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Enhancing Student Performance Using Tablet Computers

Amelito G. Enriquez
Cañada College

Tablet PCs have the potential to change the dynamics of classroom interaction through wireless communication coupled with pen-based computing technology that is suited for analyzing and solving engineering problems. This study focuses on how tablet PCs and wireless technology can be used during classroom instruction to create an Interactive Learning Network (ILN) that is designed to enhance the instructor's ability to solicit active participation from all students during lectures, to conduct immediate and meaningful assessment of student learning, and to provide needed real-time feedback and assistance to maximize student learning. This interactive classroom environment is created using wireless tablet PCs and a software application, NetSupport School. Results from two separate controlled studies of the implementation of this model of teaching and learning in a sophomore-level Introductory Circuit Analysis course show a statistically significant positive impact on student performance. Additionally, results of student surveys show overwhelmingly positive student perception of the effects of this classroom environment on their learning experience. These results indicate that the interactive classroom environment developed using wireless tablet PCs has the potential to be a more effective teaching pedagogy in problem-solving intensive courses compared with traditional instructor-centered teaching environments.

Keywords: interactive teaching, technology in education, tablet PC

Studies have long shown that the traditional instructor-centered lecture format is an ineffective learning environment, and that active participation, as well as interactive and collaborative teaching and learning methods, are more effective in various areas of science and engineering education including chemistry (Birk & Foster 1993), physics (Meltzer & Manivannan 1996), engineering (Felder, Felder & Dietz 1998), and computer science (Rodger 1995). Various uses of technology have been found to be effective in enhancing the classroom experience to achieve more interactive and collaborative environments. These techniques include handheld wireless transmitters in Personal Response Systems (PRS) (Beekes 2006), various forms of computer-mediated collaborative problem solving (Rummel & Spada 2005), and the use of wireless tablet PC technology (Koile & Singer 2006; Rogers & Cox 2008).

Correspondence should be sent to Amelito G. Enriquez, Engineering, Cañada College, 4200 Farm Hill Blvd., Redwood City, CA 94061, USA. E-mail: enriquez@smccd.edu

Tablet PCs are essentially laptop computers that have the added functionality of simulating paper and pencil by allowing the user to use a stylus and write directly on the computer screen to create electronic documents that can be easily edited using traditional computer applications. This functionality makes tablet PCs more suitable than laptop computers in solving and analyzing problems that require sketches, diagrams, and mathematical formulas. Combined with wireless networking technology, tablet PCs have the potential to provide an ideal venue for applying previously proven collaborative teaching and learning techniques commonly used in smaller engineering laboratory and discussion sessions to a larger, more traditional lecture setting. Currently, the range of use of tablet PCs in the classroom includes enhancing lecture presentations (Rogers & Cox 2008; Ellis-Behnke et al. 2003), digital ink and note taking (Colwell 2004), E-Books (books in electronic format) that allow hyperlinks and annotations (Goodwin-Jones 2003), Tablet-PC-based in-class assessments (Rogers & Cox 2008; Ellis-Behnke et. al., 2003), and tablet-PC-based classroom collaboration systems such as the Classroom Presenter(Anderson et. al., 2007), and the Ubiquitous Presenter(Price, Malani & Simon 2006) that

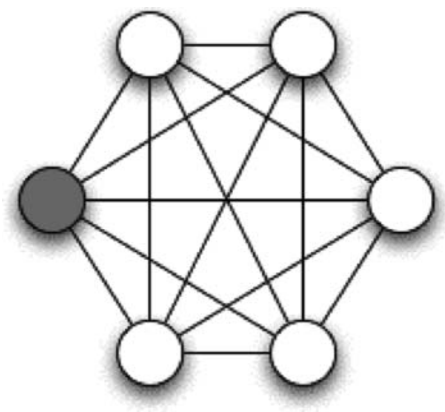

FIGURE 1 Schematic of the Interactive Learning Network showing the interactions between the instructor (shaded circle) and the students (open circles).

can enhance student learning and engagement. As the use of tablet PCs in the classroom grows, there is a growing need to understand how these various uses and applications can facilitate and enhance student learning.

This paper summarizes the results of a series of studies on how tablet PCs and wireless technology can be used during classroom instruction to create a model that is highly interactive. In this paper, this model will be referred to as an Interactive Learning Network (ILN). Figure 1 is a schematic of the ILN model of instruction showing the various two-way interactions between the instructor and the students during lecture sessions.

