Wireless Laptops as Means For Promoting Active Learning In Large Lecture Halls

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Abstract

This paper reports on a study that examined the use of wireless laptops for promoting active learning in lecture halls. The study examined students' behavior in class and their perceptions of the new learning environment throughout three consecutive semesters. An online survey revealed that students have highly positive perceptions about the use of wireless laptops, but less positive perceptions about being active in class. Class observations showed that the use of wireless laptops enhances student-centered, hands-on, and exploratory learning, as well as meaningful student-to-student and student-to-instructor interactions. However, findings also show that wireless laptops can become a source of distraction, if used for non-learning purposes. (Keywords: wireless laptops, active learning, studio classes, innovative learning environments.)

INTRODUCTION

For the past few years, there has been a growing understanding of the important role of computers and technology for learning and teaching (Barak & Rafaeli, 2004; Dori, Barak & Adir, 2003; Lerman, 1995; Hazzan, 2002). A key challenge in leveraging technologies to support innovative teaching and learning is to determine how to design curricula that effectively integrate technology in a coherent and authentic way (Barab & Luehmann, 2002). Like most engineering courses in academia, MIT's Introduction to Computers and Engineering Problem Solving, Course 1.00, was traditionally based on lectures accompanied by weekly recitation sessions. During the past few years, the course instructors have been experimenting with a new teaching format aiming at improving the learning experience of their students. The course has developed into a "studio" format where lectures are integrated with in-class demonstrations and active learning exercises through the use of wireless laptops.

Research over the last decades has recognized that students' and teachers' perceptions are important parameters of the social and psychological aspects of the learning environments (Fraser, 1991, 1998). Walberg (1984), in his theory on educational productivity, includes classroom environment as one of nine factors that contribute to the variance in students' cognitive and affective outcomes. In accordance, this study examined students' perceptions of the studio classes, characterized their learning, and evaluated whether and how the studio style classes with the use of wireless laptop computers facilitate active learning in large lecture halls.

WIRELESS LAPTOPS IN EDUCATION

Recently, there is more and more evidence of integrating wireless technology into the classrooms (Chan, Hue, Chou, & Tzeng, 2001; Finn & Inman, 2004;

Siegle & Foster, 2001). Indeed, wireless technology in general—and wireless laptops in particular—have the potential to become an integral component of teaching and learning, as well as to change the way class communication and information flows. It is argued that the use of wireless laptops will change the learning environment, and in particular the classroom settings and activities. Researchers suggest that "connected" classrooms, through the use of computers, will change the organizational structure of schools and the definition of a class (Chan, Hue, Chou, & Tzeng, 2001).

Several studies investigated the use of laptops in the classroom and found that the electronic notebooks had several benefits, such as increasing students' motivation and collaboration, strengthening connections between disciplines, improving students' problem solving skills, and promoting academic achievements (Kiaer, Mutchler, & Froyd, 1998; Mackinnon & Vibert, 2002; Siegle & Foster, 2001; Stevenson, 1998). In a study conducted by Finn and Inman (2004), laptop computers were provided to all incoming freshman. The results indicated a positive change in students' attitudes related to the educational program, and that digital divides, based on gender and field of study, were diminished.

Although there are many studies that present positive aspects, several studies describe the shortcomings of laptop usage in educational settings. A recent study found that the availability of laptop computers may increase students' opportunities for non-learning usages and limit or even reverse benefits when measured in terms of academic performance (Grace-Martin & Gay, 2001). Gardner and his colleagues found the use of portable computers to have a positive effect on students' science achievement, but it did not have a positive effect on English or mathematics achievements (Gardner, Morrison, Jarman, Reilly, & McNally, 1994). Considering these inconclusive findings and the fact that research into the educational use of laptop computers is still in its infancy, it is imperative to further study their use for educational purposes. Therefore, we decided to focus on the in-class usage of wireless laptops as means for promoting active learning among students in a large lecture hall setting.

