Promoting Collaborative Learning in Lecture Halls using Multiple Projected Screens with Persistent and Dynamic Content

Abstract: A necessary condition for collaborative learning is shared access and control of the representations of information under discussion. Much of the teaching in higher education today is done in classroom lectures with a largely one-way flow of information from the instructor to students, often using computer slides. Persistence of the information is not under student control and there is little student-initiated interaction or dynamic use of the visual aids. We evaluated the use of MultiPresenter, a presentation system that utilizes multiple screens to afford more flexibility in the delivery of the lecture and persistence of information so students can selectively attend to information on their own terms. Data about the use of multiple screens provides insights into how MultiPresenter affects classroom interactions and students' learning. We discuss these findings and make recommendations for extending MultiPresenter to better support symmetric collaborative learning within the context of large lecture presentations.

Introduction

In spite of the rise of distance learning environments in recent years, the dominant way of teaching in higher education is still conventional lectures in which the instructor presents information to a group of students. As universities accommodate more students and increasing financial and resource constraints, many classes, especially at the introductory level, are taught in large lecture halls. While most educators agree that smaller classes provide better learning environments with stronger student-instructor interaction, large lectures are likely to persist in the near future. Fortunately, the same economies of scale that lead to large lecture halls also allow universities to invest in technological infrastructure for lecture facilities, so many large lecture halls today are equipped with multiple projector screens and it is likely that future lecture halls will have even more screen real estate using higher resolution projectors or more projectors in one classroom. Unfortunately, instructors often lack the tools to fully exploit this infrastructure so they use PowerPoint or other commercial slideware to simply project the same image onto both screens.

Commercial slideware tools mostly support a one-way presentation in which the instructor transmits information for students to absorb. But most educators believe that lectures, even ones with limited audience involvement, should be dialogues in which the instructor implicitly or explicitly ascertains whether the presentation delivery is clear, and modifies delivery as necessary to enforce a point by revisiting a concept, or by providing more detail (Bligh, 2000). Focusing on the need to promote student-instructor interaction in lectures, several projects have used laptops, PDAs or other electronic devices held by students to add another channel of communication between students and instructors (Anderson et al., 2003; Dufresne, et al. 1996; Ratto, et al. 2003; Scheele, et al., 2005). These approaches all require students to have an electronic device, dedicated software, and access to communication infrastructure in the classroom. In many classes, for financial or practical reasons, this is not possible. Because presentation infrastructure scales far more efficiently in large classrooms than does provision of student devices or the establishment of better communication infrastructure, we have pursued a more lightweight solution that focuses on enabling more dynamic slide-based lectures to enhance interactivity of large lectures using existing classroom infrastructure.

There is historical precedent for our approach. Buxton (1999) notes that the introduction of the blackboard into classrooms in the Province of Ontario in the mid-1800s moved pedagogy from a single-learner focus of personal hand-held slates to a more collaborative model that utilized a large, shared blackboard visible to all students. Buxton further comments on the impact this had on education, quoting from May (1855), and observes that the on-going introduction of personal computers into classrooms runs the danger of reversing the long-standing collaborative practices within classrooms by once again focusing on small-screen single-learner interfaces. Our work examines how we might employ large-screen display technology with software explicitly designed to support collaboration within classroom lectures by providing persistence of information across multiple screens, engagement through

dynamic manipulation of content reminiscent of more traditional visual aids familiar in classrooms not "blessed" with today's digital technology, and affordances that invite collaborative learning through opportunities for multiple foci of attention and shared control of the representations of information. Buxton et al. (2000) discuss the advantages of large collaborative displays in the practice of design; we do the same for collaborative learning in classrooms.