This paper will also address the effects of these technology-enhanced interactions and collaborations on student performance and on student attitude towards the ILN model of instruction and the use of Tablet PCs in the classroom. It is expected that these studies will show that compared with courses taught with a traditional instructor-centered mode, the ILN can lead to

- better student performance in the courses where the technology is implemented, as indicated by better student grades on homework, quizzes, and tests compared with courses that do not use the technology;
- better retention of prior prerequisite knowledge of basic concepts and their applications for students in the interactive class;
- positive attitude toward the use of the ILN model of instruction and towards student use of tablet PCs in the classroom; and
- better student engagement in courses using the technology, as evidenced by higher attendance rates and more time spent on assigned tasks outside class time.

METHOD

The Circuits Class at Cañada College

Cañada College is part of the 108-school California Community College system and is one of the smallest community colleges in the San Francisco Bay Area, with approximately 6,000 students. The college is a federally designated Hispanic Serving Institution with approximately 42% Latino students. Cañada's Engineering Department is a 2-year transfer program with approximately 15–20 students transferring to a 4-year institution every year. The Circuits course at Cañada College is a three-unit, sophomore-level lecture course required of all engineering students regardless of their majors or their transfer institutions. The class meets for 3 hours a week for 16 sixteen weeks and covers topics on theory and techniques of circuit analysis, circuit laws and nomenclature, resistive circuits, controlled sources, ideal operational amplifiers, natural and complete responses of first- and second-order circuits, steady-state sinusoidal analysis, power calculations, transformers, and three-phase circuits. In the traditional instructor-centered approach to teaching the class, the instructor presents new concepts, derives important equations related to the concepts, and then presents a collection of illustrative sample problems that are solved by the instructor in detail. Additional examples are given as in-class exercises or assigned as homework problems. Periodic assessment of student learning is done in the form of quizzes and tests given during the duration of the semester. Success in this course using this approach has been limited, as Circuits has traditionally been an engineering course that has high attrition rates.

The Interactive Learning Network (ILN)

The Interactive Learning Network (ILN) is designed to enhance the instructor's ability to solicit active participation from all students during lectures, to conduct immediate and meaningful assessment of student learning, and to provide needed real-time feedback and assistance to maximize student learning. This interactive classroom environment is created using wirelessly networked tablet PCs and a software application, NetSupport School, that allows various levels of interactions between the instructor and the students during lectures. In this model of instruction, instructors spend less delivering content through traditional instructor-centered lectures. The lectures focus on introducing new concepts and applying them to a few simple examples, with more complex examples given as guided exercises. Students can access the instructor's presentation and add their own annotations using Windows Journal or PowerPoint. Throughout the lecture, the NetSupport School software allows the instructor to quickly assess individual student understanding of concepts using instant student surveys. At the end of each lecture, more involved examples are introduced as exercises that students work on individually or in groups on their tablet PCs using Windows Journal and/or other appropriate software (Excel, Matlab, MultiSIM, PSPICE, etc.). While students work on more challenging problems, the instructor has the capability to scan and monitor students' work from the instructor's tablet PC and to guide the students and assess their progress through NetSupport's Survey mode using a series of short, previously prepared leading questions. Individual student questions are received through the Help Request feature, and individual assistance can be provided using the Monitor, Share, and Control features. The instructor is also able to effectively manage the various interactions through group chat, electronic whiteboard, and file transfer and distribution, as well as control of student computer applications and web activity. The effectiveness of this model comes from the ability of the instructor to monitor and interact with individual students while they analyze problems on the computer using an input device that allows them to write and manipulate formulas and make sketches and diagrams.

This method of instruction was developed and implemented in a number of sophomore-level engineering courses at Cañada College. Students in these courses have no prior experience with tablet PCs and have access to them only during class. Results of the implementation on two circuits classes will be the focus of this paper.

