Jl. of Interactive Learning Research (2004) 15(2), 169-185

Lessons Learned Deploying a Digital Classroom

SAMI ROLLINS
Mount Holyoke College, USA
srollins@mtholyoke.edu

KEVIN ALMEROTH
UC Santa Barbara, USA
almeroth@cs.ucsb.edu

A number of university campuses have undertaken the development of *digital classrooms* that enable presentation of digital media and digital lecture recording. While educators from across disciplines are interested in using the facilities these classroom spaces provide, deploying the infrastructure for a digital classroom is difficult at best, even for a technically savvy person. As people from many disciplines become interested in building similar digital classroom spaces, there is a need to produce a useful set of design and implementation guidelines for determining the functionality of such a space and selecting and installing the equipment to achieve that functionality. The goal of this article is to report on the deployment of the UCSB digital classroom. By using this article as a guide, future digital classroom architects can reduce the project risk and steepness of the deployment curve. This article: (a) motivates the use of technology in the classroom by discussing the impact of technology on education; (b) presents a phased model for classroom deployment; and (c) categorizes the set of lessons we have learned during our deployment efforts.

Advances in technology coupled with increased familiarity with technical tools have paved the way for new paradigms in teaching and learning. Instructors are now using media such as *PowerPoint* slides and digital video in their lectures. Students can take digital notes on laptop computers or Personal Digital Assistants (PDAs). These types of technologies allow students and instructors to communicate digitally across time and space. However, while these tools are readily available, using them in a coherent manner is still a challenge. A number of university campuses have undertaken the goal of developing *digital classrooms* that enable presentation of information using cutting edge multimedia tools as well as provide the capability to digitally record an account of the classroom activity. The account can be used in realtime to enable distance learning or realtime collaboration, or can be archived and reviewed at a later time.

A number of universities have deployed digital classrooms for both teaching and research on new learning methodologies and tools. One of the earliest experiments with this kind of technology was the AT&T Learning/Teaching Theater at the University of Maryland (Schneiderman, Alavi, Norman, & Borkowski, 1995). More recent examples include 405 Soda at UC Berkeley (Wu, Swan, & Rowe, 1999) and Georgia Tech's eClass (Abowd, 1999). While the research that has come out of these projects has focused largely on user-level issues, the piece of the puzzle that has yet to be solved is the question of what basic functionality these classroom spaces should support, and more importantly, how that can be achieved. Without a useful model to draw from, there is an enormous learning curve involved in determining first, what functionality a classroom should support, and second, what technology exists to realize the design. A huge number of tradeoffs need to be considered. It is difficult at best for a technically savvy person to undertake the challenge of deploying a classroom. As people from across disciplines become interested in building similar digital classroom spaces, there is a need to produce a useful set of design and implementation guidelines for ease of deployment.

The goal of this article is to report on the set of lessons learned in the process of deploying the UCSB digital classroom. By drawing from these lessons, future classroom architects can reduce project risk as well as the steepness of the deployment curve. This article identifies four classroom functions, and suggests that a classroom should be deployed in four phases corresponding to those functions. Deployment of the UCSB digital classroom began in June of 2000. To date, the UCSB classroom has cost approximately $70,000 broken down as roughly $14,000 for phase 1, $42,000 for phase 2, and $12,000 for phase 3. To date, the deployment of phase 4 has leveraged technology purchased in the prior phases. It is difficult if not impossible to deploy a fully functional digital classroom infrastructure before testing or using it. Therefore, the goal of this article is to draw upon actual experience to develop a model to support incremental development, deployment, use, evaluation, and modification of digital classroom spaces.

This article is organized as follows. The second section discusses the motivation for using technology in the classroom and the goals of designing and deploying a digital classroom. The third through sixth sections discuss the four phases of digital classroom deployment. The seventh section presents a collection of lessons learned in practice. The eighth section concludes the article.

MOTIVATION

As technology becomes more reliable and affordable, there is a call to create technical solutions to enable and enhance a variety of activities. From medical applications to entertainment, technological advancements can provide new functionality as well as make existing tasks easier. In recent years, there has been a lot of interest in developing solutions to integrate technology into the classroom. However, without a useful set of deployment guidelines to rely on, creating a digital classroom space is still quite challenging. This section discusses the motivation for using technology in the classroom, the goals for deploying a technologically enhanced classroom, and introduces a model for digital classroom deployment.

A technology-rich learning environment can provide a number of advantages over a standard classroom environment. First, a classroom equipped with one or more computers and displays can enable instructors to use an array of media to teach students. From video to interactive multimedia presentations, learning can extend beyond facts written on a chalkboard. Additionally, students can use technology such as laptop computers and PDAs to share information. For example, a student who has found an interesting website relevant to the course material can share the information with the rest of the class. The seamless integration of this kind of technology paves the way for integration of new, more collaborative learning methodologies.