ACTIVE LEARNING—THEORY AND IMPLEMENTATION

Motivated by a desire to change the prevalent passive teaching mode and to involve students in technology enhanced active learning, several studies describe the integration of innovative learning environments as part of their curriculum (Barak & Dori, 2005; Dori & Belcher, 2005; Hopson, Simms, & Knezek, 2001). Contemporary innovative learning environments base their theoretical framework on constructivism, which is a "theory of knowledge with roots in philosophy, psychology, and cybernetics" (von Glasersfeld, 1995, p. 162). Constructivism puts the construction of knowledge in the learner's mind as the centerpiece of the educational process. In constructivist learning environments, learners are encouraged to create their own mental framework and formulate their own conceptual models. Constructivism calls for the elimination of a standardized curriculum, the implementation of hands-on problem solving, and the promotion of active learning (Bruner, 1990). Nevertheless, active learning is not a new idea.

By the beginning of the 20th century, active learning was widely promoted among progressive educators such as John Dewey (1924). Active learning is consistent with the idea that students must actively process information in order to learn in a meaningful way. In active learning, students are involved in more than listening passively; emphasis is placed less on transmitting information and more on developing their cognitive and operative skills (Keyser, 2000).

Well-delivered lectures are valuable and are common in academia. However, the thinking required while attending a lecture is too often low level comprehension that goes from the ear to the writing hand (Towns & Grant, 1997). In their summary of research on the use of lectures, Johnson, Johnson, and Smith (1998) maintained that students' attention to what the instructor is saying decreases as the lecture proceeds. The researchers found that lectures presume the listener is oriented towards auditory learning, and that they tend to promote only lower-level learning of factual information. Contrary to that, active learning environments encourage students to be engaged in solving problems, discussing ideas, providing feedback, and teaching each other, which requires higher-order thinking (Johnson, Johnson, & Smith, 1998; Towns & Grant, 1997).

Active learning puts the responsibility of organizing the learning in the hands of the learners (Keyser, 2000; Niemi, 2002) and allows for a diverse range of learning styles (Johnson, Johnson, & Smith, 1998). Requiring students to actively solve problems, talk about what they learned, and reflect upon their thoughts is most important for effective teaching and learning (DeBard & Guidera, 2000; Niemi, 2002). Because learning is considered something a learner does, rather than something that is done to the learner, active learning can support the construction of meaning among students (Johnson, Johnson, & Smith, 1998; Niemi, 2002). Integrating active learning strategies as part of the formal learning sessions can advance students' learning as well as address the concerns of instructional change (Niemi, 2002).

PROJECT STUDIO–1.00

Introduction to Computers and Engineering Problem Solving, Course 1.00, has been an important component of the engineering curriculum at MIT for more than a generation. The course serves students with a wide variety of interests and programming experience, and draws students from all schools and departments at MIT.

As modern computation techniques have evolved with the rise of interactive, object-oriented computing, the instructors faced the challenge of reinventing the course to teach engineering computation according to today's paradigms. The instructors decided to change the course content from teaching C and C++ languages to teaching Java, as well as change the traditional format of lecture-recitation-laboratory to a studio model.

The studio environment is a carefully thought-out blend of mini-lectures, recitations, and hands-on laboratory experience that are combined and mutually reinforce one another in a large lecture hall setting (Cummings, Marx, Thornton, & Kuhl, 1999; Dori et al., 2003; Pipes & Wilson, 1996). In our study, Course 1.00 consisted of three 90-minute studio classes per week, and one hour

Figure 1. A teaching assistant guiding students in the studio classes.

per week of small group tutorials. No separate laboratories were conducted, as they were integrated as part of the studio classes.

The studio classes merged short lectures with exercise sessions. Throughout the short lectures, new concepts and programming procedures were introduced, while during the exercise sessions, an assignment was presented. The assignment required students to solve a problem by using their wireless laptops.

The course instructors included two professors and an average of five teaching assistants (depending on the number of students enrolled) that were present during the studio sessions. They served as mentors and guides, moving from lecture mode into exercise and discussion, creating the important link between lecture materials and hands-on laboratory experience, as presented in Figure 1.

Studio 1.00 is one of several wireless laptop pilot projects at MIT. In our study, loaner laptops were provided for all students who did not own one. The laptops were equipped with wireless cards and with the Integrated Java Development Environment (IDE) system, which facilitated the creation, development, and examination of Java applets and applications.

