Pedagogy and/or Technology: Making Difference in Improving Students' Problem Solving Skills

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Abstract. Pen input computers combined with interactive software may have substantial potential for promoting active instructional methodologies and for facilitating students' problem solving ability. An excellent example is a study in which introductory physics students improved retention, conceptual understanding and problem solving abilities when one of three weekly lectures was replaced with group problem solving sessions facilitated with Tablet PCs and DyKnow software [1,2]. The research goal of the present study was to isolate the effect of the methodology itself (using additional time to teach problem solving) from that of the involved technology. In Fall 2011 we compared the performance of students taking the same introductory physics lecture course while enrolled in two separate problem-solving sections. One section used pen-based computing to facilitate group problem solving while the other section used low-tech methods for one third of the semester (covering Kinematics), and then traded technologies for the middle third of the term (covering Dynamics). Analysis of quiz, exam and standardized pre-post test results indicated no significant difference in scores of the two groups. Combining this result with those of previous studies implies primacy of pedagogy (collaborative problem solving itself) over technology for student learning in problem solving recitations.

Keywords: Problem solving, Computers in education, Tablet PC, DyKnow
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INTRODUCTION

Shortcomings of the traditional lecture in helping students learn physics have been well established [3-5]. Prominent physics educators, such as Nobel Prize winner Carl Wieman, have suggested that technology in general can serve as a tool in creating courses that are more interactive and engaging - and consequently more effective in promoting student learning [6].

Rapid advancement and the popularity of tablet computing devices in recent years have been attracting educators' interest as instructional devices [7]. Of particular interest for physics and STEM educators are pen-input computers due to the highly symbolic nature of annotations in these fields, combined with the complex graphical representations for which input without pen writing is inadequate or highly cumbersome. Tablet PCs, when wirelessly networked and combined with interactive software, can open a wide array of possibilities for active instructional methodologies [8].

This study investigated the instructional effectiveness of wirelessly networked tablet PCs combined with software enabling real-time information exchange among all participants (DyKnow) [9]. Tablet PCs can be operated with an electronic pen (or by touch) in addition to the keyboard and mouse/pad. Unlike most newly launched pen and/or touch slate devices, tablet PCs also support high-end personal computer processing.

Earlier studies indicated a great potential with this technology in facilitating students' problem solving ability, which is a critical aspect of effective physics learning [1,2]. In a problem solving context, the use of Tablet PCs and DyKnow, students can simultaneously annotate their respective group slide, then submit a pen-annotated solution to the instructor. From his/her computer the instructor monitors the progress of all groups in real time and if desired comments and/or annotates on student slides. Instructor can also display individual or group submissions for whole class discussions and can distribute the selected solution to all students with a click. Sisson[1,2] devoted one of the three weekly lecture classes to collaborative problem solving supported by this technology and improved students' i) conceptual understanding, ii) test scores (significantly) and iii) retention to the second semester course (significantly), all as compared to the 5-year historical average [1,2].

RESEARCH QUESTIONS AND EXPERIMENTAL DESIGN

When deploying this instructional technology, Sisson replaced one of the three lecture hours per week with a substantially different activity - small group problem solving facilitated with tablet PCs and interactive software [1,2]. The gains she saw in her metrics (conceptual understanding, problem solving ability and retention) were dramatic. However the study included potentially confounding variables because the instructional methodology was changed with a simultaneous introduction of the technology.

Following up on these earlier results, the goal of the present study was to investigate whether the observed changes could have resulted from replacement of a weekly lecture hour with collaborative problem solving sessions alone, or whether improvements in student outcomes can be attributed to use of the technology deployed to facilitate the new pedagogy. It is possible that technology has been a convenient facilitation tool for the instructor either with or without a direct effect on student learning.

To investigate this question we conducted a study combining lab and lecture parts of calculus-based introductory physics course. During Fall 2011 we had two lab sections associated with the course enabling an exchange of the experimental and control groups. These lab sections were run in three-hour long blocks and we allocated one of these three hours to problem-solving practice. Participants in this study thus had an hour of collaborative problem solving on a weekly basis on top of their regular lecture time (which was structured in two 75-min sessions per week). In order to use this setting to examine the effect of the Tablet PCs and interactive learning software on student learning, one lab section started the semester collaboratively using Tablet PCs, and the other was allotted the same time to work on the same problems, but used either 3’ x 4’ whiteboards or wall whiteboard spaces to collaboratively solve problems. After a third of the semester was over and the first exam had been administered, lab sections exchanged protocols. After the semester was two-thirds completed and the second exam was administered (with the first third corresponding to Kinematics and the second third to Dynamics), each section had approximately the equivalent time in using both whiteboards and tablet PCs. Students were then permitted to choose which technique to use when completing problem solving tasks for the remainder of the term. It was randomly chosen that the Thursday lab group (section 1) be the control during the first part of the study. The experimental design thus followed the sequence shown in Table 1.

