Technology-Enhanced Homework Assignments to Facilitate Conceptual Understanding in Physics

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Abstract: We compared the effect of an innovative homework assignment with that of traditional homework assignments on students' conceptual understanding of electromagnetic induction. Students in the experimental group were asked to interact with computer simulations, to present qualitative reasoning explaining the phenomena displayed on the simulations, and were supported with immediate feedback in the form of suggested reasoning. Students who did the traditional homework had access to peer and instructor support. The result indicates that the two modes of learning are equally effective. This outcome suggested that technology enhanced homework assignments can be a valuable educational option when peer or instructor support is not available. We also found that more students in the control group possessed factual knowledge without conceptual understanding of the underlying mechanism. This result suggested that solving traditional physics problems should not be made the only way to learning physics.

Keywords: Computer simulations, automatic feedback, homework, physics

1. Introduction

Physics has legendarily been considered a difficult subject. Many students in the physics courses are not developing a satisfactory conceptual understanding of basic physics (e.g.[1]). The challenge to help students overcome the hurdle of conceptual understanding in physics stimulate tremendous efforts in the pass few decades to reform science education and a new theory of learning is coming into focus that leads to very different approaches to the design of curriculum, teaching, and assessment than often found in schools today [2].

In the mist of scholarly effort to promote understanding in basic physics, computer simulations have been found to be an effective tool to support physics teaching and learning. Nevertheless, introducing redundant simulations may lead to the waste of valuable student time and educational resources. What is worse is that it might even impede learning (e.g. [3]). Research findings on effective ways to use simulations are far from conclusive [4]. Drawing upon research on computer simulations in physics education, we summarized three general principles to use computer simulations effectively for physics education [5]. This finding aligns with well-established principles of learning such as that suggested by Bransford and Donovan [6]. These principles are: (1) Use properly designed, interactive computer simulations to facilitate knowledge construction. (2) Provide opportunities for reflection on the computer simulations. (3) Offer prompts to help students overcome difficulties. The purpose of this study is to empirically determine the effectiveness of a learning framework grounded by the findings of this earlier work of ours. Specifically, this study utilized computer simulations which are to portray physics concepts that are otherwise impossible to depict using static graphics. In addition, students were required to present qualitative reasoning to explain the phenomena displayed on the simulations. After students reflected on the simulations, they were supported with immediate feedback in the form of suggested reasoning.

2. Methodology

2.1 Conditions, Instruments, Sample and Setting

This study utilized an experimental design. The independent variable is the different frameworks of learning. Two frameworks of learning, traditional physics learning (TRAD) and physics concept learning with computer simulations (CLCS) were examined. The post-test were to assess students' understanding of Faraday's law of induction. There were totally five multiple choice questions and one open response question on the post-test. The first three questions were from the Conceptual Survey of Electricity and Magnetism (CSEM) [7]. The last three questions were adapted from the physics achievement test of The Third International Mathematics and Science Study (TIMSS) for students in the final year of secondary school [8]. Students' answers to the one open response question (the last question) were evaluated by the first author and another rater who has a doctorate in physics. The answers were evaluated as to their overall correctness using a standardized rubric (TIMSS, pp. 151-152). The raters discussed any differences on the graded scores and came to consensus on the final scores. The posttest scores were used as the dependent variable.

The participants in this study were recruited from a grade 11 class at a public high school in the capital of China. The participants' age ranged from 15.3 to 17.5 with an average of 16.7 years old. The 41 students, 21 females and 20 males, were randomly assigned to two groups, the control group (TRAD) and the experimental group (CLCS). The school, Beijing 77 high school (pseudonym), is located in a district which has been called the silicon valley of China. The new physics lab at Beijing 77 high school was equipped with about 30 student work tables and the same number of laptop computers.