We are motivated in part by the variety of visual aids used to support collaborative learning in what is probably an idealized and stereotypical view of a K-12 classroom, but still a view that is useful when considering how university lecture halls might better support collaborative learning. A K-12 classroom often has one wall of windows, one wall with blackboards, and two other walls that are either blackboards, bulletin boards, or shelving for books and other learning artifacts. At the lower end of the K-12 range there might also be flip charts, felt boards, or manipulables to support learning; at the higher end of the range there may be maps of various sizes, periodic charts of the elements, or other specialized representations of information specific to the topics relevant to the class. All of these visual aids have degrees of persistence, they can be updated in parallel, and they are accessible to anyone in the room to use, subject only to the social conventions of the class. Thus students in K-6 are welcome to bring newspaper clippings to school to post on the bulletin boards, or to use the side blackboards to discuss a math problem with the teacher or another student, and in Kindergarten students come to the felt board to move felt cut outs around as part of their active learning experience. What is interesting is that as we move upward in the K-12 hierarchy, classroom activity becomes less and less collaborative. As one educator has noted, "The only thing kids learn in Kindergarten is to share and to work together. But as soon as they learn that, we tell them to never to do it again because it's cheating. Employers then wonder why new college graduates can't work in teams." Our goal is to reverse that trend by developing technology to encourage shared representations of information that are persistent, manipulable, and that support collaborative learning. We will focus on large lecture courses at the university level, but our techniques apply to many other settings as well.

In our previous work, we observed and compared how instructors use blackboards and computer slides in classrooms, devising design guidelines on how to better build presentation software for classroom lectures (Lanir, Booth, & Findlater, 2008). Our observations identified several practices that are common with blackboards and whiteboards, but are inadequately supported by slideware technologies: (1) *Spontaneous and non-linear presentation styles*. In contrast to slide presentations, presentations using blackboards are much more dynamic and non-linear. Instructors often diverged from the planned path to drill down through the content, using the board as support to address issues that they noticed students need more time on. (2) *Revisiting earlier information.* Using blackboards, instructors often referred back to previously written content, sometimes originating very early in the presentation. This behavior was rarely observed when instructors used slides. (3) *Using a larger surface.* Larger surfaces such as multiple blackboards are useful for supporting explanations of complex ideas. With more space, spatial relationships between concepts can be used to encode meaning. Instructors used blackboards to show relationships between two concepts drawn on different boards, or to compare these items. Based on these observations and our guidelines, we introduced MultiPresenter (Lanir, Booth, & Tang, 2008), a presentation system that aims to "mix and match" the advantages of computer slides and blackboards using multiple screens in order to enhance the interactivity of large lectures.

The current study examines how MultiPresenter was used to utilize multiple screens in actual classrooms. We observed three instructors who used MultiPresenter in their classes for most of their 13-week terms, and one instructor who used it for 5 weeks and is continuing to use it this term. We were interested in examining what kind of pedagogical usage patterns were employed with multiple screens, and how these usage patterns affect the collaborative learning of students. We wanted to find out how the usage of two screens affects the dynamics of classroom lectures, and ultimately whether the usage of two screens better supports collaboration than does a regular PowerPoint presentation on a single screen. We focus here on the first of these questions.

Computer Slides in Education

Although widely used in the classroom, the pedagogical implications of using computer generated slides remain unclear. Most studies focusing on whether or not computer generated slides are beneficial have found that students responded positively to the use of computer-generated slides in the classroom in comparison to whiteboards and overhead transparencies (Levasseur & Sawyer, 2006; Susskind, 2005; Szabo & Hastings, 2000). Students have indicated that slides help them improve organization of the course and their notes, help them learn course material more effectively, and make classes more interesting and entertaining (Levasseur & Sawyer, 2006). Students also

displayed more positive attitudes toward the instructor when he or she used computer slides by indicating that the professor "did a better job" when class lectures included PowerPoint (Susskind, 2005). In many classes, instructors are expected to use presentation software, and those who do not use slides are looked at as unprofessional (Parker, 2001). The reasons for preferring computer slides might be attributed to the novelty factor because most of these studies have been conducted when computer slides had just entered a classroom, or to the preference of students to have class notes available. How students react to computer slides is important, but a more important question is what effect computer slides have on student learning. Most studies examining the effect of computer-generated slides on learning outcomes have found no significant improvement in student performance with slides compared to other visual aids such as overhead transparencies or blackboards (Levasseur & Sawyer, 2006; Susskind, 2005; Szabo & Hastings, 2000). An exception to this is that in some cases computer slides appear to enhance learning when students have access to copies of slides. This might be attributed to the students getting an organized set of notes from the instructor, and consequently not needing to expend cognitive effort on note taking during class if they have the slides in advance (Levasseur & Sawyer, 2006)