The goal for using laptop computers was threefold: one, providing students with an easy and convenient hands-on computing experience in a large lecture hall setting; two, enabling immediate implementation of the new programming concepts or procedures taught in class; and three, providing the students with immediate feedback (from the IDE program, their fellow students, and the instructors). The wireless technology enabled students to access the course's Web site and other Web-based resources for downloading sections of Java code to their laptops, as well as reading lecture summaries and related information. In essence, the wireless laptop computers were the means for facilitating studio-based instruction in a large lecture hall setting. They enabled the integration of oral explanations (i.e., lectures), with hands-on exercise (i.e., laboratories) and immediate feedback (i.e., tutorials).

RESEARCH GOAL AND METHODOLOGY

In order to examine the use of wireless laptop computers in large lecture halls, and their potential for promoting active learning among students, we raise several questions.

1. In the affective/perceptional domain:
   a. What are the students' perceptions about the use of wireless laptops, active learning, and their learning progress?
   b. Are there perceptional differences among students with different academic and demographic backgrounds?
   c. How do students perceive the advantages and disadvantages of the studio classes?
2. In the operative/behavioral domain:
   a. What are the purposes for which students use their laptops in class?
   b. What characterizes students' learning in the studio classes?

When a new curriculum is presented and evaluated, the instruction needs to be static/fixed; that is, it needs to be taught in the same way throughout the study so the differences in the curriculum—and not the difference in the instruction—will be the cause of the reported outcomes. In our study, all instructors followed the studio-format teaching, integrating problem solving, and active learning exercises through the use of wireless laptops.

The data presented in this paper were collected throughout three semesters, reporting on the responses of 318 students (85% of the courses' participants) that studied in the studio format and signed a consent form. The students participating in this course had different academic backgrounds, majored in different courses, and had different levels of programming experience, as presented in Table 1, page 250.

In order to answer the research questions presented above, both quantitative and qualitative methodologies were employed in the analysis and interpretation of data. An online survey was conducted to examine the affective/perceptional domain, and in-class observations were conducted to examine the operative/behavioral domain.

Online survey: An online survey was administered at the end of each semester to investigate students' perceptions about the studio classes and their usage of the wireless laptops in class. The survey was developed and validated by three educational researchers at MIT's Teaching and Learning Laboratory (http://web.mit.edu/tll/). The survey included 35 open- and close-ended questions. In this paper we report on the results of eleven close-ended questions and one open-ended question that examined students' perceptions about being active in class, using their laptop, and their learning progress. The other questions examined students' demographics or their learning preferences, which are not the focus of this study.

Table 1: The Students' Distribution, by Year, Major, Gender, and Programming Experience

		Fall 2002 N=81	Spring 2003 N=141	Fall 2003 N=96
Year	Freshmen	7%	31%	0%
	Sophomore	41%	39%	35%
	Junior	26%	10%	34%
	Senior	26%	20%	31%
Major	Engineering	48%	51%	58%
	Science[1] & Mathematics	24%	17%	7%
	Management & Economics	21%	27%	32%
	Other[2]	7%	5%	3%
Gender	Male	51%	55%	63%
	Female	49%	45%	37%
Programming experience	High[3]	25%	35%	29%
	Some[4]	41%	22%	50%
	No	34%	43%	21%

[1] *Physics, Chemistry, Biology, Earth Atmospheric & Planetary Sciences, Brain and Cognitive Sciences.*
[2] *Architecture, Urban Studies and Planning, Humanities, Linguistics and Philosophy*
[3] *The student had written complex computer programs in one or more languages.*
[4] *The student had been exposed to computer programming topics and/or had written short simple programs.*

The eleven close-ended questions were on a five-point Likert type scale, one for negative and five for positive perceptions. Although the survey's close-ended questions addressed different aspects of the studio-based learning, they all indicated students' perceptions. Therefore, we report here the survey's total internal consistency, Cronbach's Alpha, which was found to be 0.84.