Another benefit of using technology in the classroom is the elimination of barriers such as physical distance and room capacity. The ubiquity of the Internet coupled with advances in audio and video streaming technology enables *webcasting* of lectures. The impact of webcasting is that physical distance no longer need be a barrier to education. Enrolled students can “web commute” rather than miss lectures, and students who may have otherwise been unable to take a class have more flexibility to choose to attend lecture from their home or office in a distant town. Additionally, the number of people who can fit in a room does not have to limit audience size. For example, if an expert speaker visits a university, the number of people interested in attending his/her lecture may exceed the capacity of the largest lecture hall on campus. Webcasting enables a virtually unlimited number of students to attend the lecture either from a remote location on campus, or from across the world.

In addition to spatial barriers, temporal barriers can also be overcome with the use of technology. The ability to archive audio and video of a presentation along with any presentation materials enables asynchronous learning. Students can watch missed lectures as well as review lectures before exams. This can reduce the burden on the instructor and teaching assistants. In addition, lectures given by experts in their fields can be archived and watched for years to come.

While the benefits of using technology in the classroom are clear, a number of goals must be met to effectively deploy a digital classroom space. The first two goals are largely technical. First, a classroom should be as extensible as possible. It is nearly impossible to purchase and install every possible piece of equipment at one time. Therefore, a classroom infrastructure should support incremental additions with minimal interruption of the existing equipment and services.

A second goal is to support technical efficiency. For example, to support a webcasting environment, an encoding computer must encode a raw video signal and send the resulting stream to a set of remote computers with minimal delay. Unfortunately, requirements such as these often require tradeoffs in terms of factors such as cost.

In fact, the third goal in designing a digital classroom space is to manage cost and stay within budgetary restrictions. Funding for a digital classroom space may be limited, or incremental. Therefore, it is imperative to understand the cost range for each piece of equipment. Additionally, it is important to understand which pieces of equipment are necessary, and which may be purchased later and easily integrated into an existing infrastructure.

These goals largely support the objective of deploying a functional infrastructure. There are also a number of higher-level goals, such as ease of use, that are not addressed here. While these goals are certainly important, the objective of this work is to build a basic, functional, infrastructure. This infrastructure not only supports classroom activity such as lectures, it provides a very important building block for research in other areas such as user-level interaction.

To support the goals outlined here, this work proposes a *phased* model for classroom deployment. The first phase of deployment supports multimedia presentation facilities in a digital classroom space. The second phase supports one-way webcasting of content generated in the classroom to one or more remote sites. The third phase supports multi-way collaboration between classroom sites. The fourth and final phase supports archival of content for future access.

To support the goal of extensibility, each phase builds upon the previous phases to support additional functionality in the classroom without requiring changes to the existing infrastructure. To support the goal of technical efficiency, each phase describes the functionality the classroom should support and introduces many of the technical complexities that must be considered. Using this guide, a classroom architect should better understand many of the decisions that need to be made as well as the tradeoffs associated with each potential solution. With this knowledge, a classroom architect can choose the solution that best fits the desired level of efficiency. Finally, the goal of cost management is supported both by the exploration of the complexities and tradeoffs involved in the decision-making process as well as by the phased nature of the model. Using the model, an architect can select the lowest cost solution that will fit the desired classroom functionality. Additionally, by using a phased deployment model, a functional classroom can be deployed and used before all of the equipment has been purchased. The following sections describe each phase in detail.

PRESENTATION FACILITIES

The first phase of classroom infrastructure deployment focuses on providing technology to allow an instructor to give a multimedia presentation in a digital classroom. It is impossible to develop an infrastructure that will accommodate every lecturer or class ever held in a digital classroom. Some professors will use *PowerPoint* slides while others prefer to use transparencies while still others stick to the standard chalkboard method. In addition, instructors using digital presentation media may require a variety of software. Managing a few pieces of software is tractable, however a system to manage lots of software is not. Fortunately, a large percentage of cases can be accommodated with a standard collection of hardware and software. Minimally, a classroom should include a data projector to show *PowerPoint* slides or other computer-based media in addition to providing an Internet connection for a presentation laptop or desktop machine.