There have been attempts to deploy presentation technology in classrooms to address some of the limitations of current slideware tools. Classroom 2000 (Abowd, 1999) was one of the earlier systems that incorporated technology into the classroom to facilitate capturing, archiving, retrieving and presenting classroom activities. Focusing on enhancing face-to-face communication in the classroom, Classroom Presenter used electronic ink to make presentations more dynamic by adding writing tools to augment prepared slides integrating PowerPoint slides with pen-based writing using a TabletPC (Anderson et al., 2004). E-Chalk (Friedland, Knipping, Schulte, & Tapia, 2004) was designed to allow instructors using electronic whiteboards to combine the ability to record whiteboard activities with multimedia items and pen-based writing in classrooms. Others focused on breaking the inherent linearity of PowerPoint slides using Mindmaps (Holman, Stojadinović, Karrer, & Borchers, 2006), or Zoomable User Interfaces (Good & Bederson, 2002). There have been a few projects that have provided support for delivering presentations on multiple projectors (Abowd, 1999; Chiu et al., 2003; Röüling, et al. 2004), but those systems were limited to showing only previous slides on the multiple projectors, each slide filling an entire screen, and they required sophisticated infrastructure in the presentation room. We used these systems as starting points supporting multiple projectors for slides and providing support for existing slideware tools. We augmented this with support for dynamic presentation practices and a few new static practices, and we simplified the infrastructure requirements to encourage rapid adoption.

The MutliPresenter System

MultiPresenter is a classroom presentation system that works on multiple and high-resolution screens with the goal of promoting audiences' learning. We briefly describe here its main ideas and features. A more detailed discussion, is provided by Lanir, Booth and Tang (2008). MutliPresenter provides instructors with the ability to run slide-based presentations from their personal laptops on the two displays available in many lecture halls today. It was designed to provide short- and long- term persistency of information and a variety of dynamic options. Instructors display a stream of imported PowerPoint slides on the primary screen, and use the secondary screen for various tasks. This way, instructors can use their existing PowerPoint slide decks and existing practices of teaching with slides, while adding other dimensions of persistency and dynamics to the lecture. To support persistency of information, the instructor can choose to persistently display information on the secondary screen either on-the-fly during lecture or while planning the lecture. Ahead of time, the instructor can indicate that certain slides should be seen alongside others (e.g., keeping a slide of the periodic table alongside the regular stream of slides in a chemistry class). During a lecture, the instructor can drag up to four slides to the secondary screen and decide how long they should remain there. An instructor can also construct the information displayed on the secondary screen using entire slides, or content that is cut-and-pasted from different slides, effectively constructing a "clipboard" for important persistent content, much like rearranging cut outs on a felt board but with the added advantage of automatic copying. The instructor can then manipulate the information by moving, resizing, deleting or adding to the content on the screen.

Unlike existing tools such as PowerPoint, that focus on content *authoring,* MultiPresenter focuses on the presentation act itself. One problem of existing slideware tools is that they are "static", forcing the instructor to a linear, rapid style of presentation (Good & Bederson, 2002, Tufte, 2003). This may suit a highly structured, well planned presentation with a singular flow such as a business presentation, but it is less suited for classroom lectures in which a more dynamic, ad-hoc style is required in order to interact with the students. MultiPresenter facilitates a wide range of dynamic practices. An instructor can pre-author a dual-screen presentation as well as have direct

control over what is displayed on the screens during the presentation, and can easily navigate his or her slides. An instructor can change between different practices during a presentation to accommodate different presentation styles. For example, one mode that is supported is to show one, two or four previous slides on the secondary display. Using MultiPresenter, the presenter can momentarily shift from this mode to instead use the secondary display as a writing space for electronic ink, to show a specific slide, or to show other selected content. The instructor can then easily shift back to the previous mode where the second display shows some number of previous slides. Finally, MultiPresenter fully supports electronic ink with different colors and pen sizes to add more dynamic options.