The "mixed methods research" model (Johnston & Onwuegbuzie, 2004) was employed by using both quantitative and qualitative methodologies in the analysis and interpretation of the students' responses to the online survey. The quantitative data (students' responses to the close-ended questions) were statistically analyzed using analysis of variance and Hochberg's GT2 post hoc tests. The perceptional differences among students with diverse backgrounds and demographics were examined by academic year, programming experience, and gender. The qualitative data (students' responses to the open-ended questions) were content analyzed by three experts in educational research. First, each researcher read the students' answers, classified each response, and summarized her/his review in writing. Based on these reviews, each researcher articulated interpretations to the way the responding students formulated their answers, reflecting on the students' perceptions about the studio format advantages and disadvantages.

Studio Class Observations: Class observations were conducted to answer questions in the operative/behavioral domain and characterize students' learning via wireless computers in large lecture halls. In our study, we conducted an overt non-participant observation. The researchers who observed the studio-classes were not part of the students' instructional team. However, the students were aware of the research goals and that they were being studied. The observations in this study were conducted by two researchers. One observed all the studio-classes using an observation table (see Appendix, page 262); the second observed several sessions randomly. Both researchers focused on students' usage of their laptops and their interactions with the instructional team and among themselves.

Concurrently, the studio classes were videotaped. The video camera was used as a "second pair of eyes." This standardized procedure was employed to maximize observational effectiveness and minimize the researcher's bias by using the videotapes as a "mirror with a memory" (Denzin & Lincoln, 2000, p. 635); that is, when doubt emerged regarding the interpretation of a certain event or behavior, the video was used for clarification.

The data's trustworthiness and the accuracy of reporting were established by the long-term engagement of the researchers and by discussing their findings among themselves and the instructional team.

RESULTS

Students' Perceptions of the Studio Classes

The students' responses to the survey are presented in Table 2, page 252.

Findings indicated that students voiced highly positive opinions about the use of wireless laptops (Total Mean=4.68, SD=0.88). They perceived the laptops as most useful for preparing their homework (Mean=4.77, SD=0.83), helpful to have in class (Mean=4.50, SD=0.99) and to bring to meetings with instructors (Mean=4.65, SD=0.90). The results also indicated that students definitely did not want to return to using desktops in computer clusters (Mean=4.79, SD=0.74). However, students were not enthusiastic about being active in class (Total Mean=3.37, SD=1.21), and they only "somewhat agreed" that active learning helped them understand programming, understand the learning material, and stimulate their interest (Mean=3.40, SD=1.25; Mean=3.52, SD=1.08; Mean=3.18, SD=1.15, respectively). On the other hand, when asked about their improvement in understanding object-oriented programming, the structure of interactive programs, their ability to troubleshoot their own code, and their sense of what real programming is, the students asserted relatively high positive opinions (Mean=4.04, SD=0.95; Mean=3.92, SD=0.89; Mean=3.75, SD=1.00; Mean=3.82, SD=1.80, respectively).

In order to examine perceptional differences among the students participating in Studio-1.00, their responses were analyzed by year in school, prior programming experience, and gender. Analysis of variance (ANOVA) showed a statistically significant difference among students from different school years. Hochberg's GT2 post hoc test (for non-equal sample sizes) showed that seniors differ from sophomores (Mean difference=0.57, $p<0.05$) and juniors (Mean difference=0.74, $p<0.05$) in their opinions towards active learning. This means that seniors asserted statistically significant higher/better opinions about the studio class compared to their classmates. It appears that students who are more mature and experienced in learning have a greater appreciation for being active in class.

Table 2: Means and Standard Deviations of Selected Close-Ended Questions on the Online Survey

Topics	Questions	Mean (on a 1–5 scale)	SD
The use of laptops	To what extent did you use a laptop for most of the course homework?	4.77	0.83
	To what extent did you think that it was helpful to have a laptop in class?	4.50	0.99
	To what extent did you think that it was helpful to have a laptop to bring to meetings with TAs and/or instructors?	4.65	0.90
	To what extent did you think that using a laptop is preferable to going to a (computer) cluster?	4.79	0.74
Active learning	How effective were active learning sessions with coding and simulation in helping you understand programming?	3.40	1.25
	After active learning sessions, how frequently did you leave class with greater understanding of the material?	3.52	1.08
	How much did the active learning sessions with coding and simulation stimulate your interest in the material?	3.18	1.15
Learning progress	How much has your understanding of object-oriented programming improved?	4.04	0.95
	How much has your understanding of the structure of interactive programs improved?	3.92	0.89
	How much has your ability to troubleshoot your own code improved?	3.75	1.00
	How much has your overall sense, of what real programming is all about, improved?	3.82	1.80