Selecting a presentation computer and data projector for purchase requires some thought about the specific classroom and the complete functionality that will eventually be supported by the classroom. There are three main concerns that need to be addressed when selecting equipment. The first is **compatibility**. A major concern is whether or not each piece of equipment will be compatible with the remaining infrastructure. For example, if the classroom will eventually have a room control system to control various components (e.g., power on/off, input device switching, etc), does the data projector support that type of control? An additional concern with data projectors is how to **install** or mount them. One option is to simply purchase a media cart where a projector can be stored. However, a media cart is not a scalable or permanent solution. The preferred solution is to mount the data projectors into the ceiling. This requires the purchase of a ceiling-mount kit for each projector. Additional concerns include providing a power source as well as ensuring that the ceiling is high enough to mount the projectors out of the way of sight for students and other equipment. Once a data projector and a presentation computer have been selected, the next concern is **connecting** them together. The standard solution is to run a VGA cable from the computer to the projector. However, in a digital classroom the distance might be too great. Thus, the quality of the video signal degrades. The solution is to purchase a signal interface. A signal interface is a device to boost a computer video signal such that it can travel greater distances.

The UCSB digital classroom shown in Figure 1 has three ceiling mounted data projectors that project on standard projection screens, two presentation laptop computers with signal interfaces at the front of the room, and one presentation desktop with signal interface at the back of the room. In addition, the room provides a VCR for showing standard VHS videotapes. Each computer has a DVD player and an Internet connection and can be used for showing DVDs, presenting *PowerPoint* slides, web browsing, or presenting a variety of other media. In addition, speakers may bring their own laptop computers with specialized hardware and/or software and use the data projectors provided. Finally, students may connect to the Internet using their own laptops or PDAs though an 11Mbps wireless network.

There are a number of potential extensions to this infrastructure. Short-term extensions include integrating additional presentation technology such as a document camera. Longer-term extensions include upgrading the display technology to be more sophisticated. For example, the three separate presentation screens could be replaced by a single, wall-sized display. Addi-

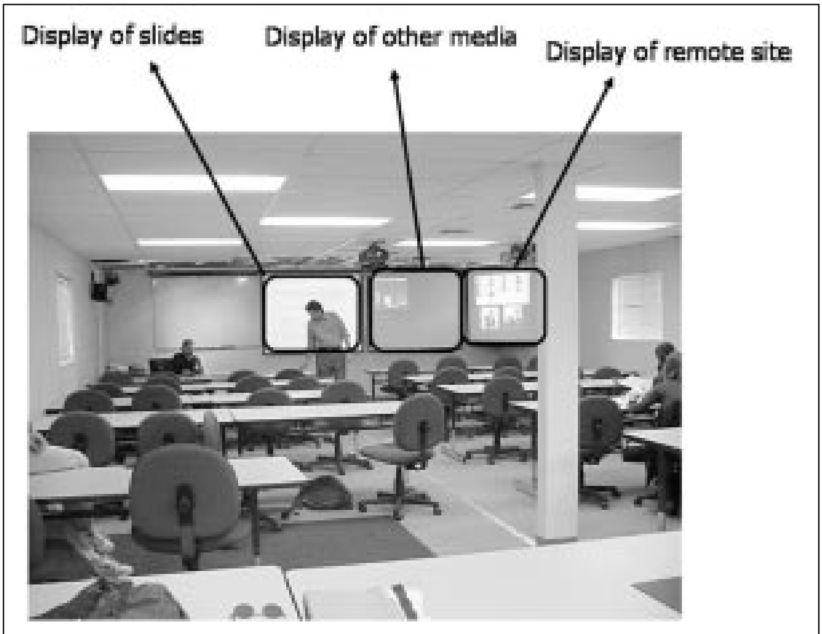

Figure 1. The UCSB digital classroom

tionally, integrating the technology to allow students to project their computer displays on the main display screen(s) would make the classroom a more collaborative environment. Finally, a lectern that integrates the plethora of devices available in the room and provides a single control interface would make the room much more user-friendly. Such a device should be simple to use, but allow control of all of the equipment including the three data projectors, two presentation computers, and the VCR.

A WEBCASTING STUDIO

Once the basic infrastructure is in place to support lectures in a classroom, the next step is to expand the infrastructure to include support for webcasting. A webcasting environment captures audio and video feeds generated in the classroom and sends them, potentially accompanied by other media such as slides, over the Internet to a remote location. There are two pieces involved in making this happen. The first is to provide support for capturing video and audio of the presentation. The remote audience should be able to see and hear the instructor. Second, media (e.g., slides) presented to the local audience should also be presented to the remote audience.