Class Deployment

We initially deployed MultiPresenter in a first year computer science (CS) class in Spring 2008. We then deployed it during the summer semester in two other computer science courses: a third year introduction to database course and a third year software engineering practices course. Class sizes were 67, 58 and 47 students, respectively. The system was used by three different instructors over the entire term to support their lectures as the main visual aid. Although MultiPresenter can be used without electronic ink on a regular laptop, all three instructors utilized the inking features available with MultiPresenter using a personal TabletPC. Classes were all held in a lecture hall equipped with two projected screens. During the current Fall 2008 term, we have deployed the system in courses in other disciplines to extend our observations to other topic domains. This helped us both to identify cross-disciplinary commonalities in use of the system and to broaden our set of domain-specific usage scenarios. Additionally, because computer science instructors are "tech savvy" and are often accustomed to using new infrastructures and interfaces, we wanted to examine how less technically-oriented instructors use the system. There are five instructors using MultiPresenter in their classes this term. We include data from nine lectures by one of the history instructors (class size of 101 students) for this reason. We examined the usage of MultiPresenter on dual displays by attending most of the lectures, recording logs of the software's use, interviewing instructors during and after the semester, and by submitting questionnaires to the students at the end of the semester. We also recorded screen captures every thirty seconds of the instructor's view (this includes a view of the two screens) from all the classes of one of the computer science instructors and the classes of the history instructor.

Usage of software features

We observed that instructors made extensive use of the features provided by MultiPresenter, utilizing both of the screens during most of the lecture time. The style of usage varied according to the topic and the individual teaching style of each instructor. We discuss here the effects MultiPresenter and the use of two screens had, focusing on our two major design goals: making lectures more dynamic and having information persist longer.

Ad hoc use of visual aids

Theory: Using MultiPresenter, instructors can author pre-made dual-screen presentations or they can show one, two or four previous slides on the secondary screen. Both these modes simply require instructors to progress through the slides similar to the PowerPoint lecture paradigm. Alternatively, instructors can decide interactively during the presentation what content would be shown on the secondary screen. We were interested in observing whether instructors would utilize the dynamic features of the system and whether they would shift between different modes.

Practice: All three CS instructors used MultiPresenter mostly in the interactive mode to decide during presentation what would be shown on the second screen. Two of them used it exclusively in the interactive mode, while one instructor combined pre-authoring with interactive features, often shifting between the two modes. Figure 1 shows a timeline representation of a two-screen lecture of one of the instructors. Line A is the primary screen, and line B is the secondary screen. We can see how the instructor dynamically moved content from the primary screen to the secondary screen many times during the lecture. In this case, it seems that the most common practice was to move certain slides from the primary to the secondary screen after they were initially introduced on the primary screen (as in minutes 1, 4, 14 and more). This behaviour of keeping the currently shown slide on the secondary screen while progressing to the next slide was common to all three instructors. It suggests that instructors recognized the need for persistence as they went through a slide, or as they transitioned away from it. Bringing previously shown slides back to the secondary screen (as in minute 8 indicated by the black arrow) was also observed, but was less common. The history instructor, unlike the CS instructors, preferred to start with a pre-made dual-screen lecture, as her lectures tended to be more structured. Yet even in these lectures, the instructor would often use the interactive features, deciding during the presentation to put a certain slide on the secondary screen instead of the pre-selected slide, and leaving room in the dual-screen pre-made presentation to be used dynamically during the presentation. In

one instance, she used the slide-back mode showing the previous slide on the secondary screen. Nevertheless, she did not use this mode for the entire lecture, but changed from that mode to interactive mode in order to have a slide with a map persist for a longer time, and then reverted to the slide-back mode. We saw that even when using the "static" methods of presentation, the instructor reverted to dynamically deciding during the presentation what to display.