The post hoc test also showed that students with no or low programming experience asserted statistically significant higher/better positive opinions about the studio classes than those with high programming experience (Mean difference=0.37, $p<0.05$). The later indicates that students with little or no programming experience benefited more from the studio format than their classmates. The investigation of differences between genders showed no statistically significant differences between male students and females related to their perceptions of the studio classes.

Students' responses to the open-ended question: "What were the major advantages and/or disadvantages of the studio classes?" consisted of 125 advantage and 116 disadvantages statements. The responses were content analyzed and three main categories of advantages and disadvantages (Tables 3 and 4 respectively) were found. The students' perceptions about the advantages of the studio classes included: immediate help and feedback (32%), concretizing the abstract

Table 3: Students' Perceptions about the Advantages of Studio Classes, Their Response Rate, and Examples

Category	Response rate (N=129)	Examples of students responses
Immediate help and feedback	32%	"It was very useful to have TAs around that could immediately point out your mistakes." "If I was confused about something in lecture, I could ask a TA or professor for help—the active learning exercise provide real time feedback."
Concretizing the abstract	28%	"It applied the material in a concrete way." "Actually DO the things we are just talking about makes lectures less hand-wavy and more concrete." "I really liked the interactive simulations, especially later in the term with more difficult/subtle concepts."
Hands-on real-world practice	40%	"The active learning exercise provided an opportunity to use the things we were learning right when we were learning them." "Getting used to the look and feel of actual code, not pseudo code, real programming experience."

Table 4: Students' Perceptions about the Disadvantages of Studio Classes, Their Response Rate, and Examples

Category	Responses rate (N=116)	Examples of the students responses
Problems related to class design and resources	28%	"If a TA is not available and you get stuck, it can be very frustrating." "It was hard to begin coding right after being exposed to the material for the first time."
Pace problems	57%	"Studio classes tend to take a lot of time, and would not be as beneficial to people who already knew general coding techniques." "I didn't have enough time to complete the exercise and became frustrated."
Attention distractions	15%	"Computers are distracting toys." "Sometimes I surf the Web during the lecture session."

(28%), and hands-on real-world practice (40%). The students' perceptions about the disadvantages of the studio classes included: problems related to class design and resources (28%), problems related to the learning and teaching pace (57%), and concerns related to attention distraction (15%).

"Hands-on real-world practice" received the highest percentage of the students' responses associated with the studio classes' advantages. (See Table 3.)

Table 5: The Types of Wireless Laptop Usage, Their Purpose, and Their Percentage

Students' use of their laptops	Purpose of use		Percentage of usage*
Positive use	1. Using the IDE system	Developing and testing Java applets and applications.	80.1%
	2. Lecture notes	Reading notes posted on the course Web site while attempting to solve a problem.	2.3%
Non-directed use	3. Web sites	Surfing the Web for news, sports, and other MIT Web sites.	4.8%
	4. E-mail	Sending e-mail messages to friends.	3.7%
	5. Other	Using word processors, electronic spreadsheets, listening to music, watching movies, or playing games.	3.9%
Neutral situation	Desktop or Screen savers	Not using the laptop.	5.2%

**The mean of all observed classes*

This suggests that students appreciated being given more realistic engineering or management problems and having the chance to practice the recently taught material and to receive an immediate feedback. On the other hand, "pacing problems" received the highest percentage of the students' responses associated with the studio classes' disadvantages. (See Table 4.) The number of responses stating that the pace was too fast was similar to the number of responses stating that the pace was too slow. This result can be accounted for by the students' diverse backgrounds and different levels of prior programming experience. Interestingly, although the use of the laptops as a learning tool was rated high by the students (Table 2), 15% of the "disadvantage" responses indicated that they may potentially distract the students' attention in class. This phenomenon was noted by the researchers during the class observations and will be further discussed.