The minimal requirements for a webcasting environment are one camera, a microphone for the instructor, and an encoding computer. However, producing a reasonable quality webcast requires a great deal more effort. First, a single camera can be limiting if you hope to capture all of the activity that occurs in a classroom. To capture all of the classroom activity including instructor and student movement, multiple cameras must be mounted in various locations in the room. In addition, capture of presentation media can be accomplished by focusing a camera on the classroom projection screen. However, capturing the computer video feed straight from the computer can produce a higher quality image. Finally, determining which streams are encoded and webcast at any given time adds a nontrivial bit of complexity to the system. Generally, a producer must be available to manually select the stream for webcast. A producer is generally a student or staff member who produces the webcast by controlling the encoding tools and selecting the appropriate video and audio streams.

Managing multiple streams simultaneously introduces a host of complexities. First, devices such as cameras have an associated **control** interface and may be controlled (e.g., zoomed) from a remote control or computer interface. However, when numerous, heterogeneous devices are installed in a room, it becomes difficult to control all of the individual elements. Rather than having multiple interfaces such as computers and remote controls, it is desirable to support a single, integrated interface that supports control of many or all of the devices in the room (Yu, Wu, Mayer-Patel, & Rowe, 2001). Also, it is unlikely that any hardware configuration would support encoding of all possible streams simultaneously. The general protocol is to **select** a subset of all available streams for encoding. In order to accomplish this, the infrastructure must include a video matrix switch. A video matrix switch is a device that takes as input a set of video signals and allows routing of the video signals to one or more of the switch output channels. By routing all video through a video switch, the architecture becomes much more modular. Audio signal capture poses many of the same problems encountered by video stream capture. If an infrastructure supports only a single microphone used by the instructor, the signal can be directly connected to a sound card. However, this model begins to break down relatively quickly. Capturing other audio sources such as audience discussion or the audio track from a VHS video is imperative. The ultimate solution is to install a professional quality audio system that is capable of mixing audio signals from the instructor, microphones placed to capture ubiquitous audience discussion, audio streams from remote sites, and other sources such as video. Finally, video format **compatibility** is a concern. Video capture hardware generally expects a composite video signal. Therefore, the computer video signal sent from a presentation computer cannot be directly encoded as part of a video stream. The solution is to use a *scan converter* to convert the high-quality computer video signal to a composite video signal.

Developing an infrastructure to manage and select multiple media streams in various formats is extremely complex and requires much thought. However, once the architecture to capture a selected stream is in place, the next step is to determine how to encode the audio and video streams into a format that can be easily distributed and viewed by remote participants. There are two primary concerns that need to be addressed. The first is **expense**. Hardware-based encoding solutions provide efficient, high-quality encoding. However, while cheaper solutions are on the way (e.g., NCast - www.ncast.com and VBrick - www.vbrick.com), current solutions can be very expensive. Software-based encoding solutions can also be expensive, but there are also a number of lower-cost solutions. While **encoding** formats such as MPEG-4 may seem to be the highest quality solution, the chosen encoding format should have a widely available, cross-platform decoder/viewer. Ideally, students would have the viewing tools already installed on their desktop thus avoiding having to download or purchase them. The most common tools currently on the market are RealPlayer and *Windows Media* Player both of which have freely available and easy-to-install viewers and encoders.

The UCSB digital classroom infrastructure supports webcast of a single video stream selected from a set cameras or other video input. In addition, the classroom implements the audio setup suggested by the Access Grid specification (www.accessgrid.org), which includes a number of microphones to pick up ambient sound and a high quality sound mixer[1]. The heart of the

UCSB classroom infrastructure is a 12-input, 8-output video matrix switch. The switch supports both composite and computer video. The first two switch inputs (Figure 2) are the composite video signals generated from the classroom cameras mounted to capture both instructor and audience views. In addition, composite video from the VCR is also routed through the switch. All computer video sources from the presentation machines, as well as remote sources, are also inputs to the switch. However, to capture and encode any of these feeds, the feed must be routed through a scan converter and converted from computer video to composite video. The resulting stream is then fed back into the switch and may be selected for encoding. The streams selected for encoding are fed into a video capture card installed on a standard PC. In addition, the mixed audio stream is fed into the sound card of the PC. The audio and video streams are then encoded using either *RealMedia* format or *Windows Media* format and webcast to a remote audience.