TABLE 1
Demographic Comparison of Spring 2006 and Spring 2005 Circuits Students

	Experimental Spring 2006 (ILN)		*Comparison Spring 2005 (non-ILN)*	
Demographics	*N*	*%*	*N*	*%*
Gender				
Female	5	12.2%	7	25.0%
Male	36	87.8%	21	75.0%
Total	41		28	
Ethnicity				
Afro-American	0	0.0%	0	0.0%
Asian	11	26.8%	7	25.0%
Caucasian	9	22.0%	10	35.7%
Filipino	2	4.9%	1	3.6%
Hispanic	14	34.1%	8	28.6%
Other	5	12.2%	2	7.1%
Tota	41		28	
Major				
Civil Engr	8	19.5%	4	14.3%
Mechanical Engr	17	41.5%	13	46.2%
Electrical Engr	9	22.0%	7	25.0%
Computer Engr	2	4.9%	3	10.7%
Other	5	12.2%	1	3.6%
Total	41		28	

The Two Case Studies

To study the impact of the ILN model of instruction, two case studies were done: Study 1 involved comparing two Cañada College circuits courses—the Spring 2006 class that used the ILN model, and the Spring 2005 class that used the traditional instructor-centered model. Study 2 involved comparing two circuits courses from two different institutions in the Spring 2006 semester, a class at Cañada College that used the ILN model and a class at San Francisco State University that used the traditional model.

Study 1: Cañada College Spring 2006 and Spring 2005. The ILN was first implemented in a Circuits class of 41 students at Cañada College in Spring 2006. Since Cañada College offers only one section of this class every spring semester, a comparison group could not be established for the study. Instead, the performance of the Spring 2006 experimental group that used the ILN model was compared with that of the Spring 2005 circuits class of 28 students. Similar homework, quizzes, and exams were given to both circuits classes. An attitudinal survey was also administered at the end of the Spring 2006 semester to evaluate students' opinion of and satisfaction with the use of the ILN model and tablet PCs in the classroom.

Table 1 shows a comparison of student demographics for the two Circuits classes that were compared in this part of the study. The two circuits classes were very similar demographically. The Spring 2006 class (ILN model) with 41 students, and the Spring 2005 (non-ILN) class started with 28 students. For both years, the majority of the students were male, and over 40% of the students were mechanical engineering majors. For both years, the ethnic distribution was diverse, with no majority ethnic group.

Study 2: Spring 2007 Circuits at Cañada College and San Francisco State University. For Spring 2007, two sections of Circuits courses were studied—one at Cañada College and one at San Francisco State University (SFSU), with both classes taught by the same instructor. As noted above, Cañada College offers only one section of circuits every spring semester. To study the impact of the ILN model on student performance in the Circuits class at Cañada College, the circuits class at San Francisco State University was selected to be the comparison group. In both courses, the instructor used a tablet PC and a combination of PowerPoint and Windows Journal presentations to deliver lectures. The only major difference between the two classes was the student use of tablet PCs and NetSupport School in the Cañada College class to create the Interactive Learning Network. Students in the Cañada class use tablet PCs to take notes, to analyze and solve problems, and to interact with the instructor through NetSupport School software's Instant Survey, Electronic Whiteboard, Chat and Help Request features.

The Circuits course at SFSU was a three-unit lecture course that met 3 hours a week for 15 weeks, 1 week shorter than Cañada's 16-week course. The first 15 weeks of the Cañada class covered topics that were identical to SFSU's topics. For the last week, the Cañada class covered a topic that

TABLE 2
Demographic Comparison of Spring 2007 Circuits Students at Cañada College and San Francisco State University

	Experimental Cañada 2007 (ILN)		*Comparison SFSU 2007 (non-ILN)*	
Demographics	*N*	*%*	*N*	*%*
Gender				
Female	2	12.5%	8	17.4%
Male	14	87.5%	38	82.6%
Total	16		46	
Ethnicity				
Afro-American	0	0.0%	2	4.3%
Asian	2	12.5%	13	28.3%
Caucasian	4	25.0%	8	17.4%
Filipino	0	0.0%	12	26.1%
Hispanic	6	37.5%	6	13.0%
Other	4	25.0%	5	10.9%
Total	16		46	
Major				
Civil Engr	4	25.0%	23	50.0%
Mechanical Engr	4	25.0%	9	19.6%
Electrical Engr	3	18.8%	11	23.9%
Computer Engr	2	12.5%	2	4.3%
Other	3	18.8%	1	2.2%
Total	16		46	

was not covered at SFSU and not included in any of the tests. The last homework set at Cañada was not included in the analysis and comparison of the performance of the two groups.

