Employing Methods in Physics Education Research (PER) to Enhance Learning in an Engineering Physics Course

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Introduction

Physics Education Research (PER) (McDermott, 2001) has been an ongoing research programme for over thirty years and its main objective is to improve the students’ understanding of physics. Through their investigation of how students tend to misunderstand and experience difficulties grasping physical concepts, and developing effective resources accordingly for physics instruction (McDermott & Shaffer, 2002), physics instructors would be well-equipped with the tools to enhance students’ learning experiences. Besides developing useful instructional resources, introducing novel teaching methods in an introductory physics course could also result in enhanced learning (Mazur, 1997; Hake, 1998; Beichner et al. 2000). While these literatures focus on improving physics lectures, there are several approaches which focus on tutorial sessions (Otero et al., 2010). Inspired and delighted by the beneficial learning results derived from PER, we decided to employ some of these strategies in our tutorials rather than in lectures, as we wanted to achieve these learning outcomes in a small group setting.

The Current Approach and Its Challenges

The module, PC1431 “Physics IE”, is a calculus-based, introductory physics course covering mechanics and thermodynamics for Year 1 Engineering students, mostly from the Departments of Mechanical Engineering, Civil and Environmental Engineering, Bioengineering, Materials Science and Engineering, and Industrial and Systems Engineering. The tutorial is conducted once a fortnight, and the classroom setting as well as teaching style utilised the conventional seminar room method with the whiteboard. The tutors go into the class, conduct the tutorial like a mini-lecture, demonstrate how to solve problems on the board, and the complete solutions are then posted after the tutorial. Students are told to attempt the tutorial before class, fill up their blank worksheets with the tutor’s explanation and compare their approach with the tutor’s. Also, they could refer to solutions if they cannot follow the class. The tutors had been working hard to deal with students’ misconceptions and difficulties in the topics presented but the conventional approach seemed ineffective, so we decided to see if the strategies introduced by PER could improve students’ understanding and problem solving abilities.

Recommended Citation

Incorporating Peer Instruction and Problem Solving Through Cooperative Grouping

We employed two strategies from PER in the PC1431 tutorials: peer instruction and problem solving through cooperative grouping. Peer instruction is a pedagogy developed in 1991 by Eric Mazur, a physics professor at Harvard University, in 1991. The idea is to set aside time for the students to discuss among themselves and explain their answers to their neighbours (Mazur, 1997). The outcomes of this method are the correction of students’ misconceptions and gains in students’ confidence in terms of their knowledge and understanding of the subject. The second strategy, getting students involved in problem solving through cooperative grouping, was first suggested by Patricia Heller and her colleagues from the University of Minnesota (Heller, Keith & Anderson, 1992). They divided the students in groups wherein they solved the problems together as a group. The outcome of this approach is the improvement in students’ problem solving abilities.

Methodology

In Semester 1 of AY2012/13, we were assigned to teach six PC1431 tutorial classes. Out of the six classes, three classes were chosen as experimental groups to adopt the methods suggested by PER, while the other three classes were the control groups, wherein the tutorials were conducted the conventional way. The questions were modified slightly, with the inclusion of hints, so that students will have a clearer idea when they attempt the questions. These were posted to the students at least one week before the actual tutorial and they are expected to attempt the questions before coming to class. The following are salient features of the two kinds of tutorial groups:

Table 1: Features of the two types of tutorial groups

<table>
<thead>
<tr>
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<th>Experimental Group (85 students in total)</th>
<th>Control Group (89 students in total)</th>
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</thead>
<tbody>
<tr>
<td>(1)</td>
<td>They have weekly tutorials.</td>
<td>They have tutorials once a fortnight.</td>
</tr>
<tr>
<td>(2)</td>
<td>Students formed groups of three in random, irrespective of their abilities.</td>
<td>No groups were formed; students were seated at random.</td>
</tr>
<tr>
<td>(3)</td>
<td>The tutors (Dr Nidhi and I) walked around in class to listen in on their discussions and to clarify their misconceptions.</td>
<td>I demonstrate how to solve the problems on the whiteboard; I will stop and ask questions from time to time, to check whether they are still with me</td>
</tr>
<tr>
<td>(4)</td>
<td>Occasionally, I demonstrate how to solve the harder questions on the whiteboard when I feel that it is a commonly asked question from most of the class.</td>
<td>Additional questions are available on the website for them to download for their own practice.</td>
</tr>
<tr>
<td>(5)</td>
<td>Additional questions are provided during class for students who are able to finish the tutorial questions before the rest of their tutorial mates.</td>
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In order for students to discuss effectively in groups, we require those in the experimental group to come for weekly sessions, so that they will have more contact with their group members and the tutors, making it easier to build rapport for better group dynamics. If there were only five tutorial sessions, just like the control group, we felt that by the time they actually got to know each other better, it would have been the end of the semester, and group discussions will end up playing a smaller role towards their learning.
During the semester, we spent 10 to 15 minutes in the first and the fifth tutorial sessions explaining to students the rationale behind the experimental group setting. This is to ensure that they understood our intentions, so that they will cooperate with a positive mindset, and make full use of the opportunities provided to them. This message was also communicated in the tutorial website where we had put up additional materials they could refer to.

