in reflection with peers about problem solving. The recitations for an introductory physics course with 200 students were broken into the “Peer Reflection” (PR) group and the traditional group. Each week in recitation, students in the PR group reflected in small teams on selected problems from the homework. The graduate and undergraduate teaching assistants (TAs) in the PR group recitations provided guidance and coaching to help students learn effective problem solving heuristics. In the recitations for the traditional group, students had the opportunity to ask the graduate TA questions about the homework before they took a weekly quiz. On the final exam with only multiple-choice questions, the PR group drew diagrams on more problems than the traditional group, even when there was no external reward for doing so. Since there was no partial credit for drawing the diagrams on the scratch books, students did not draw diagrams simply to get credit for the effort shown and must value the use of diagrams for solving problems if they drew them. We also find that, regardless of whether the students belonged to the traditional or PR groups, those who drew more diagrams for the multiple-choice questions outperformed those who did not draw them.

Keywords: physics education research, problem solving, peer reflection
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INTRODUCTION

Reflection is an integral component of effective problem solving [1]. While experts in a particular field reflect and exploit problem solving as an opportunity for organizing and extending their knowledge, students often need feedback and support to learn how to use problem solving as an opportunity for learning. Our prior research has shown that, even with minimal guidance from the instructors, students can benefit from peer interaction [2]. Those who worked with peers not only outperformed an equivalent group of students who worked alone on the same task, but collaboration with a peer led to “co-construction” of knowledge in 29% of the cases [2].

Here, we describe a study in which algebra-based introductory physics students in the Peer Reflection group (PR group) were provided guidance and support to reflect upon problem solving with peers and undergraduate and graduate teaching assistants in the recitation class [3].

METHODOLOGY

The investigation involved an introductory algebra-based physics course mostly taken by students with interest in health related professions. The course had 200 students and was broken into two sections both of which met on Tuesdays and Thursdays and were taught by the same professor who had taught both sections of the course before. A class poll at the beginning of the course indicated that more than 80% of the students had taken at least one physics course in high school, and perhaps more surprisingly, more than 90% of the students had taken at least one calculus course (although the physics course in which they were enrolled was an algebra-based course).

The daytime section taught during the day was the traditional group and had 107 students whereas the evening section called the “Peer Reflection” group or PR group had 93 students. The lectures, all homework assignments, the midterm exams and the final exam were identical for the daytime and evening sections of the course. Moreover, the instructor emphasized effective problem solving strategies, e.g., performing a conceptual analysis of the problem and planning of the solution before implementing the plan and importance of evaluating the solution throughout the semester in both the traditional and peer-reflection groups.

Each week, students in both groups were supposed to turn in answers to the assigned homework problems (based upon the material covered in the previous week) using an online homework system for some course credit. In addition, students in both groups were supposed to submit a paper copy of the homework problems which had the details of the problem solving approach at the end of the recitation class to the TA for some course credit. While the online homework solution was graded...
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ing involving modeling, coaching, and fading to help stu-
dents learn effective problem solving heuristics. In this 
approach, “modeling” means that the TA demonstrates 
the students should learn. “Coaching” means providing 
skills. “Fading” means decreasing the feedback gradually 
with the focus on helping students develop self-reliance.

The specific strategy used by the students in the PR 
group involved reflection upon problem solving with 
their peers in the recitations, while the TA and the under-
graduate teaching assistants (UTAs) exemplified the ef-
effective problem solving heuristics. The UTAs were 
chosen from those undergraduate students who had earned 
an A+ grade in an equivalent introductory physics course 
previously. The UTAs had to attend all the lectures in the 
semester in which they were UTAs for a course and they 
communicated with the TA each week (and periodically 
with the course instructor) to determine the plan for the 
recitations. We note that, for effective implementation of 
the PR method, two UTAs were present in each recita-
tion class along with the TA. These UTAs helped the TA 
in demonstrating and helping students to learn effective 
problem solving heuristics.

In our intervention, each of the three recitation sec-
tions in the traditional group had about 35-37 students. 
The two recitations for the PR group had more than 
40 students each (since the PR group was the evening 
section of the course, it was logistically not possible to 
break this group into three recitations). At the beginning 
of each PR recitation, students were asked to form nine 
teams of three to six students chosen at random by the TA 
(these teams were generated by a computer program each 
week). The TA projected the names of the team members 
on the screen so that they could sit together at the be-

As noted earlier, both recitation sections for the 
evening section (93 students total) together formed the 
PR group. The PR group intervention was based upon a 
field-tested cognitive apprenticeship model [4] of learn-
ing involving modeling, coaching, and fading to help stu-
dents learn effective problem solving heuristics. In this 
approach, “modeling” means that the TA demonstrates 
and exemplifies the effective problem solving skills that 
the students should learn. “Coaching” means providing 
students opportunity to practice problem solving skills 
with appropriate guidance so that they learn the desired 
Skills. “Fading” means decreasing the feedback gradually 
with a focus on helping students develop self-reliance.