The primary extension of this infrastructure is replication of the existing pieces of equipment. For example, installing additional cameras provides more flexibility in terms of capturing various views of the room. Additionally, installing additional encoding equipment, either PCs or hardware-based solutions, can allow the producer to select more streams for production. For example, video from two cameras, instead of one, can be streamed to the remote location. Alternatively, more encoding hardware can provide the

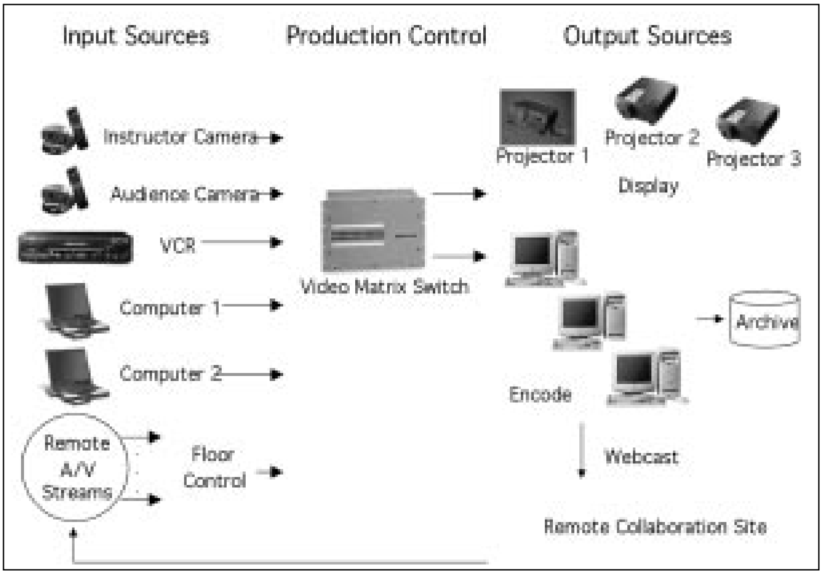

Figure 2. The UCSB digital classroom infrastructure

ability to encode and send the same stream, but in multiple different formats. For example, a camera view of the instructor can be encoded using *RealMedia*, *Windows Media*, and *MPEG* simultaneously. By sending all available streams, the end-user can then choose the most accessible format.

REMOTE COLLABORATION

The one-way distance learning scenario supported by a webcasting studio does not capture the true learning experience. For distance learning to truly be effective, remote students must be able to ask questions, participate in discussion, and otherwise appear to be at the local site. This requires two pieces. First, the remote site must have facilities similar to that of the local site. Second, the technology to communicate, in realtime, between the two sites must be in place.

Ideally, a **remote site infrastructure** would be an exact replica of the primary site. In reality though, the infrastructure of a remote site is generally a subset of the infrastructure deployed at a primary site. Minimally, a remote site must include a camera, a microphone, an encoding machine, and a decoding machine. This could take the form of a standard webcam and microphone connected to a student's home PC where the PC is both the encoding and decoding machine. However, if a remote site is designed to support multiple students (e.g., an extension campus) a more complex infrastructure is necessary. For example, displaying video of the instructor on a PC screen is probably not sufficient. In addition, the camera should be able to capture an audience larger than a single person. Fortunately, the problems encountered when developing the remote site infrastructure are the same problems encountered when deploying the primary classroom and thus we can apply the same solutions.

While deploying the remote site infrastructure itself is relatively straightforward and follows directly from the discussion in the previous section, deploying a **communication layer** on top of the infrastructure is more difficult. There are two main topics to be addressed. The first is realtime encoding. A basic solution is to use the same software encoding solutions used for one-way webcasting. However, off-the-shelf encoding software such as *RealMedia* and *Windows Media* introduce intolerable delays from 7 to 15 seconds one-way due to buffering requirements. As with many of the challenges, extremely expensive encoding solutions exist. But, deploying these solutions without knowing whether or not they are going to work is a risky venture. The alternate solution is to use encoding software designed for video conferencing such as vic or Microsoft *NetMeeting*. While off-the-shelf video conferencing software is generally easy to use, quality is sacrificed to meet realtime requirements. Also, in addition to watching video generated at a primary site, students at a remote site should be able to ask questions (Malpani & Rowe, 1997) and access shared components such as whiteboards. Additionally, as the number of remote sites grows, it becomes necessary to manage the sites so that only one remote site is asking a question or sourcing video at a given time. Some of these problems may be solved with standard videoconferencing software. However, the requirements are different for any given infrastructure and differences require specialized solutions.

In addition to the basic classroom infrastructure, a UCSB remote *kiosk* has been deployed across the campus from the classroom. The kiosk has one camera, a single microphone (to be passed from participant to participant), a single encoding machine, and two decoding laptop computers connected to data projectors for display (Figure 3). Microsoft *NetMeeting* is used to communicate between the sites. The primary classroom sends slides (using the *NetMeeting* screen sharing facility), a video feed of the speaker, and an audio stream from the speaker microphone to the kiosk. The kiosk sends a single video stream and a single audio stream back to the primary classroom where it is displayed on a side mounted projection screen. Figure 4 shows the flow of streams between sites.