**Evaluation**

Mid-semester feedback and end-of-semester feedback exercises were conducted for the experimental group to see how the students felt about the new approach. We did not conduct these feedback exercises with the control group because the statements are more applicable for the experimental group.

**Quantitative Student Feedback**

There are five statements in the mid-semester feedback exercise; for the end-of-semester feedback exercise, students answered the same five questions and an additional sixth question. Students responded to these questions using a 4-point Likert scale (from “Strongly Disagree” to “Strongly Agree”). The questions are shown below:

1. I am able to complete the tutorials with minimal help.
2. The hints provided in the tutorials are helpful.
3. I can get help from my peers during tutorial discussion.
4. I managed to clarify my misconceptions with the tutors during class.
5. I feel that this tutorial style is effective for my learning.
6. I will recommend this tutorial style for my juniors in the future. (End-of-semester only)

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**A BOUT THE A UTHORS**

Mr Chang Sheh Lit was a teaching assistant in the Dept of Physics. He was keen in incorporate active learning in engineering physics tutorials. He will be pursuing a PhD in physics education research at University of Washington, Seattle.

Dr Nidhi Sharma is a lecturer for Engineering Physics courses in the Dept of Physics. She is keen on trying out new active learning teaching methods in lectures.
The survey results are shown in Figure 1. There were 65 respondents in the mid-semester survey and 40 respondents in the end-of-semester survey. From the responses collected for Statement 1 (“I am able to complete the tutorials with minimal help”), we can see that more than 50% of the students require help in completing the tutorials, which shows that students generally have difficulty in solving the problems given to them. Furthermore, there is a dip in the percentage of students who agreed to Statement 1, which corresponds to the higher proportion of students who require assistance in problem solving. We attribute this to the increase in difficulty level of the content, and the students’ lack of confidence in their ability to solve the problems on their own.

From the responses collected for Statement 2 (“The hints provided in the tutorial are helpful.”), more than 85% of the students felt that the hints provided in the tutorial were helpful; this shows that students welcomed our efforts in helping them understand the questions better. More than 90% of the students felt that they can obtain help from peers during tutorial discussions and managed to clarify their misconceptions with us during the class. This
shows that they found the increased interaction with their peers and tutors to be beneficial to their learning. There was a slight decrease in the percentage of students who were able to get their misconceptions clarified at the end of semester, which could be attributed to the increase in difficulty of the content after the Recess Week. Over 80% of the respondents felt that this kind of tutorial setting was effective for their learning. Lastly, 95% of the respondents in the end-of-semester feedback exercise would recommend this tutorial style to their juniors in the future. This shows that students in general welcomed this change in the tutorial format.

Qualitative Student Feedback

We also prepared open-ended questions for the mid-semester feedback exercise. They are as follows:

1. What was your expectation for PC1431 tutorials before the start of tutorial?
2. What do you love about this class?
3. What do you hate about this class?
4. If you could change one thing about this class, what would it be?

Based on their written responses, the students generally expected the tutorial class to be conducted mini-lecture style, where the tutor explains and demonstrates how to solve the problems in the class; discussions are favoured if there is time, and whenever possible, tutors should cover all the questions in the tutorial. In this tutorial format, they enjoyed having the tutors approach them during the small group discussion, where they had their doubts clarified and there were more interactions with their peers and the tutors. However, time is always in short supply, and some of them felt that this tutorial format was too time-consuming. Due to the large class size, sometimes it was impossible to clarify all of their doubts during the tutorial as the tutors might be preoccupied with other groups. As such, some students were unhappy that their doubts were not addressed on time.

We made some changes to the tutorial format in the second half of the semester based on their written feedback in the mid-semester feedback exercise. The changes made included:

1. Getting students to put up their doubts online before they come to class. We would take a look at their comments before going to class, and address them together if it is a commonly held doubt within the class. This was effective in helping to manage the time.

2. Providing a summary together with the tutorial, which we would go through with them if time permits.

Few students would put up their doubts in an online form, but we would still read through the ones who did submit something and answered them individually via email if we were not planning on going through the questions in class.

We also asked open-ended questions at the end of the semester, and they are as follows:

1. How do you feel about PC1431 tutorials so far?
2. Any improvements for PC1431 tutorials?

The respondents for the end-of-semester feedback exercise tend to be students who followed the weekly schedule faithfully and their written comments were generally positive:

- “The tutorials are more effective than standard tutorials where the tutor simply provides answers. Peers are more likely to ask each other questions then raise it in class. The tutorials with hints are very useful as well.”