The Use of Laptop and the Characteristics of Learning in the Studio Classes

An analysis of the observation tables indicated five purposes for which students use their laptops in class. (See Table 5.) The laptop usages were divided into "positive use" and "non-directed" (i.e., non-Java learning purposes). There was also a "neutral" situation—when desktops or screen savers were observed. The most common usage was writing programs or lines of code using the IDE program for solving an engineering/management problem (80%), but 12% of the students occasionally used the laptop for non-directed purposes, such as surfing the Web, writing e-mails and more.

Based on the qualitative analysis of the comments in the observation tables and on the researchers' interpretations, three major learning characteristics/strategies were indicated: hands-on exploratory learning, student-centered learning, and multi-interaction learning, as presented in the following:

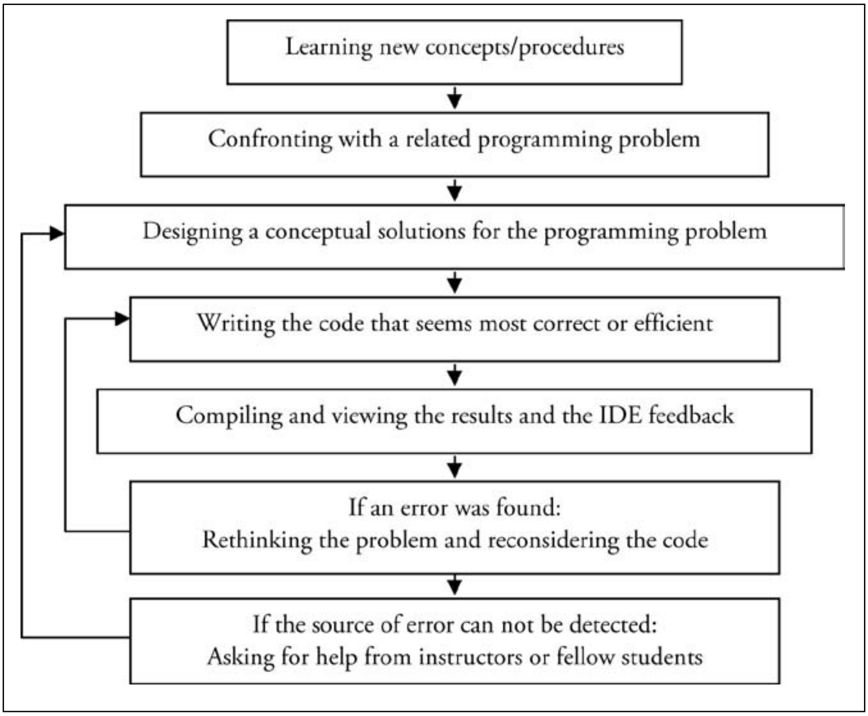

Figure 2. The exploratory cycle that characterizes students' learning in the studio classes.

Hands-on exploratory learning: During the studio classes students were observed solving a problem while using the IDE system on their wireless laptops. While solving a problem by writing lines of Java code, students processed new information and constructed new meanings. Once they compiled and ran the code they received instantaneous feedback that encouraged them to reinvestigate their code, find errors and learn from their mistakes. This learning process generated an exploratory cycle that enhanced students' problem solving abilities and their understanding of programming. The exploratory cycle is presented in Figure 2.

Student-centered learning: Student-centered learning—informal sitting positions, casual conversations, and free movement in class—were observed during the studio sessions. While engaged in solving a problem, the students were observed changing their sitting positions so they would be comfortable holding the laptop or could easily call for the instructors for assistance. In these sessions, the lecturer and TAs were not the center of attention or "sages on a stage," instead, they were constantly moving across the lecture hall, sitting next to the students as "guides on the side," providing them support and help. The students were observed exploring, experimenting, and creating their own lines of code. While doing so, they were relaxed, and they smiled—especially when they successfully solved a problem or manipulated a simulation. Those who did not succeed in their assignment did not show much frustration, and did not hesitate to ask the instructors for help. The students seemed to feel comfortable asking questions and/or answering questions posed by the lecturer.