TABLE 1. Outline of the Experimental Design

	1st third of semester	**2nd third of semester**
Section 1 (Thursday)	Experimental (technology users)	Control (whiteboard users)
Section 2 (Friday)	Control (whiteboard users)	Experimental (technology users)

Students were also randomly assigned to collaborative groups. In solving problems, students were not using the computer’s processing power for tasks different than facilitating classroom interaction to avoid advantaging one of the groups in ways not intended by experiment. During the Tuesday lecture class following the problem solving sessions in the preceding week, students were given a 15 minute quiz. Students from both sections were enrolled in the same lecture class, so they each took the same quiz at the same time. Quiz problems were chosen to be either directly isomorphic (the problem changed numbers and/or surface features only) or indirectly isomorphic (the same conceptual problem, but a different variable solved for – such as solving a kinematic problem for final velocity during the recitation, and for initial velocity on the quiz). Quiz problems were explicitly solved using a structured problem solving approach, and prompts for the structure were included on the quiz itself. In both the first and second part of the study, we gave three quizzes. The students regularly solved the same set of problems in both lab sections, with the instructor taking care that equal amount of time was given to each problem in both sections.

Exam scores were also collected, as well as end-of-course grades, as broader measures of student ability in physics problem solving, and these data streams were examined with respect to the problem solving technology used, as well as student demographic variables. All problem sessions were video-taped, although that analysis will be reported elsewhere.

Results and Analysis

The main findings reported here revolve around three independent metrics:

a) Student scores achieved on common class quizzes following problem solving sessions.
b) Class exams associated with topics of kinematics and dynamics respectively, each of which corresponded with one part of the study
c) Normalized gains on standardized tests associated with kinematics (TUG-K test) and dynamics (FCI test).

There were three quizzes associated with kinematics and another three associated with dynamics. Each section had 20 students so the possible number of quizzes that they would have taken was 60 for kinematics and another 60 for dynamics part. Results are presented in Table 2 below. From the quiz scores, we eliminated instances of quizzes taken by students who were absent from the preceding problem-solving session/lab.

According to the quiz results presented in Table 2, the Thursday section performed better in both segments of the study by a very small margin (average of 72.6% vs. 67.5% for kinematics, and 71.9% versus 71.6% for dynamics). Standard deviations are also similar showing slightly larger variability in Friday group.

We ran an ANCOVA test to determine the statistical significance of these differences (i.e. to show statistical insignificance). The data satisfied the test of homogeneity of slopes assumption as the interaction between students and technology mode was not significant (p=0.802) and also with partial η^2=0.000, indicating that in the sample the mean differences in quiz results are not a function of the individual student differences or similarities. ANCOVA was performed with individual students defined as covariant, as the same students were taking multiple quizzes. This test was not significant for the treatment effect, F(1,206)=0.487, MSE=4.930, p=0.486. Partial η^2=0.002 for the technology usage (with η^2=0.004 for student variable).

TABLE 2: Student Scores on Quizzes and Tests Associated With Kinematics and Dynamics

		1st third of semester (Part I) Kinematics THURSDAY Section used Technology			2nd third of semester (Part II) Dynamics FRIDAY Section Used Technology		
Section	**Metric**	**N quizzes (of 60)**	**Average (%)**	**SD (%)**	**N quizzes (of 60)**	**Average (%)**	**SD (%)**
THU	Individual quiz score averages	54	72.6	21.4	53	71.9	21.5
FRI	Individual quiz score averages	55	67.5	24.7	50	71.6	23.8
Section	**Metric**	**N students (of 20)**	**Average (%)**	**SD (%)**	**N students (of 20)**	**Average (%)**	**SD (%)**
THU	Test Averages	20	70.9	14.7	20	69.7	11.1
FRI	Test Averages	20	70.5	17.0	20	69.3	10.6

Table 2 also shows that the differences in test score means between the experimental and control groups were virtually nonexistent (smaller than 1% for both tests), further supporting the finding that the usage of technology in solving problems did not make a difference. The Thursday section was again indistinctly better in both segments (70.9% versus 70.5% for kinematics and 69.7% versus 69.3% for dynamics). We report next on the findings associated with student scores on standardized test for kinematics (TUG-K) and dynamics (FCI) in respective parts of the study (Table 3).

