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In a world increasingly shaped by scientific advances and rapid developments, the fields of communications, science, technology, engineering, and mathematics will certainly enjoy the prospect of rapid growth in coming years. However, educators in these fields face a range of challenges if that potential is to be realized. Computer science (CS), for instance, has one of the highest growth potentials of any academic field, but the percentage of students majoring in CS is dwindling (National Science Foundation 2008; Vegso 2005). Inherent shortcomings in high school curricula along with societal pressures that keep girls and other minorities out of math and computing classes make it harder to attract and retain students in this field, especially female and minority students (Burge and Suarez 2005; National Science Foundation 2008; Perelman 2008). These difficulties are compounded by the disconnect between the practical CS skills required by industry and those usually acquired by students in an academic setting (Ludi and Collofello 2001).

Moreover, since students entering introductory courses in these fields come with a wide range of skills, learning styles, and expectations, these courses need to be designed to appeal to a broad collection of learners. In order to engage students and improve retention and recruitment rates, it is imperative that we find innovative ways to offer courses that meet students' diverse needs and that adapt to the evolving nature of the discipline. Our experience with a variety of CS courses indicates that using technology in creative ways to promote learning and student engagement can help meet some of these challenges. One promising pedagogical framework for closing this gap is technology-enhanced active learning.

Active Learning

Active learning (AL) is an instruction method in which students actively participate in their learning process (Bonwell and Eison 1991) via learner-centered activities that exercise the higher-order thinking skills of analysis, synthesis, and evaluation (Bloom 1956) rather than passively listening to a lecture. As Svinicki (1999) has pointed out, the idea of learner-centered teaching models has been around since the 1980s. Chickering and Gamson (1987) emphasized active or collaborative learning in their “Seven Principles of Good Practice” for undergraduate education. Later, Bender (2003) illustrated how technology can be used to facilitate learner-centered activities. Recently, Boettcher (2007) reported on ten core principles for designing effective learning environments, elaborating on a fundamental design framework for structured learning experience with four elements that put the learner at center. Thus, there has been a noticeable shift from passive learning to learner-centered learning where students are in constant engagement with the content.

Interaction—between students and content, between students and instructors, between students and their tools, and among students—is a key element in active learning and in the implementation of Chickering and Gamson's (1987) seven principles (Chickering and Ehrmann 1996). In this article, we report on one effort to integrate technology-enhanced AL in computer science classes and describe how interaction with technology, or learner-interface interaction, can promote active learning in computer science education.

Interaction in Active Learning

Moore (1989) identified three types of interaction that shape the learning process: learner-content interaction, learner-instructor interaction, and learner-learner interaction. Hillman, Willis, and Gunawardena (1994) added another type: learner-interface interaction, which describes the interaction between the learner and the tools needed to perform the required task (Exhibit 1). While interaction has been shown to be of vital importance in distance learning (Thurmond and Wamback 2004), interaction becomes crucial in the context of AL even within traditional face-to-face courses. Multiple studies have advocated techniques to enhance the first three types of interactions (Milheim 1996; Juler 1990; McDonough 2004). Less work, however, has been done to explore the role of learner-interface interaction (see, for instance, Mattheos 2004).

Using tablet notebook computers and interactive software, we sought to exploit learner-interface interaction to promote AL in computer science classes, encouraging students to interact with their technological tools while continuing to interact with content, instructors, and other learners. The benefits of AL in computer science education have been acknowledged (McConnell 1996), and several educators have used tablet computers in active learning settings. University of Notre Dame faculty members, for example, have reported how using tablet PCs has made their teaching more productive (Clark and Abbott 2004). Simon et al. (2004) used Classroom Presenter with tablet PCs for both students and instructors in a CS classroom and found that the system supported active and collaborative learning.