Multi-interaction learning: During the studio class sessions, multi-dimensional and multi-directional communication were observed. Simultaneously, many questions were asked and answered. "Back and forth" interactions between an instructor and a student were observed: the student would pose a question, the instructor would explain a certain concept or a programming process and reply with another question, generating a "question-question" (as opposed to "question-answer") interaction. The "question-question" interaction that was observed in the studio classes facilitated students' construction of understanding of the learning material. Moreover, while the instructor was explaining an idea to one of the students, other students sitting nearby listened and, in some cases, joined the discourse by posing their own questions or adding remarks. An example of this "question-question" interaction:

> **Student:** I have no idea how to begin solving the exercise. Can you help me? I am not sure I understood the learning material.
> **Instructor:** Well, look at your notes and try to explain, in your own words what are the Java data types?
> **Student:** Emm…[looking at his notes for a few seconds]… there are eight primitive or built-in data types, which include four integer types, two floating point types, boolean and character.
> **Instructor:** OK, good. What else did we learn?
> **Student:** We discussed the data type needed for storing different information and the way to do so.
> **Instructor:** So what is the problem?
> **Student:** In this exercise, we need to write expression to test if int x is greater than double y, and x less than y^2 and x not equal x^2.
> **Instructor:** What would be your first step? Look at your notes.
> **Student:** To declare x and y?
> **Instructor:** Exactly! What next?
> **Student:** Emm… [looking again at his notes] I think… to write a logical expression.
> **Instructor:** Great! Now try doing that on your own. If you have more questions don't hesitate to ask me.

DISCUSSION

This paper highlights the challenges and opportunities presented by the integration of wireless laptops in large lecture hall settings. Central to the effective use of technology in class is the importance of having students engaged in active learning and problem solving, whereby they not only learn theoretical concepts but also practice hands-on programming.

The research findings showed that the students expressed positive perceptions about the new learning environment in the studio classes. Our results are consistent with other studies on students' perceptions of innovative learning environments in the context of learning technologies, indicating positive attitudes once the technology was successfully employed (Barak & Dori, 2005; Hopson, Simms, & Knezek, 2001). The students in our study perceived the laptops as most useful and efficient for their learning, and did not want to return to using desktops in computer laboratories. These findings are in agreement with Siegle and Foster (2001), who suggested that students' use of laptops is superior to the traditional computer lab. When students use a computer center or a lab, computing often becomes a separate activity.

The online survey indicated that "active learning" obtained medium ratings, meaning that the students were not too keen about being active in class; however, on the open-ended questions, they perceived "hands-on real-world practice" as one of the studio classes' major advantages. These results seem to be contradictory. They might be explained by the fact that the students, being familiar with traditional teaching, found it odd to be active and solve problems in class. Research has established that most curriculum changes are accompanied with difficulties, inconveniences, and sometimes even resistance from both the teachers and the students (Barak, in press; Pahl, 2003), as was indicated in the students' responses to the close-ended questions. However, when the students were asked to describe the advantages of the studio classes (the open-ended question) they then expressed positive aspects of active learning.

Different learning preferences were indicated by the year of school and level of prior programming experience of the participants. Senior students were more apt to value active learning through usage of laptop computers than other students. This suggested that the more mature and ready for scholarly pursuits the students are, the better they understand the importance and effectiveness of being active in their learning. In addition, students with less previous programming experience valued the use of laptops and indicated greater improvement in their programming skills than those with a higher level of prior programming experience.

Our findings show that the use of wireless laptops in a large classroom setting has many educational advantages, and that if used judiciously it can facilitate students' active learning through solving problems, exploring phenomena, and sharing ideas. The wireless laptops enable instructors and students to enjoy the advantages of using computers as cognitive tools, free of concerns related to classroom settings and the number of students enrolled. In line with educational reforms and the constructivist theory, wireless laptops enable instructors to integrate innovative learning environments in regular lecture halls with no need for specially designed computer laboratories.

The educational advantages of the wireless laptops shown in our findings are fourfold:

- First, they facilitate the construction of procedural understanding of the learning material by enabling hands-on problem solving and exploratory learning via the Web and designated software.
- Second, they facilitate the receiving of immediate feedback and help from both machine (the designated program) and humans (the course instructors), who can indicate errors and provide an appropriate response in real-time.
- Third, they facilitate the concretization of abstract concepts by enabling

visualization and simulation applications, and thus promote conceptual understanding of the learning material.
- Fourth, they facilitate in-class multi-interactions and collaborative work among learners and instructors by enabling them to share their work, ideas, and understandings.