2.2 Treatment and Procedures

The learning materials used in this study were carefully designed based on principles summarized in our earlier work [6]. The simulations were selected from the physics education technology (PhET). The PhET project was initiated by one of the Nobel Laureates in physics, Carl E. Wieman, with the intention to enhance physics understanding using web-based interactive simulations [9]. All simulations in PhET have gone through user testing before final release. The selected simulations were from a package called Faraday's Electromagnetic Lab. All students in the CLCS group completed a worksheet while interacting with the assigned computer simulations. Specifically, questions on the worksheet asked students to (1) identify the physics principle(s) or concept(s) to explain the physics phenomena, (2) articulate the rationale to use a particular principle or concept to explain the physics phenomena, and (3) describe how principles or concepts are applied to explain the physics phenomena. A website was constructed for the study to allow students download the simulations, submit their reasoning and receive immediate feedback through the Internet. The website was so designed that students can only submit their answers twice, one before receiving support from the computer and one after receiving support.

After students had learned some basic concepts of electromagnetic induction, the CLCS group was given an orientation to the simulation activities. After the orientation, the physics laboratory was opened for several time windows during students' lunch break for students to interact with the computer simulations. (It was necessary for the students to finish the study at the school setting because about half of the participants did not have access to computers or the Internet access at home.) Students were not allowed to discuss any physics concepts with anyone. However, they were free to refer to any book. In addition to the one orientation session, students in the CLCS group were given 6 sessions in the physics laboratory to complete the computer simulation assignments with each session lasted about 40 to 50 minutes. The student worksheet was divided into three parts with each part dealing with one simulation only. The simulation assignments included three simulations and six problems. Student worksheet and suggested reasoning were updated about every two sessions after all students had accessed the latest suggested reasoning.

All students were assigned traditional homework by the participating instructor as usual. However, homework was *not* collected as it was the routine for the participating teacher to not collect homework. According to the participating teacher Mr. Chen (pseudonym), homework was usually assigned at every class and discussed at the very next class meeting. The normal scenario of lunch break is that most students got right back at studying immediately after finishing lunch and students had access to feedback from the teacher as well as peer learners. The difference in treatment between the experimental and control groups is that the experimental group was asked to finish the computer simulation assignments during their lunch break, while the control group continued the routine to do traditional homework with access to peer and instructor support. The posttest was administered to both the TRAD group and the CLCS group following the completion of the unit instruction and the simulation assignments.

3. Results

Although the experimental group did score higher than the control group (an average of 5.00 versus 4.36), t-test comparison indicates that there is no significant difference between the two groups, $t(1, 39) = 1.742$, $p = .089$. This result, albeit not statistically significant, was close to the significance level at $\alpha = .05$. This result also suggested that the computer simulation assignments were at least as effective as the traditional assignments combined with peer or instructor support. Technology enhanced homework assignments can be a valuable educational option when peer or instructor support is not available.

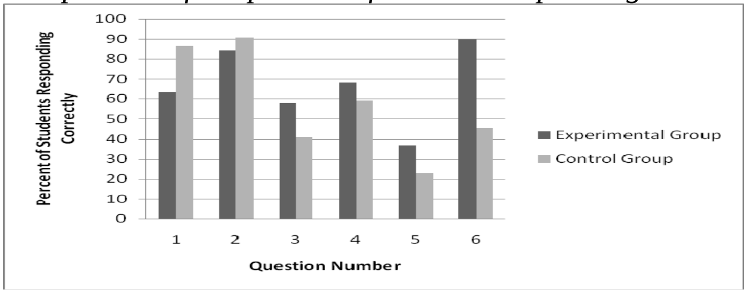
Even though there was no statistically significant difference between the two groups on the average scores, students' performance on the individual test questions showed mixed results. Comparison of the percent of students responding correctly on each question is shown in Figure 3.2. (The percentage shown in Figure 3.2 for the last question is only for those students who received full credits.) The experimental group scored significantly higher than the control group on the last question ($p < .05$ by t test), while the control group scored significantly higher than the experimental group on the first question ($p < .05$ by one tailed binomial test). Some possible reasons which might lead to the experimental group's lower score on the first two questions included the disturbance and technical trouble such as slow network speed the experimental group had experienced during the study. There is no statistically significant difference on scores for all the other questions ($p > .05$ by one tailed binomial test).