Table 2 shows a comparison of the demographics of the two groups of students for Study 2, with 16 students in the Cañada class, and 46 in SFSU. Both groups of students were ethnically diverse, with Hispanics making up the biggest group at Cañada and Asians the biggest group at SFSU. At SFSU, 50% were civil engineering majors, while the students at Cañada were more evenly distributed among the different majors. With respect to gender, the Cañada group had a slightly lower percentage of female students (12.5% vs. 17.4%).

Due to the inherent differences between the two groups of students in Study 2 (Cañada College being a community college, and SFSU being a university), a diagnostic test was given to the both groups to ascertain whether the students' levels of preparation for the class were comparable. The diagnostic test consisted of 15 multiple-choice questions measuring student knowledge of electric circuits concepts and their applications. These questions involved topics that were covered in the prerequisite physics course. Results of this diagnostic test showed no statistically significant difference in the average and median scores of the two student groups.

PROCEDURES

Classroom Formats

Table 3 summarizes the similarities and differences in the classroom structure of the experimental and comparison groups of the two case studies. All four of the courses in the studies were taught by the same instructor. For the two experimental groups that used the ILN model, each student was given a tablet PC to use during lectures, and interactivity during delivery of new topics was achieved using NetSupport's Instant Survey and electronic whiteboard features that allow participation from all students. As previously described, most of the illustrative examples were given as exercises that students solved using the tablet PCs, while the instructor observed and guided their progress and provided individual assistance through the NetSupport School software. For the comparison, in the non-ILN groups, the class structure was instructor-centered and non-interactive during both the introduction of new topics and solutions of illustrative examples.

The last row of Table 3 shows that for three of the four groups (2006 Cañada, 2007 Cañada, and 2007 SFSU) the instructor used the same method in generating and delivering lecture notes to the students. For these three groups, the instructor used a tablet PC in combination with PowerPoint and Windows Journal to deliver class material. The tablet PC replaced the blackboard and chalk (or whiteboard and pen), making it possible to have an electronic record of all the lecture notes prepared before and during class. An outline of the day's lecture was usually prepared using a combination of PowerPoint and Windows Journal presentations.

TABLE 3
Comparison of Classroom Formats for the Experimental and Comparison Groups of Study 1 and Study 2

	Study 1		*Study 2*	
Classroom Format	*Experimental Cañada 2006 (ILN)*	*Comparison Cañada 2005 (non-ILN)*	*Experimental Cañada 2007 (ILN)*	*Comparison SFSU 2007 (non-ILN)*
Student Use of Tablet PC	Yes	No	Yes	No
Lecture Delivery of New Material	Interactive with Students using NetSupport	Not Interactive	Interactive with Students using NetSupport	Not Interactive
Presentation of Illustrative Sample Problems	Interactive with Students using NetSupport	Not Interactive	Interactive with Students using NetSupport	Not Interactive
Instructor Lecture Notes	Tablet PC	Blackboard and Chalk	Tablet PC	Tablet PC

During lectures, the instructor added and saved handwritten annotations, sketches, derivations, illustrative problems, and problem solutions to the lecture notes that were then posted on the class Web site. This allowed subject material to be covered more efficiently and adjustment of the class agenda to be done more easily to accommodate student progress. For the non-ILN Spring 2005 Cañada group, the traditional chalk and blackboard was the main medium for generating and delivering lecture notes.

Data Analysis

To measure the impact of the ILN on learning, the performance of the ILN and non-ILN groups for each of the two case studies were compared. For each case study, scores of the two groups of students on 15 homework sets, four quizzes, four tests, and a final examination were compared. Identical homework problems were assigned from the textbook for the ILN and non-ILN groups within the same case study (Study 1 or Study 2). The final examinations were also identical for the ILN and non-ILN groups within the same case study. For Study 2, the four tests were also identical for the two groups. For Study 1, the four tests were slightly different between the two groups (since they were given in 2 different years), but the topics covered, the nature and format of the questions, and the skills and knowledge tested were the same. They were also designed so that difficulty levels were comparable. The average scores for the experimental and comparison groups were computed, and independent Student t-tests were used to evaluate the statistical significance of the results.

For Study 2 consisting of Cañada 2007 and SFSU 2007 classes, an additional pre- and posttest performance comparison was done. The Diagnostic Test given in the first week of the semester was again given a week before the final exam as the posttest. The average scores for the experimental and comparison groups were computed, and independent Student t-tests were used to evaluate the statistical significance of the results.