Electronic ink is also useful for adding dynamic interaction to classroom presentations (Anderson et al., 2004). MultiPresenter fully supports electronic ink for annotations on both screens using different ink sizes and colors. All three CS instructors used electronic ink with MultiPresenter. Ink was used for emphasis, attentional gestures, and as a way to add dynamic content, as is often done with a blackboard.
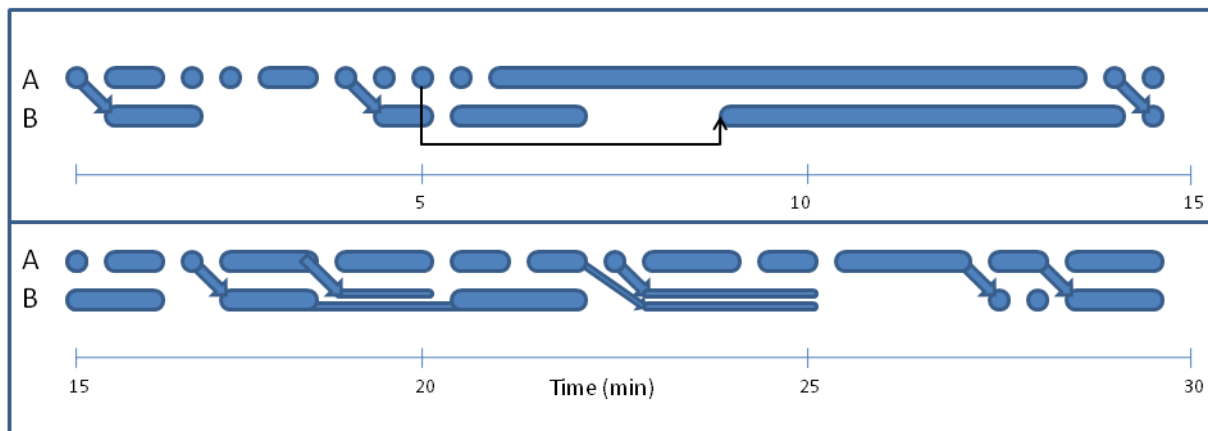
Figure 1 – A timeline representation of 30 minutes from one lecture that used two screens. Row A shows the primary screen, while Row B shows the secondary screen. Slides are shown as ellipses with the size of the ellipse depicting the length of time the slide appeared on screen. Arrows represent transitions of slides from the primary to the secondary screen.

Persistency of Information

Theory: It is important to help learners to be able to integrate multiple sources of information presented over time. Disparate sources of information should be physically and temporally integrated, minimizing the need of learners to engage in mental integration, so extraneous working memory load is reduced, freeing resources for learning (Ayres & Sweller, 2005). With MultiPresenter, instructors can present information spatially together instead of sequentially over time, thus reducing cognitive load for students.

Practice: Instructors used the secondary screen mostly to have selected information persist longer to use as a reference to the current theme. The information could be slides that were just shown, pre-set topics or important slides (e.g. a map slide in a history class) that were designed to be shown longer, information that was seen earlier in the lecture (for example, in Figure 1 at around 8 minutes, a slide that was shown at minute 5 was brought back), or even slides that are later in the slide stream, breaking the linearity of regular slide presentations. Bringing information to the second screen would usually be according to the instructors' immediate needs, explaining a concept that would be aided by previous information, comparing two pieces of information, or reacting to students' questions when the instructor would bring the relevant slide to the second screen. Three of the four instructors put only full slides on the second screen. The fourth instructor occasionally had two or three slides persistent on the second screen (as can be seen in Figure 1 in minutes 18 and 23, in which there are two slides on the secondary screen). He was the only instructor who used the clipping feature that enables cutting and pasting of pieces of information from one screen to the other, but only twice. We believe the reason the clipping feature was hardly used is that its operation was too complex for the instructors to operate or plan during the class. During class, instructors need to focus on their teaching task, and do not wish to spend cognitive effort operating the software's interface, or changing their existing practices. Instructors are already used to the slide paradigm and build their slides as "whole" pieces of information. They therefore continue to use this paradigm to exploit additional space, by putting "full" slides on the second screen.

Other than the one time mentioned earlier, instructors did not use the previous slide-back mode (that shows previous slides on the secondary screen). In responding to questions about why this mode was not used, instructors commented that it can be a useful way of running their presentation, but they preferred having more control over what is displayed at any given time. It is interesting to examine these results in relation to other presentation systems that use multiple displays. Classroom 2000 (Abowd, 1999) and others (Rouling et al., 2004; Chiu et al., 2003) are restricted to displaying only previous slides on the other displays. Yet we saw that across the four observed instructors, this was nearly never preferred over pre-planned use of the space or dynamic use. We believe that this feature can be useful for other instructors, who prefer not to handle the interface during the presentation, yet MultiPresenter's deployment realizes the importance of allowing instructors full control of what is displayed on all screens.

Instructor and student feedback

In general, instructors commented very favorably on the use of MultiPresenter, and of using two screens for their presentations. All three CS instructors said it was useful for them to use MultiPresenter, and that they thought it helped the students learn. All three instructors said they would like to continue using MultiPresenter in classrooms that have two screens, and that they would recommend it to their peers.