In building the kiosk, a number of simplifying assumptions have been made. First, to avoid the problems of floor control and remote stream selection, it is assumed that there are only two sites participating at any given

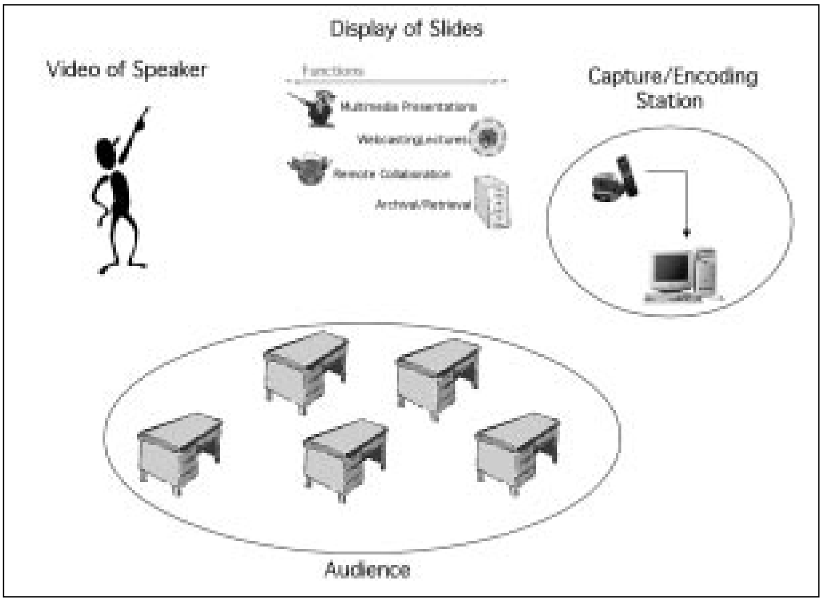

Figure 3. Remote site infrastructure

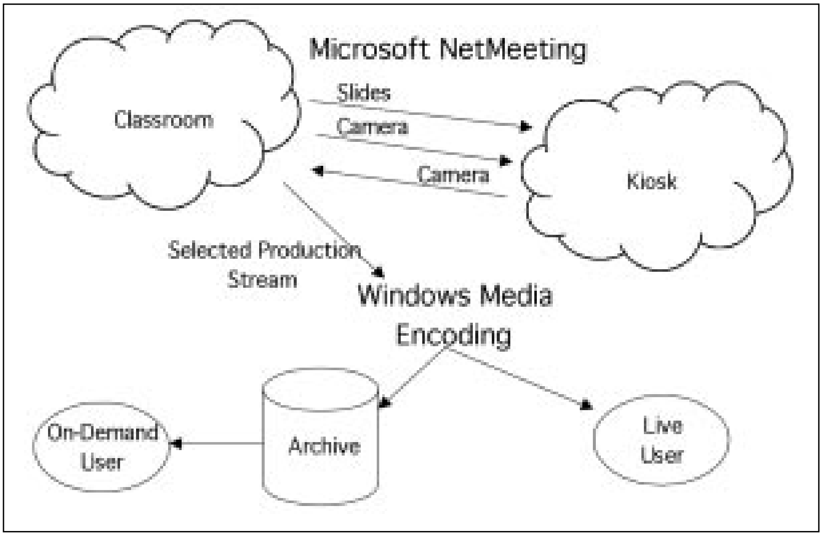

Figure 4. Classroom and remote site communication

time. Second, it is assumed that the only audio stream for either site is generated from the single microphone available at that site; thus the audio signal does not have to be mixed.

The obvious extension to this infrastructure is simply to add more sites and to extend remote sites to provide all of the functionality the original site provides. Another extension is the addition of an advanced floor-control mechanism. Such a mechanism should both multiplex all audio and video signals such that any signal can go to any possible destination as well as provide a user-friendly mechanism for selecting which signal should be sent to which destination at any given time.

LECTURE REPLAY

One of the primary advantages of recording a lecture or course is that it may be reviewed after the fact. Students may review material at the end of a course or before an examination. In addition, lectures given by guest speakers or experts in their field may be archived and watched by students for years to come (Tsichritzis, 1999). There are a number of issues involved with recording lectures for replay. However, most of the difficultly lies in providing more functionality over straightforward, sequential playback. The goal of the basic classroom infrastructure is simply to provide a content base that may be accessed and used to research new methods of access. The challenge is to record and encode the content such that it may be accessed later in different ways using a variety of tools. Subsequent use of mechanisms to support VCR-style interactivity as well as integration of multiple media types can provide a more effective replay experience.

There are two main issues in the deployment of an infrastructure for lecture replay. The first is the deployment of a **media server**. An hour of lecture can be 500Mbytes or more depending on the encoding scheme. Therefore, the first concern is to deploy a media server with enough disk space to hold the recorded lectures. The second issue is to determine which **encoding** standard to use. The simplest solution is to simultaneously save the stream already being encoded for webcast. However, it may be desirable to support postprocessing of the stream such as including synchronization between video and slides (Mukopadhyay, 1999).