We created a dynamic setting for learning that integrated classroom and computing environments in computer science courses at Fairleigh Dickinson University starting in Fall 2007. The system used a novel technology that combines DyKnow software with a hardware platform of pen-enabled Hewlett-Packard tablet notebook computers to provide a versatile learning environment that combines a hands-on approach with real-time feedback. DyKnow has been used with tablet PCs in teaching engineering (Fisher, Cornwell, and Williams 2007) and physics courses (Kirtley et al. 2006). We employed this technology for teaching both introductory and advanced CS courses in order to demonstrate how learner-interface interaction facilitated by this hardware-software combination can promote AL across a wide spectrum of CS courses for both non-majors and majors. Our introductory course is geared toward nonmajors seeking to achieve computer literacy; students in advanced courses are juniors, seniors, and graduate CS majors, learning complex data structures and computer architectures. The fundamental learning issues we tried to address included how to foster active learning with interaction in our CS curriculum and how to effectively deliver course content for a variety of courses using available technology to shift students' focus from copying notes to actually understanding content while simultaneously increasing collaboration with the instructor and other students in class.

Implementing the Technology

After exploring several software options for incorporating learner-interface interaction into CS courses, we decided to use DyKnow software technology because of its rich interaction-promoting features and its ability to store lecture sessions on a server for later asynchronous playback (Exhibit 2). The software's features range from note-taking and annotating tools to utilities that facilitate collaboration and sharing of student-generated content. These features empower students to take an active role in their learning process and encourage productive participation in class. Such immersive activities have tremendous potential to support communication among students and between students and instructors and to enhance interactive learning experiences (Saunders 2007).

We conducted a pilot study in Fall 2007 to evaluate the learner-interface element of AL in face-to-face courses ranging from introductory to advanced levels. Additionally, we compared learner outcomes in one technology-enhanced advanced course with a previously offered, lecture-based section of the same course.

Sample Interaction Session

In a typical class session, we used DyKnow in a number of ways to foster active engagement with material and encourage collaborative learning, creating an active, dynamic class structure (Exhibit 3). A detailed examination of one class session shows how the interactive software allowed students to shape their learning. At the beginning of the class, notebook panels displayed the lecture notes for a chapter on searching and sorting algorithms in the form of Powerpoint slides provided by the textbook publisher (Figure 1; Dale 2007). During the session, the instructor used the interface to annotate the notebook panels with handwritten notes and arrows to help explain a selection sort algorithm (Figure 2). An in-class discussion of the midterm exam then encouraged a student to create a panel demonstrating a doubly linked list (Figure 3). This student-generated panel was displayed to the entire class for discussion. The chat tool as well as polling request and response screens helped the instructors adjust the pace of the lecture and class activities in response to students' self-reported level of understanding.

While teaching these courses, we tried to present a new topic and then immediately follow that presentation with a hands-on application on the DyKnow system, dynamically integrating the classroom and computing environments (Exhibit 4). The pen-enabled tablets with DyKnow software enabled this versatile learning environment, allowing us to implement a hands-on approach with real-time feedback and to focus on practical CS applications. This form of learner-interface interaction can go a long way toward uniting theoretical information with the practical skills that are vital to the CS industry.

Results and Analysis

Although most of the students participating in the study had taken Web-based classes, all students were using the DyKnow interface for the first time. For quantitative data collection, we used Likert-scale questionnaires (Likert 1932) administered in class (Table 1). We also included open-ended questions to assess the qualitative impacts of this teaching methodology on student engagement, course participation, and overall performance (Exhibit 5). In addition to these methods, we compared attendance records and project and exam grades with a previously offered, lecture-based section of the same course.

Survey Results for Advanced and Intermediate Courses

The advanced CS course in our study was comprised of nine students: 83% seniors and juniors and 17% graduate students. The intermediate course included 14 students, most of whom were juniors and seniors.