The three finalists’ solutions were projected one at a 
time on a screen using a web cam and computer projec-
tor. Each of the three panelists (the TA and two UTAs) 
gave their critique of the solutions, citing what each of 
the finalists had done well and what could be done to fur-

After each question was announced to the class, each 
of the nine teams were given three minutes to identify the 
“best” solution by comparing and discussing among the 
group members. If a group had difficulty coming up with 
a “winner”, the TA/UTA would intervene and facilitate 
the process. The winning students were asked to come to 
the front of the room, where they were assembled into 
three second-round groups. The process was repeated, 
producing three finalists. These students handed in their 
homework solutions to the TAs, after which the TA/UTA 
evaluation process began.

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The weighting of each component of the course, e.g., 
midterm exams, final exam, class participation, home-
work and the scores allocated for the recitation were the 
same for both classes. Also, as noted earlier, all compo-
nents of the course were identical for both groups except 
the recitations which were conducted very differently for 
the PR and traditional groups. Although the total course 
weighting assigned to the recitations was the same for 
both groups (since all the other components of the course 
had the same weighting for both groups), the scoring of 
the recitations was different for the two groups. Students 
were given credit for attending recitation in both groups. 
Attendance was taken in the recitations using clickers for 
both the traditional group and the PR group. The tradition-
group recitations were traditional in which the TA 
would solve selected assigned homework problems on 
the blackboard and field questions from students about 
their homework before assigning a quiz in the last 20 
minutes of the recitation class. The recitation quiz prob-
lems given to the traditional group were similar to the 
homework problems selected for “peer reflection” in the 
PR group recitations (but the quiz problems were not 
identical to the homework problems to discourage stu-
dents in the traditional group from memorizing the an-
swers to homework in preparation for the quiz). Students 
in the PR group reflected on three homework problems 
in each recitation class but no recitation quiz was given 
to the students in this group at the end of the recitation 
classes, unlike the traditional group, primarily due to the 
time constraints. The recitation scores for the PR group 
students were assigned based mostly on the recitation at-
tendance except students obtained bonus points for help-
ing select the “best” student solution as described below. 
Since the recitation scoring was done differently for the 
traditional and PR groups, the two groups were curved 
separately so that the top 50% in each group obtained A 
and B grades in view of the departmental policy.

The specific strategy used by the students in the PR 
group involved reflection upon problem solving with 
for correctness, the TA only graded the paper copies of 
the submitted homework for completeness on a three 
point scale (full score, half score or zero).
by each of the panelists, the students, using the clickers, voted on the “best” solution. The TA and UTAs did not participate in the voting process.

In order to encourage each team in the PR group to select the student with the most effective problem solving strategy as the winner for each problem, all students from the teams whose member advanced to the final round to “win” the “competition” were given course credit (bonus points). In particular, each of these team members (consolation prize winners) earned one third of the course credit given to the student whose solution was declared to be the “winner”. This reward system made the discussions lively and the teams made good effort to advance the most effective solution to the next stage.

While we video-taped a portion of the recitation class discussions when students reflected with peers, a good account of the effectiveness and intensity of the team discussions came from the TA and UTAs who generally walked around from team to team listening to the discussions but not interrupting the team members involved in the discussions unless facilitation was necessary for breaking a gridlock. The course credit and the opportunity to have the finalists’ solutions voted on by the whole class encouraged students to argue passionately about the aspects of their solutions that displayed effective problem solving strategies. Students were constantly arguing about why drawing a diagram, explicitly thinking about the knowns and target variables, and explicitly justifying the physics principles that would be useful before writing the equations are effective problem solving strategies.

Furthermore, the “American Idol” style recitation allowed the TAs to discuss and convey to students in much more detail what solution styles were preferred and why. Students were often shown what kinds of solutions were easier to read and understand, and which were more amenable to error checking. Great emphasis was placed on consistent use of notation, setting up problems through the use of symbols to define physical quantities, and the importance of diagrams in constructing solutions.

At the end of the semester, all of the students were given a final exam consisting of 40 multiple choice questions, 20 of which were primarily conceptual in nature and 20 of which were primarily quantitative (students had to solve a numerical or symbolic problem for a target quantity). Although the final exam was all multiple-choice, a novel assessment method was used. While students knew that the only thing that counted for their grade was whether they chose the correct option for each multiple-choice question, each student was given an exam notebook which he/she could use for scratchworks. We hypothesized that even if the final exam questions were in the multiple-choice format, students who value effective problem solving strategies will take the time to draw more diagrams and do more scratchworks even if there was no course credit for such activities. With the assumption that the students will write on the exam booklet and write down relevant concepts only if they think it is helpful for problem solving, multiple-choice exam can be a novel tool for assessment. It allowed us to observe students’ problem solving strategies in a more “native” form closer to what they really think is helpful for problem solving instead of what the professor wants them to write down or filling the page when a free-response question is assigned with irrelevant equations and concepts with the hope of getting partial credit for the effort.