The UCSB digital classroom primarily focuses on replay of the webcast stream. During webcast, the encoded *Real* or *Windows Media* stream is saved to a file and may be streamed from the server later. The UCSB classroom has generated only a small content base and thus has not yet deployed a server to support large amounts of data.

To fully deploy the infrastructure to support lecture replay, a much larger server must be installed into the classroom infrastructure. Additionally, each produced stream should be archived in an extensible encoding format that can be translated later if necessary. For example, after a lecture has been recorded, students may request that it be made available in a format other than the original (e.g., *RealMedia* instead of *Windows Media*). Ideally, it should be easy to perform such a transformation on the saved data. Finally, as much of the original content as possible should be archived. This includes the instructor's presentation material, and any other media presented during the lecture.

LESSONS LEARNED

To date, we have used the UCSB classroom for four different types of events: (a) we have hosted and recorded a collection of standard courses; (b) we have conducted a graduate student seminar with participants distributed between the classroom and our remote kiosk; (c) we webcasted a talk given by a Nobel laureate to an elementary school classroom located in a nearby town; and (d) we conducted and recorded an ongoing lunchtime seminar. The Nobel laureate's talk was also viewed from other locations in the US, as well as in the UK.

Through the course of deploying, using, and iteratively improving the classroom we have had to overcome a number of challenges we feel are not unique to our classroom. While it would be impractical to report every relevant experience we have had, the goal of this section is to take a critical look at our experiences and extract a set of lessons that can benefit any future classroom architect. We have classified those lessons into three categories: (a) successes, (b) room for improvement, and (c) the most challenging issues. Our hope is that this set of lessons can help to make the process of deploying a digital classroom less tedious and more efficient for classroom architects of the future.

Successes

Minimization of backtracking. It is inevitable, especially when deploying a classroom infrastructure in phases, that it will be necessary to purchase equipment *now* that will be obsolete *later*. For example, in the first phase of deploying a multimedia presentation space it is necessary to purchase cabling to connect a presentation computer to a data projector. When deploying a video switch in the second phase, that cabling may or may not be reusable. Another example is encoding hardware. A set of standard PCs with video capture cards to capture and encode a composite video signal may be the best initial solution. However, a number of products that provide a single box solution to video encoding and decoding are currently making their way to market. Most of these products provide an ease-to-use, clean, rack mountable solution to video encoding and decoding and may render the PC solution obsolete. While it is important to realize that the purchase of equipment that will later become obsolete is unavoidable, the goal of this article is to minimize the required amount of backtracking by illustrating the components necessary to reach the end goal. Learning from this work as well as from other classroom architects can greatly reduce the amount of backtracking required when building a classroom infrastructure. This can both minimize cost and effort required of future classroom architects.

Created an extensible architecture. For nearly every user of the classroom, there will be a different request for an addition to the architecture. One instructor may need a VHS VCR while another may request a laser disc player. A variety of instructors have used the UCSB classroom and its facilities. Some instructors have used only the multimedia presentation functionality while others have recorded lectures and done remote collaboration. As a result, it has become clear that adding new components to the existing architecture is relatively easy and straightforward. For example, early on an instructor requested to add a VCR to the infrastructure. Placing a VCR at a convenient location in the room and running a BNC cable from the VCR to the video switch was a quick and easy task. Adding additional video sources is equally as simple, however care must be taken to avoid creating an equipment management nightmare.

Room for Improvement

Staffing. Creating and maintaining a classroom is a full time job. In addition, it requires not only technical consultants, but also facilities staff who can perform tasks like mounting projectors. A high-quality classroom also requires professional consultants that have a knowledge of components such as audio and lighting. Many of the subproblems encountered in building a classroom, such as deploying an audio system, are problems that have already been solved. In an effort to minimize expense and complexity, we have tried to put together all of the pieces of the classroom ourselves. What we have discovered is that some pieces of the classroom puzzle should be left to the professionals. For example, while it has been relatively straightforward to deploy video equipment, audio has been more difficult. Our first attempt at an audio solution resulted in fairly poor quality and did not support much of the functionality we desired. What we have learned is that the delay we incurred trying to learn about and deploy the audio ourselves could have been avoided by bringing in an audio expert from the beginning. The lesson is really to evaluate whether or not it is worth it to invest the time learning about and devising a solution to a problem that may already have a slightly more costly solution.