To determine students' attitudes towards the use of tablet PCs and the ILN model of class instruction, an attitudinal survey was given to the two experimental groups at the end of the semester. This survey has two parts: one on NetSupport School use and one on student use of tablet PCs. It was designed to determine students' perceptions of the impact of the ILN model on student learning and teaching effectiveness. Simple averages of student responses were computed to summarize the results.

RESULTS

Study 1: Cañada College Spring 2006 and Spring 2005

In this section, performance of the two groups of students, the Spring 2006 class with ILN format and the Spring 2005 class

TABLE 4
Comparison of Circuits Student Performance for Spring 2006 and Spring 2005

Experimental Spring 2006 (ILN)	*Comparison Spring 2005 (non-ILN)*	*Difference N=41*	*Categories N=28*
Quiz Average (out of 5)	4.7	3.4	1.3*
Homework Average (out of 10)	9.3	8.6	0.7*
Test Average (out of 100)	76.6	70.8	6.2
Final Exam (out of 100)	83.4	77.8	5.6

**Note.* The difference is statistically significant [$p < .01$].

with a traditional format, will be compared. Additionally, results of the attitudinal survey on student perception of and satisfaction with the ILN model of instruction and the use of Tablet PCs will be presented.

Class performance comparison. A summary of the comparison of the performances of the two groups of circuits students is shown in Table 4. Quiz Average is the average of four quizzes, Homework Average is the average of 15 homework sets, and Test Average is the average of four tests. The last column of Table 4 is the difference between the average scores received by Spring 2006 students and Spring 2005 students. There is a significant difference between 2006 and 2005 results in Homework Average [$t(1, 42) = 2.61$, $p < .01$] and Quiz Average [$t(1, 33) = 8.06$, $p < .001$]. Although the average of the four tests from the two groups have no statistically significant differences, two of the four have statistically significant differences—Test 3 [$t(1, 54) = 2.05$, $p < .05$] and Test 4 [$t(1, 42) = 2.52$, $p < .05$]. Although the difference for the Final Exam is not statistically significant, the corresponding letter grade for the Final Exam was a "B" for the 2006 class, and a "C" for 2005 class.

Attitudinal survey on tablet PC and NetSupport School: Spring 2006 only. Table 5 summarizes the results of the attitudinal survey administered in the Spring 2006 ILN class at the end of the semester. They show overwhelmingly positive attitudes toward the use of both NetSupport School software and tablet PCs in the classroom. With respect to the use of NetSupport School, the "Help Request" feature was perceived most positively by students, with the control features (locking of student computers, Internet, and Applications controls) viewed the least positively. With respect to the use of tablet PCs in the classroom, students viewed them as helpful in improving student performance and the instructor's teaching efficiency, and creating a better learning environment.

When students were asked the open-ended question of what they like most about the NetSupport School software and the tablet PCs, student responses included increased attentiveness and focus during lectures, real-time assessment of their knowledge through polling, immediate feedback on

TABLE 5
Summary of Student Opinions of NetSupport School and Tablet PC Use in the Classroom

Use of NetSupport School Software Response Scale: 4 – Strongly Agree, 3 – Agree, 2 – Disagree, 1 – Strongly Disagree, 0 – No Opinion.	*Average Response (N=37)*
NetSupport School program was helpful in improving my performance.	3.49
NetSupport improved the instructor's teaching effectiveness.	3.64
The "Help Request" feature of NetSupport was useful to me.	3.68
My overall experience with NetSupport School has been positive.	3.67
Use of Tablet PCs Response Scale: 4 – Strongly Agree, 3 – Agree, 2 – Disagree, 1 – Strongly Disagree, 0 – No Opinion.	Average Response (N=37)
Using the Tablet PCs in class helped me improve my performance.	3.58
Tablet PC use improved the instructor's teaching effectiveness.	3.62
I would like to have Tablet PCs available for student use in other courses.	3.60
My overall experience with Tablet PCs has been positive.	3.68

their work, increased one-on-one time with the instructor, ease of communication with instructor, and quick assistance when needed.

Study 2: Spring 2007 Circuits at Cañada College and San Francisco State University

The performance of the two groups of circuits students—the ILN Cañada class and the SFSU class that used the standard instructor-centered approach—will be compared in this section. Additionally, results of the survey on student engagement, expectations, and confidence on mastery of course content will be presented.

