Supporting Active Learning and Example Based Instruction with Classroom Technology

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ABSTRACT

This paper describes an application of classroom technology in support of teaching through the use of examples and active learning techniques. Here we report on using Classroom Presenter, a Tablet PC based classroom interaction system, in a senior level course in Algorithms – a domain for which the instructor believes working on sample problems is critical to student learning in the classroom. The role of the technology was to integrate activities into the lecture so that students have the opportunity to work with concrete examples in class, while the instructor can collect and review student work in real time, incorporating selected student answers into the discussion. In this paper, we describe the pedagogical goals of the instructor, the types of activities used to achieve those goals, and the role that technology played in supporting those goals and activities. The contributions of the paper are in showing how classroom technology can be used to support pedagogical choices, as well as in emphasizing the value of having clear pedagogical goals when incorporating a new technology in the classroom. We believe the application of technology as illustrated in this work could bring similar benefits to the instruction in other disciplines.

Categories and Subject Descriptors

K.3.1 [**Computers and Education**]: Computer Uses in Education – *collaborative learning, computer-assisted instruction*

General Terms

Human Factors

Keywords

Pedagogy, Active Learning, Collaborative Learning, Example Based Instruction, Technology in Education, Digital Ink, Tablet PC, Student Submissions, Algorithms.

1. INTRODUCTION

There are many different ways to teach material for a particular subject. Instructors choose specific approaches based upon their philosophies, their assessment of the student needs, and their own personal styles. Many instructors view flexibility in the choice of the approach as being critical to success in teaching. In this paper, we look at a course in Algorithms, where the instructor emphasized the use of concrete examples in teaching the subject. This class was taught using Classroom Presenter, a Tablet PC based classroom interaction system, to support a style of teaching that revolves around the practice of students working through examples in class, and student results being then incorporated on-the-fly into the classroom discussion. The role of the technology – discussed in more detail in Section 3 – was to make the distribution and collection of work instantaneous, and to allow the instructor to anonymously display student work to the class in the same format as lecture slides.

Through this case study of using technology to support a particular pedagogical approach in a specific course, we hope to illustrate two broader issues that relate to classroom technology and pedagogy:

- how technology-enhanced instruction can support pedagogical choices; and
- the importance of having clear pedagogical goals when incorporating new technology into the classroom.

In our course deployment, the instructor lectured from a Tablet PC, and each student also had a Tablet PC on his or her desk. Classroom Presenter allowed electronic slides to be shared between participants and shown on a big screen. To support a classroom activity, the instructor's tablet would send to all student machines a slide describing that activity; then, the students would write (annotate) their answers with digital ink on their copies of the slide, and send the ink back to the instructor when they were finished. The instructor would receive the submitted answers in real time, preview student submissions, and selectively show them on the big screen. When an activity was completed, the instructor would continue with the prepared lecture slides.

The course described in this paper was a senior level undergraduate course taught at a large public research university in the United States. The enrollment of the class was 20 students, all computer science majors. The course met 3 times a week, and Classroom Presenter with student submissions was used about once a week.

2. INSTRUCTOR'S PHILOSOPHY

Although the curriculum for a course is often defined externally or set by a textbook, an instructor still has substantial discretion in how the material is taught and learning goals achieved. The design of the lecture materials and choice of in-class activities often directly reflect the instructor's philosophy of teaching a particular course. We now give a brief summary of the instructor's views, in the first person, prior to discussing the course materials he produced to embody this philosophy:

My goal for a course in Algorithms is to introduce the students to 'algorithmic thinking' and to teach them to understand the core algorithms well enough so that they can implement and apply *them. Proofs are not particularly important by themselves; the value of a proof in this domain is in providing understanding of why something works.*

In terms of classroom atmosphere, I highly value participation. I want students talking in class, being alert and engaged throughout the entire class period. I also want participation to be broad and representative, as opposed to coming from a small number of advanced or vocal students. My expectation is that much of the learning about algorithms will take place out of class, primarily through working on problems, and possibly through reading and thinking about the text. My goals for class time therefore include giving students scaffolding for their out-of-class reading and problem solving, providing motivation and overview, as well as fostering a basic understanding of selected key points in the domain. For a lecture to be worthwhile it is necessary that certain basic points be understood before proceeding – e.g., what the problem is that will be discussed. However, not every point needs to be understood by everyone in order to proceed effectively.