However, the use of wireless laptops also has disadvantages. A fraction of the students (12%) used their laptops for non-directed (i.e., non-learning) purposes, such as surfing the Web or sending e-mail messages. A similar fraction of students (15%) indicated that the wireless laptops distracted their attention in class. This leads to the conclusion that wireless laptops should be employed in class only when the instructor requires the students to do so. Our findings are in agreement with Grace-Martin and Gay (2001), who found that social computing (e.g., e-mail and instant messaging) is one of the primary uses of wireless laptops by students. The researchers claim that students' achievements and productivity may be boosted by limiting network access in certain contexts (Grace-Martin & Gay, 2001). Overall, the use of wireless laptops within a large lecture hall classroom successfully supported students' active learning and problem-solving activities and gave students an opportunity to share thoughts, difficulties, and ideas with peers and instructors.

In our study we focused on students' affective (perceptions/opinions) and operative (behavior) domains, yet when harnessing the capabilities of wireless laptop computers for promoting active learning, many research questions could be raised related to the cognitive domain. Does the use of wireless laptops in a studio setting enhance students' learning outcomes? Can it improve their conceptual understanding? Can it improve their higher-order thinking skills? These interesting and important questions are yet to be investigated.

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APPENDIX: OBSERVATION TABLE

Session 16, Lab 6. Friday, October 10, 2003

Time	Session	No. of students in Class	No. of open Laptops	Students-Instructors interaction	Students-Students interaction	The view on the students laptop monitor	Comments
11:00-11: 09	Lecture	59	45	2 Instructor questions.	-	IDE 8, Lecture notes 4, E-mail 7, Web news 4, Desktop 9, Card game 1, General Web sites 5, Word processor 2	About 30 students are holding the PPT slides handout. Five students are engaged in answering questions for another course.
11:10-11:19	Lecture	65	48	-	Pair discourse: 2	IDE 10, Lecture notes 5, E-mail 6, Web news 2, Web sports 3, Desktop 7, General Web sites 9,	E-mail and surfing the Web are major distracters during lectures.
11:20-11: 29	Lecture	72	48	3 Instructor questions 2 Students questions.	Pair discourse: 2 Threesome discourse: 1	IDE 10, Lecture notes 4, E-mail 7, Web news 3, Desktop 9, General Web sites 9, Stellar system 2,	One of the lectures questions was not answered by the students. The same student answered two of the three questions
11:30-11: 39	Lecture	72	50	-	-	IDE 11, Lecture notes 3, E-mail 5, Desktop 14, General Web sites 8, Stellar systems 4, Word processor 1	About 10 students don't have a pen or a pencil near them—when they need to sign the attendance sheet they borrow from their peers.

11:40-11: 49	Exercise	70	67	TA1 helps 1 student, TA2 helps 2 students Instructor helps 1 student.	Pair discourse: 6	IDE 58, E-mail 1, Stellar system2,	Some students seem to be ‘stuck’—they read the exercise, read again the lecture notes but don’t start.
11:50-11: 59	Exercise	54	52	TA1 helps 3 stud,TA2 helps 3 students, TA3 helps 2 students, Instructor helps 2 students.	Pair discourse: 7 Threesome discourse: 2	IDE 45, E-mail 1, Desktop 2	The instructors make the connection between the lecture notes, the exercise problem, and the IDE program.
12:00-12: 09	Lecture	54	52		Pair discourse: 3	IDE 42, General Web sites 3, Music program 1	
11:10-11:19	Exercise	50	48	TA1 helps 2 stud,TA2 helps 1 student, TA3 helps 2 students.	Pair discourse: 5 Threesome discourse: 3	IDE 41, General Web sites 2	There is an informal atmosphere, students laugh with each other or with the Instructors (TAs and lecturer). They discuss the solutions with each other.
11:20-11: 29	Exercise	35	35	TA2 helps 1 stud, TA3 helps 2 stud	-	IDE 30	