While the first two questions of the post-test examined students' concept of the conditions which may or may not cause electromagnetic induction, the last three multiple choice questions all examined students' understanding of the Faraday's law of induction.

Namely, the first two questions were about *what* conditions might cause electromagnetic induction and the last three multiple choice questions were all about the concept of *how* electromagnetic induction happens. That the experimental group constantly scored higher, albeit not statistically significant, on these three multiple choice questions, suggested that the learning framework under examination has somewhat positive effect. Specifically, it suggested that the dynamic features of the selected computer simulations did provide somewhat helpful visual clues to learn *how* the Faraday's law of induction works and that the requirement to reflect on the simulations and immediate support did somewhat facilitate such understanding, when compared to the traditional homework combined with peer or instructor support.

Figure 3.2

Comparison of the percent of students responding correctly on each question



The fluctuations from knowing *what* kinds of conditions cause electromagnetic induction to knowing *how* electromagnetic induction works also came to our concern. It can be seen from Figure 3.2 that the control group's knowledge of electromagnetic induction is more *unstable*. That is, many students in the control group knew *what* kinds of conditions may or may not cause electromagnetic induction but they did not understand *how* electromagnetic induction works. To clarify that more students in the experimental group who correctly answered the "what" (question 1 and 2) questions also answered the "how" (question 3, 4, and 5) questions correctly, correlation between the "what" and "how" questions were calculated for both groups of students. The Spearman rank order correlation coefficients between the two types of questions were -.136 for the control group and .037 for the experimental group. Although the correlation coefficient changed from a negative value for the control group to a positive value for the experimental group, the two groups of students do not significantly differ from each other on this measure ($p > .05$). However, this result indicates that more students in the experimental group were on the track to learn both the "how" and "what" knowledge after completing the computer simulation assignments. It appeared that having students do many traditional problems only enhanced students' knowledge so much as to what conditions may or may not result in electromagnetic induction. Understanding of how electromagnetic induction happens remained a more difficult task for the control group.

4. Discussion and Conclusion

When used properly, computer simulations have been proven to be a useful tool to learning [6]. The present study suggested that technology enhanced homework assignments were at least as effective as traditional homework assignments combined with peer or instructor support. Therefore, when support from peer learners or instructor is not available, technology enhanced homework assignments can be valuable alternatives.

However, inappropriate use of technology could become a hindrance to learning [4]. In the present study, students in the experimental group did not score higher than the control group did on questions about *what* conditions might cause electromagnetic induction. Past studies have reported that student frustration caused by technical difficulties, such as slow response of the computer can have negative effect on student learning (e.g.[10]). If badly used, an excellent simulation will be ineffective, as will an excellent activity that utilizes a poorly designed simulation [9]. Would students in the experimental group have performed better if the implementation of this study were done differently? A study by the PhET research group who also developed the simulations used in this study indicated that the negative effect caused by computer trouble was reversed when the trouble was removed from different experimental group using the same learning material [12]. What appears to be a trivial disturbance has the power to impede learning. We, as educators, must be cautious about every components of our practice.

In one of China's neighbor countries, Korea, students of high competence were found to still have common conceptual difficulties after solving more than 1000 traditional problems [11]. In the present study, students in the control group were given traditional physics problems in electromagnetic induction at every class meeting. In certain questions, we found that these students did score higher. However, it was the factual knowledge of physics with which these students had advantage. Students in the control group still had common conceptual difficulties understanding Faraday's law of induction after working on traditional problems. Given that one important goal of science education is to help students understand how science works, this result serves to caution educators the consequences of making practice traditional problems the only way to learn physics.

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