Algorithmic thinking is an internal process, which develops through practice and experience, rather than through passive reading or listening to presentations of results. For me, the most important step in gaining understanding of an algorithm is to work through specific problem instances relating to it. This can contribute to learning in at least two ways: it can promote discovery (of properties, relationships, limitations), which enriches student understanding; it can also help to reinforce ideas, which solidifies what has been learned.

Next, we look at the merits of the technology with respect to these objectives. Following that, Section 4 discusses a set of technologically enhanced activities that were used in the classroom to instantiate this instructional philosophy.

3. ROLE OF THE TECHNOLOGY

Active learning is widely used in Computer Science education [9] and does not require technology for its implementation. Indeed, all of the activities discussed in this paper could be done as pencil and paper exercises that students work on during class. However, the use of networked pen-based computers changes the logistics and facilitates the integration of activities into the classroom discussion in ways that would be difficult to achieve without the technology. Specifically in our context, technology was used to:

- distribute examples (on slides) to students in real time over a network;
- collect the students' answers (as annotated slides) to an assigned activity and deliver them to the instructor as soon as students submit their responses;
- allow the instructor to privately preview (on a tablet) submitted student work;
- enable the instructor to selectively show student work on a public display.

While the instantaneous distribution of activities in digital form to students is important for allowing efficient incorporation of activities into a lecture, it is the other direction – where students can instantaneously submit their work back to the instructor – that is very different from relying on paper and where some of the crucial benefits of using the technology lie. The efficiency and flexibility of the submission process allow students to send in their responses as they finish an activity, which enables the instructor to evaluate student answers and gain an immediate impression of how students are doing on an activity. A further advantage of electronic submission is that students retain copies on their tablets, so they can continue to refer to them, or even update their solutions. Our experience has been that the instructor is able to take advantage of the time window when students are working on activities to look at early submissions, and to provide additional commentary and direction. When students send in their submissions, those answers are viewable through a preview window on the instructor's tablet, allowing the instructor to look at and evaluate the solutions. Although there are challenges in evaluating a large number of submissions, the technology is not to blame for this – that task would be difficult with pencil and paper-based exercises too. As far as previewing submissions, doing so digitally is likely easier than shuffling through many sheets of paper.

Even though the logistics of distribution of activities, collection of responses, and support for flexible workflow with the instructor are important, the most significant part of the classroom interaction system is the integration with a public display. After reviewing submissions, the instructor can show selected student solutions anonymously on the public display. This can spark a discussion about key points and it can (eventually) provide closure to the activity too. The role of the display is essential also because many of the activities are sufficiently involved that, in order to make them an effective part of a class discussion, the answers would need to be visualized, as opposed to expressed only verbally.

The ability to incorporate actual student artifacts in the discussion can be very important too, for several reasons. It powerfully establishes that the students are direct contributors to the learning environment in the class, which in turn provides an incentive for them to participate and to practice clearly articulating their thoughts in writing. In addition, a diverse set of student responses can help to illustrate different aspects of the same problem, or to present alternative solutions. Finally, the ability to show incorrect solutions and to talk about them without identifying their sources gives the instructor a means to directly and safely address student misconceptions in class.

4. CLASSROOM ACTIVITIES

We now describe activities from class that used examples to achieve different pedagogical goals. In all cases, the instructor distributed problems to students, had the students work on the problems, collected the solutions, and then discussed the results. We illustrate each activity with a student response from the Algorithms course. The activities are divided into three groups: Problem Exploration, where students gain an initial understanding of a problem by working on an example; Pedagogical Point, where an example is used to demonstrate or reinforce a particular technical point; and Active Learning, where doing an activity is used in lieu of instructor explanation of a concept.

4.1 Problem Exploration

One type of activity used in the class was giving students specific instances of a problem to work on before any algorithms for solving that problem were discussed. The instructor had multiple goals in having students work on examples at the start of a new topic. These goals included: verifying that students understand the problem under consideration; having the students discover aspects of the problem in advance of the follow-up classroom discussion; using student solutions to illustrate properties of the problem; and engaging the students with formalizing an algorithmic solution to the problem, after having attempted to use ad hoc methods for solving it. Below, we elaborate on each of these four goals.