We decided to divide the students’ work in the notebooks and exam-books into two categories: diagrams and scratchworks. The scratchworks included everything written apart from the diagrams such as equations, sentences, and texts. Both authors of this paper agreed on how to differentiate between diagrams and scratchworks. Instead of using subjectivity in deciding how “good” the diagrams or scratchworks for each student for each of the 40 questions were, we only counted the number of problems with diagrams drawn and scratchworks done by each student. For example, if a student drew diagrams for 7 questions out of 40 questions and did scratchworks for 10 questions out of 40 questions, we counted it as 7 diagrams and 10 scratchworks.

**RESULTS**

Although no pretest was given to students, there is some evidence that, over the years, the evening section of the course is somewhat weaker and does not perform as well overall as the daytime section of the course historically. The difference between the daytime and evening sections of the course could partly be due to the fact that some students in the evening section work full-time and take classes simultaneously. For example, the same professor had also taught both sections of the course one year before the peer reflection activities were introduced in evening recitations and thus all recitations for both sections of the course were taught traditionally that year. Thus, we first compare the averages of the daytime and evening sections before and after the peer reflection activities were instituted in the evening recitation classes. Table 1 compares the difference in the averages between the daytime and evening classes the year prior to the introduction of peer reflection (Fall 2006) and the year in which peer reflection was implemented in the evening recitation classes (Fall 2007). In Table 1, the p-values given are the results of t-tests performed between the daytime and evening classes. Statistically significant difference (at the level of \( p = 0.05 \)) between groups only exists between the average midterm scores for the year in which peer reflection was implemented. The evening section scored lower on average than the daytime section on the final exam but the difference is not statistically significant (\( p=0.112 \) for 2006 and \( p=0.875 \) for 2007), as in-

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Average Midterm Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime</td>
<td>85.2 (n=50)</td>
</tr>
<tr>
<td>Evening</td>
<td>78.9 (n=50)</td>
</tr>
<tr>
<td>Difference</td>
<td>6.3 (p=0.112)</td>
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</tbody>
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<tr>
<th>Table 2</th>
<th>Average Final Exam Scores</th>
</tr>
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<tbody>
<tr>
<td>Daytime</td>
<td>90.4 (n=50)</td>
</tr>
<tr>
<td>Evening</td>
<td>83.1 (n=50)</td>
</tr>
<tr>
<td>Difference</td>
<td>7.3 (p=0.875)</td>
</tr>
</tbody>
</table>
dicated in Table 1. We note that while the midterm questions differed from year to year (since the midterms were returned to students and there was a possibility that the students would share them), the final exam, which was not returned to students, was almost the same both years.

**TABLE 1.** Means and p-values for comparisons of the daytime and evening classes during the year before peer reflection was introduced (Fall 2006) and during the year in which it was introduced (Fall 2007). The following were the number of students in each group: Fall 2006 daytime N=124, evening N=100, Fall 2007 daytime N=107, evening N=93.

<table>
<thead>
<tr>
<th>Daytime vs. evening classes</th>
<th>Daytime means %</th>
<th>Evening means%</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006: midterm</td>
<td>57.7</td>
<td>52.7 (non-PR)</td>
<td>0.112</td>
</tr>
<tr>
<td>2007: midterm</td>
<td>58.1</td>
<td>57.7 (PR)</td>
<td>0.875</td>
</tr>
<tr>
<td>2006: final exam</td>
<td>52.7</td>
<td>65.8 (non-PR)</td>
<td>0.101</td>
</tr>
<tr>
<td>2007: final exam</td>
<td>58.1</td>
<td>73.4 (PR)</td>
<td>0.004</td>
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We also investigated whether the final exam score is correlated with the number of problems with diagrams or scratchworks for the traditional group and the PR group separately (R is the correlation coefficient). The null hypothesis in each case is that there is no correlation between the final exam score and the variable considered, e.g., the total number of problems with diagrams drawn. We find that, for both the traditional group and the PR group, the students who had more problems with diagrams and scratchworks were statistically (significantly) more likely to perform well on the final exam.

**DISCUSSION**

According to Chi [5], students are likely to improve their approaches to problem solving and learn meaningfully from an intervention if both of the following happen: I) students compare two artifacts, e.g., the expert solution and their own solution and realize their omissions, and II) they receive guidance to understand why the expert solution is better and how they can improve upon their own approaches. The PR approach uses such a two tier approach in which students first identify that other student’s solution may be better than their own and then are guided by the UTAs/TA to reflect upon the various aspects of the “winning” solutions.

**REFERENCES**