Learning in the Digital Age: Paving a Smooth Path with Digital Lecture Halls

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Abstract

In the transition from traditional teaching and learning to eLearning, this paper emphasizes smoothness. We claim that many virtual university and corporate university efforts worldwide try to showcase big leaps forward yet lack sustainability, suffer from in-vitro conditions, and leave behind the big mass of teachers (learning and teaching are used in the largest sense of these terms). The digital lecture hall (DLH) project accommodates traditional teaching methods right on the spot – making them 'digitally' available for computer assistance – but also reaches out to a large variety of computer assisted methods and to accompanying new organizational and business models. Apart from this smooth transition yet far reach, DLH has a second focus: the attempt to exploit venues which go well beyond class room size; as opposed to known "electronic classroom" efforts which are limited to some 15 to 30 local participants, audiences without size limits are supported in DLH, with the first implementation in operation offering a seating capacity of about 150.

1. Rationale

1.1 The "Digital Audio" analogy

When the audio CD was introduced some two decades ago, this analog-to-digital move changed quite little for the consumers and the musicians: consumers had to buy discs just as before, they had to use an affordable consumer-electronics device, and the whole business model and most of the production technology remained basically unchanged. Of course, there were some – rather minor – quality improvements: discs became smaller, had more music capacity, and were said to be more durable; the first quantitative improvement was the ability to play the disc arbitrarily often without noticeable degradation. On the other hand, many "connoisseurs" of HiFi music claimed to notice quality degradations – a claim neither substantiated nor eradicated to date. Briefly speaking, hardly anything really changed. Nevertheless, the "almost invisible" move from analog to digital signals – carried out by the masses and not by an "elite" as with "exotic" technology like laser discs (which weren't fully digital anyway)! – was a prerequisite for all the change that was to come: digital studio technology that would mark big changes in the production process, digital compression that boosted HiFi audio communication and storage possibilities, pen-size devices and portable phones "acting" as players, lately even peer-to-peer exchange servers (cf. Napster) which are about to challenge even the entire business model, and more to mention and more to come.

In this paper, we argue that computer-assistance in teaching and learning is still in the "laser disc" era after some four decades: Of course, there are gorgeous achievements demonstrated at conferences and in "in-vitro" showcases, but the "mass" reality is quite different still: computer-assistance is *not* common in lecture halls and classrooms (except maybe for the replacement of slide and overhead projectors by beamers, but even here a look at common practices is discouraging); for the (still *relatively* few) cases where computer-assistance has become a commodity, like in HiTech companies, sophistication is rather low: CBTs and WBTs resemble behavioristic presentation-CAIs of the mid sixties, teleteaching lessons resemble boring peep-shows, and "virtual universities", behind a shiny "welcome screen" facade, offer mostly on-line versions of lecture notes originally conceived as paper documents (this analysis is furthered in the next subchapter).

Given this deplorable state, we advocate a policy in analogy to the introduction of the audio CD: a move from "analog" to "digital" teaching with as little as possible *imposed* change for the user i.e. teacher / learner. Hence, i) the digital lecture halls proposed here remain physical venues, virtuality is not an immediate goal; ii) they even accommodate teachers who want to continue scribbling proofs or discourses by chalk and who are used to "filling" an entire handful of subsequent blackboards with a single proof or discourse; and iii) they offer "after-hours" availability of such "traditional" lectures as a first noticeable improvement over traditional teaching and learning models. We will show that it requires considerable yet feasible effort to make this almost "invisible" analog-to-digital move (again, this compares to the introduction of the audio CD which required considerable but not exceedingly high investment, such that - within the typical lifespan of a disc player – the "masses" could move to new technology).

The remainder of this paper will also show that the proposed initial analog-to-digital "mass movement" is the only prerequisite for many changes to occur (cf. our analogy again). Most of these changes are targeted by present "virtual university" projects, but as to changes *for the masses*, we consider our approach much more promising.