Class performance comparison. Table 6 shows a comparison of the performance of the two groups of Spring 2007 circuits students. Quiz Average is the average of four quizzes, Homework Average is the average of the 15 homework sets, and Test Average is the average of four tests. The last column of Table 6 is the difference between the average scores received by Cañada students and SFSU students. The tabulated results also show higher scores for the Cañada

TABLE 6
Comparison of Spring 2007 Circuits Student Performance for the Cañada College Class and the SFSU Class

Categories	*Experimental Cañada (ILN) N=16*	*Comparison SFSU (non-ILN) N=46*	*Difference (Cañada – SFSU)*
Quiz Average (out of 10)	8.3	7.2	1.1*
Homework Average (out of 10)	8.4	8.0	0.4
Test Average (out of 100)	79.9	72.3	7.6*
Final Exam (out of 100)	86.4	79.4	7.0*

**Note.* The difference is statistically significant [$p < .05$].

(ILN) class in all categories. Differences between the scores are statistically significant for Quiz Average [$t(1, 20) = 2.56$, $p < .05$)], Test Average [$t(1, 35) = 2.11$, $p < .05$] and Final Exam [$t(1, 25) = 2.17$, $p < .05$]. The difference for the Homework Average is not statistically significant.

Pre- and posttests. Table 7 summarizes the results of the pre- and posttests. Although the pretest scores of SFSU students are slightly higher than those of Cañada students, there is no statistically significant difference between the average pretest scores. The pretest averages are significantly higher than the pretest scores both at Cañada [$t(1, 26) = 8.41$, $p < .001$] and at SFSU [$t(1, 79) = 7.50$, $p < .001$]. It should be noted that these tests were designed to be a diagnostic test that measures students' knowledge of basic concepts of electrical circuits and their applications—topics that have been covered in the prerequisite physics course. Although the Circuits class increased the understanding and retention of knowledge in these topics for both groups of Study 2, the ILN group's improvement is significantly better than that of the non-ILN group as indicated by the posttest results. The average posttest score is significantly higher for the Cañada group compared with the SFSU group [$t(1, 29) = 3.97$, $p < .001$].

SUMMARY AND CONCLUSIONS

In assessing the impact of the ILN on student performance, it is important to determine how the different components of the model positively or negatively affected student learning. One of the most important components of the ILN teaching model is the immediate assessment of student learning and feedback on their performance. Research on learning theory has long shown that immediate feedback is an effective tool in increasing learning efficiency (Shute 1994). For the case study at hand, the effect of immediate feedback can be seen in quiz and homework scores of the ILN classes. As a result of solving problems in class with the instructor's

TABLE 7
Summary of Pre- and Post-Test Results for Spring 2007 Circuits Students for the Cañada College Class and the SFSU Class

	Experimental Cañada (ILN) N = 16		*Comparison SFSU (non-ILN) N = 46*		*Difference** (Cañada – SFSU)*	
	Pre	*Post**	*Pre*	*Post**	*Pre*	*Post*
Average	5.5	12.3	5.7	9.8	−0.2	2.5
Median	5	13	6	10	−1	3
Stand Deviation	2.4	1.9	2.6	2.3	–	–

*Statistically significant difference [$p < .001$] between pre- and posttest average scores for both groups.
*No statistically significant difference between Canada and SFSU for pretest average scores.
Statistically significant difference [$p < .001$] between Canada and SFSU for posttest average scores.

guidance, students not only learned the material but gained confidence such that they were more successful in completing homework assignments and were better prepared for quizzes. Consequently, the completion and submission rates of homework assignments for the interactive classes were observed to be higher compared with the traditional instructor-centered classes (greater than 95% completion rate for both interactive groups and less than 87% completion rate for the non-interactive groups). This difference may be attributed to a tendency observed by the instructor for students in the non-interactive classes to delay studying class material until immediately before a test. For example, during exam review sessions, many of the questions raised by students in the non-interactive classes were similar to those raised by students in the interactive classes much earlier in the learning process.

Improved performance in the interactive classes may also be attributed to increased focus and attentiveness during class as a result of the instructor's survey questions and the awareness that the instructor observed their progress. Furthermore, the "Help Request" feature of NetSupport was found useful by the students because it allowed them to ask specific questions anonymously. Another advantage of the electronically monitored interactive problem-solving sessions in class was that it enabled the instructor to identify common student misconceptions early in the learning process, thereby reducing student frustration when solving problems on their own. This early assessment of student learning sometimes presented a need for the instructor to adjust course material, making the class more dynamic and more responsive to the needs of the students.