Since understanding the essence of a problem is both a precondition and a motivator for understanding solutions to it, to ensure that everyone has made this important step[1], the instructor felt it was essential to address misconceptions about the problem statement as early as possible, and before talking about specific algorithms. The mechanism for achieving this was to have students work through an example, and for the instructor to proactively clarify the problem statement if and when students showed signs of not grasping it. Students were also encouraged to discuss with one another in class, which allowed some misconceptions to be cleared by the students themselves.

Examples were also used to have students discover some of the richness of a problem in advance of particular points being made in the discussion. This included gaining familiarity with the mechanics of the problem, discovering approaches that would not work, appreciating the need for approaches that scale with the size of the problem, or seeing properties hold that would later be formally established.

The incorporation of student solutions into lectures allowed certain aspects of the corresponding problems to be discussed by analyzing those solutions in front of the class. This would commonly be done while showing different valid solutions to the problem at hand. For example, when the point was being made that several different solutions could be found by an algorithm for a given problem (Figure 1), using student submitted solutions made this multiplicity more concrete.

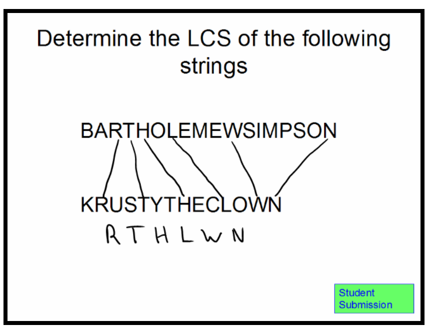

Figure 1. Finding the Longest Common Subsequence (LCS) of a pair of strings. The specific example afforded multiple solutions, of which students found two – “R T H L W N” and “R T H E O N.”

Finally, the instructor believed that students would be more engaged in learning about a topic if they had worked through examples relating to that topic. The “theory” was that in working with specific examples students would start to think about the more general cases, and would be interested in seeing how to formalize their approaches as algorithms. It was also conjectured that working with specific examples would make the problem seem more real, increasing the motivation for developing real algorithms. Figure 2 is an example of an activity where student engagement went so high as to result in a 10-minute discussion between students over which solution was right.

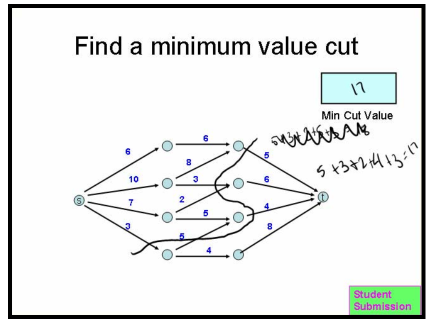

Figure 2. Finding the minimum value cut in a graph. This example generated a substantial amount of unprompted classroom discussion between students who had identified different values for the solution.

4.2 Making a Pedagogical Point

Another type of activity centers on making a particular point. For this, students would work on examples designed to lead the student toward discovering a specific result, while subsequent discussion would reinforce the key point. The instructor’s view was that the process of discovery would make the concept more memorable than if the instructor simply stated the end result. Thus, the instructor wanted all students to be engaged by participating in the discovery process. In a traditional lecture, such examples would be shown to the class and the instructor would pose questions to the entire audience. Unfortunately, in that situation it is common that a small subset of the students consistently provide answers before others have had a chance to explore the problem.

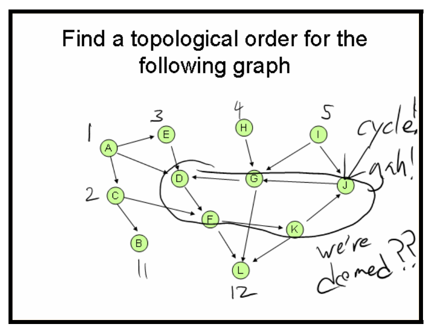

Figure 3. Numbering the vertices of a graph in Topological Order. In this activity, students were asked to find a topological order in a graph that had a cycle. Since a cycle precludes the existence of a topological order, the students were thus asked to do something impossible. The goal was to have them discover that the cycle ruled out a topological ordering.