To assess students' subjective perception of the system, we administered questionnaires to the students. We asked students in the three classes to fill out an online questionnaire about their attitudes and thoughts on the use of the presentation system in class. Students were given a 5-point Likert scale to solicit their opinions on several statements. A total of 66 students from the three classes filled out the questionnaire. The questions and results aggregated across the three classes are presented in Table 1. In the Likert scale, 1 represented strongly disagree, while 5 represented strongly agree.

Table 1: Students' subjective ratings of MultiPresenter as they have seen used in class (*n=66*).

Statement	Average	SD
Seeing two slides helped me understand the material better than a one-slide presentation	**4.03**	0.65
Having two screens helped the instructor present the material better	**4.22**	0.86
I would encourage other instructors to use two screens in a similar way	**4.19**	0.74
I had problems physically seeing one of the screens	**2.56**	1.2
It was good that the instructor had more space to write on (with electronic ink)	**4.12**	0.82
It was helpful for me when the instructor showed certain slides for longer periods on the second screen	**4.39**	0.73
It was helpful for me when the instructor used both screens to compare two slides	**4.28**	0.79
The presentation system helped increase my attention in the lecture	**3.30**	0.73
The presentation system helped me learn better	**3.73**	0.83

As we can see from Table 1, students' general attitude toward the way the instructors used the two screens was very positive. Most students thought that seeing multiple slides helped them understand the material better, and that having two screens helped the instructor present the material better. Also, most students agreed that it helped them when the instructor showed certain slides for longer periods of time, and when the instructor used both screens to compare two slides. Students' responses to the use of two screens were overall positive. As one student commented:

> "The instructor was able to use the extra space to write notes instead of using the white board; and a few times he displayed the main slide on one screen with snapshots of up to 3 other slides on the second screen. Having the main presentation material plus the secondary

reference material available to look back at was extremely helpful for me. During exercises, having a question on one screen … while the second screen displayed a list of possible answers was also a real benefit, allowing me to concentrate on what the question was asking instead of trying to remember the list."

Usage patterns of two screens

We describe here some of the usage scenarios and patterns we observed. All figures are taken from actual classes.

Comparing two slides

A common teaching practice is to compare two items, to emphasize the similarities and differences between the items to the students. For example, an instructor may wish to compare two algorithms side by side, highlighting the differences between them. Two different solutions for a problem or two definitions for the same idea might also be compared. Figure 2 shows a comparison of the advantages and drawbacks of a

Figure 2 – Comparing two slides

programming technique. When using PowerPoint, the instructor either needs to flip back and forth between the slides to compare the two items, or needs to cram the two items into one slide, making the items smaller. Using MultiPresenter, it is natural to compare two slides side by side at full size, providing the students a visual comparison of the two objects.
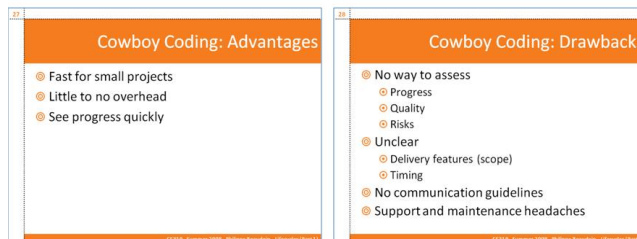
Having information persist longer

A common practice in all classes was to use the secondary screen to keep an important slide persistent, while showing the regular stream of slides on the primary screen. This happened, for example, when the instructor wanted to have a definition slide available for the class to remember, or when having a problem slide persist while showing the solution slides on the other screen. This allows the students a view of the problem throughout the time the instructor spends on the solution, helping them remember the details of the problem. Figure 3 shows an example in which the instructor referred to relevant locations on a persistent map of the Persian Empire, while going over the regular stream of slides describing specific information about the Persian Empire. Other examples included keeping a database schema or database definition table available for a long time in a computer science course while going over an example about that database, or having a slide with administrative information available through the first part of the class.