- “The group format ‘forces’ everyone to do their work extensively before class which will aid in generating discussion during tutorial, a more productive method than ‘absorbing’ in class.”

Their comments sent us a strong message that we are heading towards the right direction in terms
of getting students to participate more actively in their learning journey. Effective learning can only happen when students are actively involved with the content, as compared to having them attend and passively listen to mini-lecture style tutorials. The conventional tutorial format, while efficient to some extent in helping students complete their assignments, may not be as effective in ensuring deep learning and understanding of the subject matter.

**Impact of PER Methods on Academic Performance**

Besides looking at students’ responses to the new format implemented for the PC1431 tutorials, we also wanted to find out whether this tutorial style has proved beneficial to their performances in test and exams. We extracted the test and exam scores of students in the control and experimental groups, and looked at the percentage of students who scored above the class average. The students that we selected were those who have garnered a tutorial attendance rate of more than 60% in both groups. This information is summarised in Table 2 below.

In both the control and experimental groups, more than half the group managed to get assessment scores that were higher than the class average. On taking a closer look, we observed that the students in the control group did slightly better than those in the experimental group, especially in the exam.

**Table 2. Performance of Control Group and Experimental Group compared to Class Average.**

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Students</th>
<th>Attendance &gt;60%</th>
<th>Test Score &gt; Class Average</th>
<th>Exam Score &gt; Class Average</th>
<th>Test + Exam &gt; Class Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>83</td>
<td>47 (56.6%)*</td>
<td>49 (59.0%)</td>
<td>48 (57.8%)</td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>72</td>
<td>41 (56.9%)</td>
<td>37 (51.4%)</td>
<td>39 (54.2%)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: The values in parentheses refer to the percentage of students compared to the total number of students whose attendance is above 60% in the semester.*

**Limitations of the Study**

PC1431 is a physics module with a large enrollment and this posed certain logistical challenges. For instance, as we needed two tutors to handle the discussion groups during class, it would be a challenge to justify an increase in manpower if the performances of the students do not improve.

In addition, some students in the experimental groups might not appreciate our rationale of having weekly sessions if they compare the relatively lower frequency of tutorials and the efficiency of the tutorial class (e.g. the number of questions discussed in class) with the control groups. Hence they may choose to skip our tutorials and attend other tutors’ classes instead.

Also, although having two tutors has made it easier to manage such a large class, we still encounter instances in which some students do not come to class prepared; in our opinion, the tutorial session would not be as beneficial for them.

In spite of these challenges, we were not keen to make big changes or revert back to the traditional mode of instruction, especially after we had obtained the generally positive responses from the mid-semester feedback exercise. This is because we felt that it would take time for students to get used to the new approach; hence, we decided to persist and make small changes to the new format instead.
As this was the first time we were making changes to our tutorial instruction, it would serve as a preliminary trial and this experience would be valuable in improving future tutorials.

Future Work

In this section, we would like to bring out one issue that arose when we conducted the discussion-based tutorials. Through our interaction with students, we found that it was difficult during the tutorials to correct students’ misconceptions or alternative conceptions to the physical ideas. These misleading ideas that they had were preventing them from learning more advanced concepts in the course, which led to students experiencing difficulties in solving the problems.

As physics instructors, it is our duty to make sure our engineering students gain an accurate understanding of physical concepts. In future semesters, we will continue to employ methods from PER, assess our effectiveness in our physics instruction in correcting students’ misconceptions, and continue to help our students be better problem solvers.

An Update on the Implementation of PER Methods in PC1431

We continued implementing this approach for the PC1431 class offered in Semester 2 of AY2012/13¹ and the author’s (Chang Sheh Lit) student rating (based on effectiveness) dropped from 4.203 (in Semester 1 AY2012/13) to 3.625 (in Semester 2 AY2012/13). We did not do a deep investigation into the reason for the decrease in the student rating by 0.6 points. However, we surmised that one reason for the higher student rating in Semester 1 was that these students were mostly freshmen who were open to any mode of instruction, whereas students taking PC1431 in Semester 2 had gotten used to the traditional mode of instruction and were less receptive to any deviation from the usual approach.

Conclusion

In summary, we have tried to use strategies from PER, such as peer instruction and problem solving through cooperative grouping, in three PC1431 tutorial groups and its effectiveness was compared with three other tutorial groups which served as the control. One main difference between the experimental group and control group was the increase in peer interaction among students, which those from the control group may not have had the opportunity to experience. Even though the performance in the test and exam did not reflect any significant improvements between the two groups, we believe we can continue to refine our approach and make this alternative tutorial style more effective in future semesters.

Endnote

1. The author (Chang Sheh Lit) incorporated the comments obtained from the student feedback exercise in AY2012/13 and made certain changes to his PC1431 tutorial instruction in AY2013/14, which will be reported in another article.

References


continued on the next page ...
Employing Methods in Physics Education Research (PER) to Enhance Learning in an Engineering Physics Course

...continued from pg 27