One particularly compelling type of activity produces individual “A-ha!” moments when students discover something unexpected leading them to the point that the instructor wanted to make. Designing such an activity requires crafting an example that makes the desired point and does so in a setting that provides some element of surprise or possibly even deception. For instance, the conclusion may come out somewhat differently than the question had asked for, as in the example in Figure 3, where the requested object does not exist

[1] This lock-step method of teaching – by ensuring that everyone has caught up before moving on with a topic – does not have to be used constantly. At some critical junctures, however, such as the start of a new discussion, it is essential.

Activities can also be designed to combine making a particular point with an assessment of whether the issue was broadly understood. Lectures have key technical points that are essential for understanding subsequent material. An activity that highlights those points on a concrete example can be used to evaluate the students' understanding. This is particularly effective when the instructor anticipates the misconceptions that students are likely to have, and designs the example so that these misconceptions, when present, are manifested in the student submissions. The instructor shows the submissions (which are anonymous) to illustrate the misconceptions. An alternative approach is to display student solutions and ask the class to evaluate them. Figure 4 gives an example of an activity specifically designed to clarify an important technical point needed for a subsequent argument.

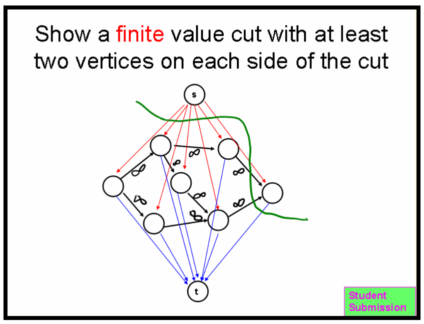

Figure 4. Finding a finite value cut in a graph. In this example, the students were asked to find a finite value (S,T) cut in a graph where the solid (black) edges were all assigned infinite costs. The point was to illustrate the importance of the asymmetry: an infinite cost edge from T to S is not a problem, unlike from S to T.

4.3 Active Learning

For many students, learning by doing is more effective than learning by listening [6][7]. This approach is supported in activity-based instruction by having students work through examples, and then reviewing and discussing the results, instead of having the instructor work through the examples while students passively observe.

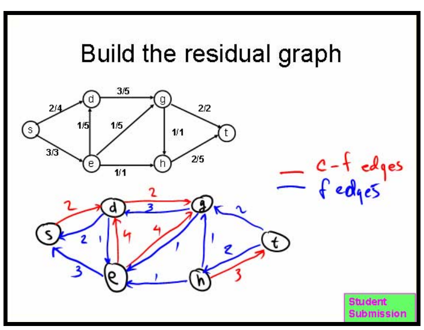

Figure 5. Building a residual graph. For this activity students were asked to construct the residual graph for the network shown on the slide. Constructing a residual graph is a mechanical process that the instructor presented and then had the students work through.

For points that are fairly straightforward, the instructor can present the idea and have students exercise that idea on an example. The act of writing out the example reinforces the idea in a way that merely listening to it does not. After students finish working on the example, the instructor can receive feedback on whether the idea really was as straightforward as expected. Figure 5 shows an activity where a concept was defined formally, and then the students worked through the example, designed to expose a few technical details.

Routine exercises solved by students produce artifacts which can be used to support the classroom discussion. Even with activities which are straightforward, there are often details of the solution which can be brought to the attention of students. An advantage to basing the discussion on actual submissions by students is that it shows that the particular issues being discussed do occur in student work, as opposed to being strictly hypothetical cases. Figure 6 shows an example where the instructor made some detailed points about the three uncircled vertices.

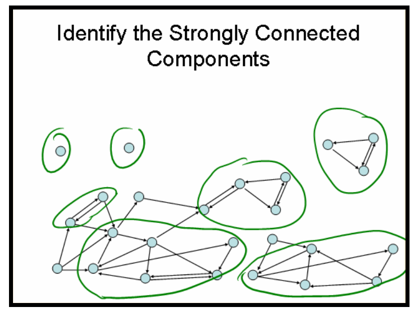

Figure 6. Identifying the strongly connected components of a graph. In this activity students were to circle the strongly connected components of a graph.

5. IMPACT

Classroom Presenter was used for student submissions in 7 lectures during the 10-week course. In total, there were 26 activities, with between 3 and 5 activities per 50-minute lecture. The time students spent working on activities averaged 4:29 minutes, ranging between 1:42 and 9:56 minutes; and the following discussion time averaged 2:41 minutes, ranging between 0:14 and 4:51 minutes. The instructor had the impression that his traditional lectures covered more material than his activity-based lectures, although this is not supported by statistics: the traditional lectures averaged 14.5 slides presented, while the activity-based lectures averaged 14.0 slides.