The survey results for DyKnow and tablet usage in the advanced course (Figure 4) and the intermediate course (Figure 5) show that the majority of the students agreed or strongly agreed on all 12 questions about the benefits of the technology except on question 6, which related to the technology's impact on interaction with other students. For this question, only about 40% of the respondents agreed or strongly agreed that DyKnow improved interaction with other students. This result came as a surprise to us; we were hoping for a greater increase not only in instructor-student interaction (addressed in question 5) but also in student-student interaction (addressed in question 6). While in the advanced course, more students agreed or strongly agreed for most questions, disagreeing significantly with only one item, students in the intermediate course expressed disagreement with more of the items and expressed strong disagreement on two questions.

Survey Results for Introductory Course

In an introductory course in CS offered to 10 nonmajors, most of the students agreed or strongly agreed on questions 1-3 and 7-12 (Figure 6). On question 4, only 30% of the class agreed that the technology had improved their participation. In response to question 6, only 10% of respondents agreed that the technology improved interaction with other students, a far lower result than we saw in the intermediate and advanced courses. However, 40% of the students agreed that the instructor-student interaction had improved. More students in the introductory course responded "neutral" or "disagree" to survey items than in the advanced and intermediate courses, suggesting that students in introductory courses were not as comfortable embracing this technology.

Interactions using DyKnow-Tablet Interface

We studied how learner-interface interaction promotes AL across courses by examining responses to open-ended questions regarding how students interacted with the DyKnow and tablet interface (Exhibit 5). A majority of the students agreed that DyKnow is easy to use (Figure 7) and tablets are fun to use (Figure 8). They also felt that the technology helped them work on their assignments and turn them in quickly (Figure 9). Most of the students in the advanced course that used the DyKnow system agreed that using enhanced technology helped them understand and learn concepts better than traditional lecture-based classes (Figure 10).

After examining these results, we looked at instructor-student (Figure 11) and student-student interactions (Figure 12) in more detail. The majority of the students across all courses perceived a marked improvement in their interaction with the instructor after having used the technology but only a slight improvement in their interactions with other students. Because student-student interaction in classes contributes to the development of team work and collaboration skills that are important in the industry, we need to design more activities that require students to work in groups or on sequential aspects of real-world projects that feed one student's output as an input to another student's work. Such skills can narrow the theory-practice divide and are highly desired by potential employers.

Comparison with Traditional Lecture-Based Course

To further examine the results of our study, we compared the attendance records and project and exam grades of a traditional, lecture-based section of the advanced course offered in Fall 2005 with the technology-enhanced section. The average performance based on project grades increased almost 20% from 83% in the lecture-based course to 99.8% in the technology-enhanced course (Figure 13). Exam grades improved by 7% and attendance improved by 8%. Although these results indicate an improvement in attendance as well as student performance, they need to be carefully analyzed and studied with future comparisons since attendance and performance may be affected by a range of factors unrelated to technology, including the attitude of the instructor and other students as well as the day, time, and location of the course.

Conclusion

Our experience indicates that using technology in creative ways to promote AL can help meet some of the challenges of teaching CS. Based on our results, we think such learner-interface interaction promotes AL in computer science education and could eventually narrow the gap between theory and practice, increase student engagement and retention in an active learning environment, and attract a variety of students to CS courses (including those who are intimidated by disparate technology and theoretical concepts).

In order to study the impact of this technology on retention rates, additional data needs to be collected over an extended period of time. Eventually, we want to understand if this technology could help reverse the decline in the number of students majoring in CS by attracting a more diverse population including women and minorities, who are traditionally underrepresented in the field. Using DyKnow with tablet PCs has allowed us to reap the benefits of technology to open new doors for our students and encourage them to take an active role in their learning process. Offering courses in this innovative way will help us meet students' diverse needs and adapt to the evolving nature of this discipline. This will go a long way toward increasing student engagement and improving retention and recruitment rates.

Our future work will consider the impact of this technology on learning outcomes in quantitative detail and further study its impact on special student populations. Further research is needed to evaluate the impact of such technological and pedagogical innovations on student recruitment and retention—especially for female and other minority students—and for teacher recruitment as well.
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