TABLE 3: Student pre-post performance on standardized tests for Kinematics (TUG-K) and dynamics (FCI)

		1st third of semester (Part I) TUG-K test FRIDAY Section used Technology					2nd third of semester (Part II) FCI test THURSDAY Section Used Technology				
Section	**Data set within standardized test Pre-Post score**	**N (out of 20)**	**Average normalized gain**	**SD**	**Normalized gain for class average scores**	**Average Post test score (%)**	**N (out of 20)**	**Average normalized gain**	**SD**	**Normalized gain for class average scores**	**Average Post test score (%)**
THU	All PRE-POST Results	19	NA*	NA*	39.6	75.9±15.0	19	51.6	24.3	50.3	71.4±20.3
	Without student with perfect pre-score	18	26.8	54.4	40.3	74.9±14.7	19	51.6	24.3	50.3	71.4±20.3
	Positive gains only	14	50.5	23.0	49.3	75.5±15.4	19	51.6	24.3	50.3	71.4±20.3
FRI	All PRE-POST Results	17	45.5	31.6	46.7	75.1±21.3	18	51.0	27.4	49.5	70.9±20.3
	Positive gains only	16	50.4	25.0	48.2	74.7±20.9	17	54.0	25.0	53.3	73.5±17.5

*One student in the Thursday section had a perfect score on the pretest and missed one problem in the posttest which makes the normalized gain score undefined.

Although the technology using group had larger gains in both standardized tests (Friday section for kinematics and Thursday section for dynamics) the differences are very small and not statistically significant. The ANCOVA test for differences in normalized gain scores is $F(1,67)=1.431$, $MSE=1402.54$, $p=0.236$ with partial $\eta^2=0.021$ for the technology usage which makes the effect of technology usage very small, and possibly comparable to factors unaccounted for. Note that this treatment was less likely to produce a measurable effect on standardized tests than on quizzes and exams that involved (to various degrees) isomorphic problems. This was the case in Sisson's study [1,2] as well.

Analysis was further performed on the data from the class as a whole, examining it for demographics trends. As students did not all take the SAT, concordance scores between ACT and SAT were utilized to extend comparisons based on student mathematical ability. No significant correlations were found between gender and any of the following: raw quiz score semester total, quiz totals after the first third of the semester, second third of the semester, individual exam scores or final exam scores.

CONCLUSIONS

Earlier studies showed strong improvements of student learning when a portion of a lecture-based course was dedicated to technology-facilitated group problem-solving sessions [1,2,10]. The goal of this study was to determine whether the improvement in student performance was primarily due to the change in methodology within the course, due to the technology usage itself, or possibly both. We replicated Sisson's[1,2] earlier successful deployment, in which she replaced one of the three hour long lecture classes per week with technology-facilitated recitations. We kept the total of a 3-hour per week lecture intact and added one hour per week of such recitations to the course by using one out of the three hours of the lab sessions per week. Using two lab sections for collaborative problem solving we were able to exchange experimental (technology facilitated) and control (whiteboard facilitated) treatments.

We found no difference in students' performance when they did and did not use computing technology. In addition to the possibility of true irrelevance of the collaborative medium, it is possible that the finding may be caused by students' limited exposure to technology which resulted in insufficient proficiency in using it effectively. For example the Friday group which started with technology, used it three times for one hour before the switch). Lack of a distinguishable effect due to insufficient exposure to different treatments is possible especially in light of our earlier studies in which we found that consistent usage of this technology in a lecture may have a large positive impact on physics learning [11].

Our experimental design with two groups did not allow for comparing the effect of these treatment variations with the absence of any treatment. Sisson's results suggest this difference exist and is large. For simultaneous gauging of effects, the third group would have been required for which no additional problem solving would have been organized. Inclusion of such control was not logistically feasible. Such omission of the extra problem solving opportunity would also have to be compensated for students otherwise, to avoid ethical conflicts. However, as a pointer for future studies, this might be a productive direction to further discern answers to proposed research questions.

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