Student reaction to the technology was strongly positive. In an end of class survey, 18 out of 19 students indicated that the system had a positive effect on their learning experience (1 "slightly negative"). 18 out of 19 indicated that writing down their answers to the activities had a positive effect on their learning (1 "no effect"), while 16 out of 19 said that seeing other students' responses displayed to the class had a positive effect on their learning (2 "no effect", 1 no response). Written student responses were also positive. One student said: "It is a great experience since it keeps me awake, gives better explanation, stretches our thinking, and makes us know how other students think." Another indicated: "It encouraged me to keep up with the reading and to pay a lot of attention in class ☺." When asked to compare the class period when the system was used to those when it was not used one student claimed that the days when the system was used were "Much more interactive. I especially enjoyed the opportunity to work through the sample problems."

Student participation rates in activities were high. This is very important, since one of the instructor's goals was to get broad participation from the students. Student submissions were anonymous and students were made aware of that from the very start, so the instructor did not have a way of knowing which students authored which submissions during class. Over all activities, 69% of students present in the corresponding lectures made submissions. This includes some activities where there were only a small number of submissions because of the difficulty level, or because of shortage of time. Over all 7 classes when technology was used, an average of 97% of the students present that day submitted a response to at least one of the activities used that day. 18 out of 19 (95%) respondents indicated that they were more engaged in lecture during the classes where the system was used (1 "about the same").

As a pilot offering, we did not evaluate how the technology impacted learning outcomes. The instructor believes that the classroom activities were successful in giving students a greater understanding of the particular problems, and student performance on exam questions related to the classroom activities was good too; but since we do not have base line data for comparison, this is just a perception. However, there are a number of important observations we can make about the impact of the technology. We mention two of them here: peer instruction and impact on the instructor's preparation time. Peer instruction [8] refers to developing activities so that students learn from each other through small-group discussion during class. Although activities were not designed with peer instruction in mind, on a number of occasions small-group discussion started as students tried to convince one another of the correctness of their solutions. The activity shown in Figure 2 was an excellent example of this; students were split between two potential results. In this case, the key for the activity to generate student interest was achieving just the right level of difficulty so that there were different but close enough answers that became grounds for discussion. The other observation is that the instructor's preparation process was very different for a lecture using student submissions versus for a standard slide-based lecture. The difference is that whenever the instructor designed a lecture with student activities, he began by articulating the desired learning outcomes for the lecture, then developed activities to evaluate if those outcomes were met, and only at the end prepared the actual slide materials. The instructor found it necessary to do this in order to have a framework for creating the activities, and not because it is recognized as a good practice. He did not design his other lectures from a learning goals point of view, but following the traditional approach of designing lectures with respect to content coverage. However, the instructor did feel that his preparation time was higher for lectures using student submissions.

6. RELATED WORK

With the advent of wireless networks and mobile computing there is a multitude of projects looking at enhancing the lecture environment by supporting in-class collaboration. The Classroom 2000 project [1] was the seminal one in the area, with other more recent classroom collaboration projects including Active Class [10] and Debbie [4]. Our work has been using Classroom Presenter [2][12]; other Tablet PC based approaches include Ubiquitous Presenter [13] (an extension of Classroom Presenter) and DyKnow [5]. A different approach to classroom technology from the approach in this paper is that of Classroom Response Systems [11], where well-formed student responses are aggregated for the instructor and for public display. We see both approaches as having potential for impact in the classroom, and in many situations a synthesis of the two would be appropriate. In terms of pedagogy, there is a substantial literature on techniques for engaging students in a lecture environment, through active learning and classroom assessments [3][7].

7. CONCLUSIONS

In this paper, we have shown in-depth examples of the type of pedagogy that can be enhanced by the use of classroom technology. In broader terms, our work shows that technology can be used to support course-specific and instructor-specific innovations in the classroom. In our experience, a key to the success of active learning (whether technology supported or not) is having a deep pedagogical basis. Although the examples in this paper come from an Algorithms course, the general principles should carry over to other disciplines.

8. ACKNOWLEDGEMENTS

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