Referring to previously shown information

Often in a blackboard lecture instructors refer back to previously written information, sometimes even to information written thirty minutes back (Lanir, Booth, and Findlater 2008). This is done to relate the current

Figure 3 – Having information persist on the secondary screen

theme to a previously taught one, and to show how the current information relies upon the previous data. Visually referring students to previously taught information helps students integrate the knowledge, seeing the related information side by side instead of sequentially over time (Mayer, 2001). Using PowerPoint, although possible
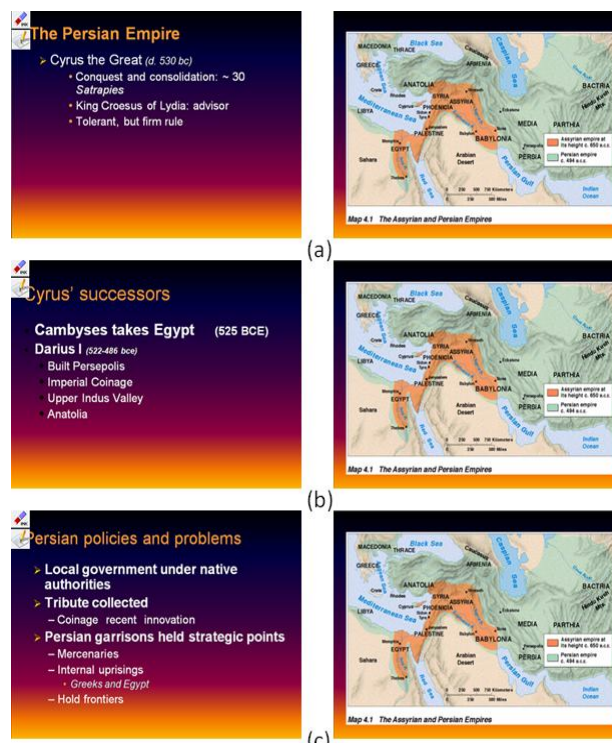
using the presenter's view, it is difficult to directly go to a previously shown slide without knowing its slide number. In the default presentation mode, the instructor needs to flip back through his or her slides, find the related slide, and revert to that slide. Also, when going back to the previous slide, students do not see the current slide and cannot visually integrate the two pieces of information. That is probably why reverting to previous slides was observed to happen rarely if at all when using PowerPoint (Lanir, Booth and Findlater 2008). Using MultiPresenter, the instructor simply brings the related slide to the secondary screen, allowing students to visually integrate the previously taught information with the current theme.

MultiPresenter affords simple navigation of slides using the instructor's view to easily see and jump to previous and future slides. Using MultiPresenter, we observed that often during the lecture, when the instructor referred back to previously shown information, he or she put the previously shown slide on the secondary display. The instructor usually kept that information alongside the current slides until it was no longer relevant to the current theme.

Extending a topic area onto two slides

Often, one slide is not enough to explain a single topic. This again forces the instructor to either cram too much information onto a single slide, making it difficult for the students to read the slide and comprehend it, or to divide the topic onto two or more slides, showing them sequentially over time. As one instructor commented about using PowerPoint: "I often feel a slide is too small, and a lot of times it's because there is something I'd put

Figure 4 – Extending a single topic

on one slide that I wish I could put on the other slide and see them at the same time" (Lanir, Booth and Findlater, 2008). With MultiPresenter, we often observed instructors showing two slides on the same topic area side by side, thus allowing the students to "see the whole picture" when a large topic is explained. When more than two slides describe a topic, often instructors show the latest two slides on the topic, or choose the more important slide of the topic to be kept on the secondary screen (Figure 4).
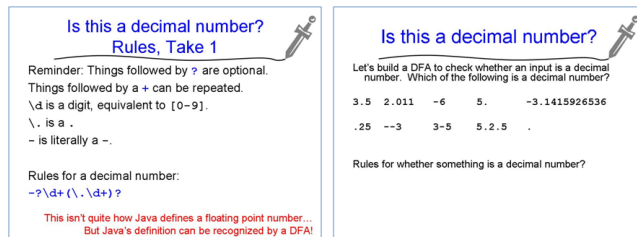
Showing overview slides

In many lectures, it is useful to give the audience some knowledge of the structure of the lecture: where in the whole lecture is the current point, and where are we heading. To achieve this, often an overview slide that is shown at the beginning of the lecture, and again between each topic is used. In his first lecture, one instructor used the secondary screen to show an overview slide of the lecture, while progressing in his slides on the

Figure 5 – Overview slide on the left side, stream of slides on the right side.

other screen. The instructor used attentional gestures with electronic ink to mark each topic he was going over on the overview slide (Figure 5). Another observed example was during a history class on the Persian Empire. The instructor had an overview slide describing each ruler. While showing this slide as an overview, detail slides concerning the era in which the ruler lived were displayed.