Address all concerns in the planning stage. While, overall, we have done a good job of planning and deploying our infrastructure incrementally, there are two main issues that we have postponed throughout the process. The first concern is audio and the second is the design of a lectern with a console used by the instructor to control the equipment in the room. These are expensive problems to solve and therefore we elected to deploy the remainder of the infrastructure first. However, in retrospect we feel that these are essential problems and we should have addressed them earlier in the process. Even if it is not feasible (financially or otherwise) to implement all of these issues from the beginning, it is important to understand the limitations of the classroom infrastructure without all of the components.

The Most Challenging Issues

Using the room you are given. One of the biggest challenges we have faced has been building a digital classroom in an arbitrarily assigned room. In particular, the room we have used is a 58 foot by 23 foot portable trailer with an 8 foot ceiling. This has been limiting in a number of ways. First, the low ceiling makes it difficult to ceiling-mount data projectors and other equipment. Second, the depth of the classroom makes it very difficult to see from the back of the room. This is a problem for the students in the room as well as for the producer of the webcast since the control station is at the back of the room. In addition, it has been challenging to choose mount points for the cameras, particularly for the instructor camera. Mounting it in the back of the room meant that it was too far away to capture a close up view of the speaker at the front of the room. Ultimately, we mounted it on a post that stands directly in the middle of the room. The problem with this solution has been that for the camera to be out of the way of students walking by, we mounted the camera about 1 foot from the ceiling. Therefore, it captures much of the ceiling and the data projectors in its view. Ideally, a digital classroom would be custom-built. A relatively square room with a high ceiling is the best solution. This allows cameras to be mounted at the back of the room and possibly built into a cabinet to protect them from passing students. Additionally, the room should have the facility to easily run cabling from an equipment rack or cabinet to the various pieces of equipment in the room. Finally, care should be taken to provide electricity and Internet connectivity to equipment in the room. This is especially important if each student desk supports a laptop or other workstation.

Quality. Quality of a webcast or recorded session is extremely important. Ideally, the classroom should be a studio-quality production environment with professional lighting and sound. In reality, this is nearly impossible. As previously mentioned, the room itself (or the environment in general) can be constraining. In addition, a high quality webcast or recording requires knowledgeable staff members who know how to operate the equipment to capture the ideal camera angles, and so forth. Deciding where to trade quality for effort and expense has been one of the most challenging aspects of deploying our classroom.

Promoting classroom use. As we have completed our classroom deployment, we have run into a chicken-and-egg problem. We want instructors to use the facilities we provide to teach their courses. However, nearly every instructor either requires functionality that we do not provide, or refuses to use functions we do provide (e.g., concern over video taping lectures). While we want to provide a usable facility, we also want to evaluate the equipment we have deployed. In some cases, this requires instructors to use equipment they may not traditionally use (e.g., *PowerPoint* slides) in teaching their classes. Until technology-rich lectures become more commonplace, promoting the use of digital classroom facilities will continue to be a challenge. The best we can hope for is that a few technically savvy instructors will be willing to invest the time to modify their lecture style and experiment with the capabilities of the digital classroom.

CONCLUSION

Deploying the infrastructure for a digital classroom is a long and often tedious process. In theory, it involves technical staff, facilities staff, as well as researchers. In the first year of deployment, we brought the UCSB digital classroom online to support the four functions defined by our model to varying degrees of completion. While the process has been slower than we originally anticipated, delays in deployment can be attributed to lack of staff as well as to factors such as back-ordered equipment and equipment incompatibility. However, we are pleased with the resulting infrastructure and its use so far. While we are working toward automating the process of set up and configuration as well as lecture production, our infrastructure supports nearly all of the intended functionality.

Recently, we have further documented our experiences in two separate articles. The first describes the four primary sources of complexity in the digital classroom, and outlines a set of solutions that a classroom architect can use to reduce the complexity of managing and operating a digital classroom to a minimum. The second article describes a demarcation point between producing a classroom event, and encoding and archiving the event. The article argues that separating the classroom functions along logical barriers can facilitate ease of management.

Throughout the process of designing and implementing our classroom model, we have identified a number of considerations that may not be immediately obvious to the designer or implementer. These considerations range from high-level decisions such as supported functionality to low level choices such as required equipment. We would like to acknowledge many helpful discussions with Larry Rowe and other classroom architects that have helped us to determine the common properties of most digital classrooms. We believe that most digital classroom implementations support similar functionality. Thus, it is unnecessary for each design team to start from ground zero. As campuses around the world begin to embrace technology in their curriculums, it is essential to be able to quickly and easily deploy technologically enhanced meeting spaces.

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Note

[1] The Access Grid is an initiative to enable research labs and universities to conduct large-scale, distributed meetings over the Internet through an always on infrastructure.