The ILN resulted in better student engagement, as evidenced by higher attendance rates (average number of absences of 2.3 for the ILN group and 7.5 for the non-ILN group of Study 2) and more time spent on assigned tasks outside class time, as indicated by the students in an end-of-semester survey (an average of 6.8 hours per week for the ILN group and 5.4 hours per week for the non-ILN group of Study 2). Students also expressed positive attitudes toward the use of the ILN model of instruction and toward student and instructor use of tablet PCs in the classroom.

The use of tablet PCs in the classroom further resulted in a number of distinct advantages that could have contributed to the improved performance of the ILN students. From the students' point of view, the use of Tablet PCs during lectures provided enhanced note-taking ability, improved their ability to organize class materials, and allowed them to integrate handwritten notes and course materials. These features make a tablet PC highly adaptable to individual students' learning strategies (Ellis-Behnke et al. 2003). From the instructor's point of view, the use of PowerPoint and Windows Journal in presenting material coupled with the ability to incorporate handwritten annotations, sketches, mathematical equations, derivations, and animations increased teaching efficiency by allowing the instructor to cover more material during a shorter period of time. These class notes, along with annotations generated during lectures, can easily be stored in electronic format and made available for student use outside class.

For the two case studies considered in this paper, there was a statistically significant improvement in performance for the interactive classes as compared with the traditional classes. The observed gains in the Quiz Average were statistically significant for both Study 1 and Study 2. The observed gain in the Homework Average was statistically significant for Study 1 but not for Study 2. The observed gains in the Test Average and Final Exam were statistically significant for Study 2, and not statistically significant for Study 1.

The results of the pre- and posttests of Study 2 indicate that although both the experimental and comparison groups significantly improved the test scores during the semester, the gain for the ILN group was significantly higher than the non-ILN group. Since the questions given for the Tests were taken from topics previously covered in the prerequisite physics course, these results indicate that not only were there significant gains in the learning of new topics covered in the circuits class, the ILN model of instruction also proved effective in retaining, understanding, and reinforcing previously learned topics.

In summary, the studies done here show that the interactive learning environment resulted in improvements in student performance compared with the traditional instructor-centered learning environment. These gains can be attributed to enhanced two-way student-instructor interactions, individualized and real-time assessment and feedback on student performance, increased student engagement, and enhanced and more efficient delivery of content.

IMPLICATIONS

The persistent decline of student enrollment in STEM (Science, Technology, Engineering, Mathematics) majors and the increasing importance of these fields in our nation's global competitiveness warrant the development of pedagogies that develop quantitative and analytical skills. Such skills will maximize students' opportunity for academic success in these highly demanding fields. The results of the limited studies done here indicate that the ILN developed using wirelessly networked tablet PCs has the potential to be a more effective teaching pedagogy compared with traditional instructor-centered teaching environments.

As technology is infused into the classroom, mathematics, science and engineering faculty in all levels of education should consider using tablet PCs over laptop and desktop computers in the classroom. Networked tablet PCs enable students and faculty to analyze problems, collect data, take notes, and combine handwritten and other electronic class materials. They also offer the flexibility to write and manipulate mathematical formulas, draw sketches, and add ink annotations when solving and analyzing problems. These benefits should be weighed against the additional cost of a few hundred dollars for a tablet PC compared with a regular laptop computer.

The studies done here are limited, and further studies are needed in larger institutions using multiple sections of the same course to ensure that the experimental and comparison groups are comparable, thus increasing the reliability of the results. These studies should attempt to isolate the impact of the various components of the ILN on student learning to determine whether immediate feedback through instant polling during lectures, individual monitoring and assistance during problem-solving sessions, or the combination of both factors are responsible for improved student performance.

Additionally, these studies should attempt to delineate the effects of Tablet PC use by the instructor from the effects brought about by enhanced interactivity due to student use of tablet PCs in the classroom. Furthermore, strategies to adopt this instructional model to much larger class sizes (more than 100 students) should be developed.

Similar studies should be done on courses with high attrition rates: courses that are traditional "bottle necks" for STEM students and courses that are problem-solving intensive and requiring high levels of critical thinking. Finally, other software applications that promote interactivity in the classroom should be considered in conjunction with tablet PC use.

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