Electronic ink with multiple screens

MultiPresenter fully supports ink annotations in different colors and sizes to allow more dynamic interactions during a lecture. Using MultiPresenter, the instructor can use one mouse click to switch to a full view of one of the screens, to increase resolution while annotating with electronic ink. Electronic ink was often used for attentional gestures, to help the audience focus on what the instructor was currently explaining. With the extra information available on the multiple

Figure 6 – Using electronic ink alongside slides

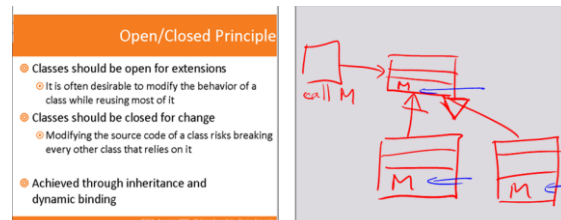screens, it was important for instructors to sometimes focus the audience's attention on specific areas. A common

usage we observed was for the instructors to use the secondary screen as an empty canvas on which to write information (Figure 6). This allows the instructor to use the screen as a whiteboard providing more flexibility, while still having the slides viewable on the other screen for reference. As one instructor commented on the use of ink with multiple screens:

> "It really combines well with the dual screen, because otherwise you run out of space very quickly and you find that you cannot write that much. Also, now you can leave stuff on one screen and start writing on the other screen."

Using another environment together with slides

Today, large lecture halls with multiple screens are equipped with infrastructure that allows the instructor to bring in content from different sources. These sources can be the podium PC to show a browser window or material from a USB drive, the DVD player, the video player, or the instructors' laptop computer. However, most lecture halls do not allow control of the entire screen space using one single source. The instructor needs to choose which source will be seen on each screen. This causes the common practice in which the instructor, when having no other input from other sources to display, uses his or her laptop to display the same slide on many projectors at once.

To control the multiple screens from a single laptop, we provided instructors with a USB monitor adapter, providing the laptop with another graphics card using a simple plug-and-play USB interface. Today this costs less than a 100 dollars. This simple solution allows the instructor to control the entire screen space using his or her own laptop. With this solution, in addition to MultiPresenter, the instructor can also use the multiple screens to show other applications from his or her laptop alongside their slides. For example, the instructor can easily show a browser window, a document, or pop-up a prepared programming environment, all from his or her laptop to display alongside the computer slides. Driving the displays from the instructor's laptop simplifies screen management for the instructor, who is familiar with his or her working environment.

Conclusions and on-going work

With the move from blackboards and whiteboards to computer-generated visual aids in large lecture halls, classrooms have lost many practices that enhanced engagement with students and promoted collaborative learning. Using MultiPresenter, we can reclaim some of these practices while retaining the advantages of computer slides. In this paper, we have shown how MultiPresenter is being used in classrooms, and we classified instructor's usage patterns lecturing with two screens. Initial results from the deployment of MultiPresenter are promising: both instructors and students thought the system was beneficial for learning. By supporting persistent and manipulable representations of information we believe collaborative learning is fostered.

To further engage students, we are augmenting MultiPresenter for audience control of the shared view. This will enhance students' participation and increase collaborative learning by allowing them to contribute content and to annotate and write on the shared presentation space, as well as provide them with the ability to add, change, or highlight existing information on the projected display. When multiple screens are available, it would be natural for an instructor to use one screen for his or her slides while allowing the audience to control the other screen. We envision usage scenarios such as having group activities with the audience using the second screen as a shared resource, having the audience post questions, having the audience contribute content, or having an audience member highlight some aspect of the instructor's material when asking a question or providing clarification on an earlier point. Some of the issues that need to be addressed when designing such a system are how to mediate interaction, what kinds of access control should be built in for such a system to work effectively, and what pedagogical patterns are best for each type of audience engagement.

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