1.2 Virtual universities vs. a step-wise process

Continuous and tertiary education worldwide are currently faced with a race towards corporate and virtual universities. Politicians and managers seem to be delighted with the budget-relieving vision of virtual teachers that can be replicated by way of keystrokes. However, a closer look at the large number of virtual universities accessible on the Web reveals two basic problems:

- Firstly, the development efforts for suitable course material are tremendous in a virtual university set-up (This explains why visiting a virtual university would typically be appealing at the first glance – offering, say, a VR model of the campus and some main buildings such as library, lecture hall, etc. – but would be disenchanting at the second glance – offering, say, ordinary slide copies and lecture notes for most of the courses).
- Secondly and even more important, very little teaching experience exists in virtual set-ups – especially compared to the thousands of years of existence of schools in the broadest sense. Neither the technological nor the pedagogic and didactic concepts applied have converged towards a stable culture. This explains why – in contrast to shiny publications – the bare facts about virtual teaching are rather disenchanting, too.

As a consequence of the above, we propose to avoid leapfrogging from real to virtual universities. Rather, we suggest a smooth transition that starts with the current and well-understood real universities – hence the analog-to-digital transition without big changes for teachers and learners described in chapter 1.1. By augmenting current teaching venues with new technology, these teaching venues become digital (often called "electronic") classrooms, digital lecture halls, and digital (often called "virtual") laboratories. This paper concentrates on digital lecture halls since both electronic classrooms and virtual laboratories on the Internet are investigated in other projects (although with a slightly different focus); to the knowledge of the authors, no project has addressed venues of large size yet (i.e. lecture halls for hundreds of learners). Therefore, digital lecture halls **(DLH)** will be emphasized further.

"Just" an analog-to-digital move? The question may be posed whether the proposed "analog-to-digital mass movement" is the only concrete step proposed and whether all other achievements of computer-assisted teaching shall be ignored. On the contrary, the remainder of the paper will show that the DLH concept accommodates all types of synchronous and asynchronous, local and distributed, strongly-guided to open explorative teaching methods. The difference is that by setting the "entry threshold" for ordinary teachers low, we intend to motivate virtually all teachers to enter the digital era; also, the variety of computer-assisted teaching methods can be introduced at an individual pace and based on the experiences gained "along the road" – a policy which we claim to be indispensable if the fast-moving computer / networking technology and the slow-moving "teaching culture" (pedagogy, didactics, instructional sciences, …) are to be synchronized. By gradually adapting pedagogic / didactic concepts to the improved possibilities, the evolution process can keep pace with urgently needed feedback and evaluation. Such a "right-paced" smooth transition may include the following intermediate steps, all of which represent computer-aided teaching set-ups in their own rights (they are realized as different yet integrated components of the DLH hardware/software, each in turn consisting of several subcomponents; the detailed description of the steps equals components will form the core of chapter 2 and of the entire paper):

Step 1 - DigiMax: Computer-augmented frontal teaching is immediately available in the digital venues (same-time / same-place), providing a "Digital Audimax" setting (DigiMax for short) in the digital lecture halls DLH.

Step 2 - LearnerLoop: Cooperative learning can be introduced by offering mobile computing solutions for the learners in the audience owning portable devices

Step 3 - AfterHours: As mentioned already, "after-hours" i.e. asynchronous rehearsal is the first immediate gain if streaming servers are added and lectures are kept on-line for a reasonable time

Step 4 - NetExL (remote experts and learners): by hooking the digital venue in synchronous mode ("live") onto the Internet, both remote humans (e.g., guest expert teachers) and remote bits (data such as Web sites, code such as simulations, virtual Internet labs, etc.) become available. By mirroring the digital venue, distributed DLHs can be created, allowing distributed classes to follow a lesson. As streaming and eventually multicast support are added, individual distance learners may join in.

Step 5 - CourseLine: Taking different kinds of recordings (see below) as raw material, the AfterHours level of different-time/different-place learning can be furthered: raw material can be post-authored into valuable course material for rehearsal and/or self-paced learning.

As stated early on, the DLH project is based on the belief that current virtual-university projects focus on virtuality and virtual reality (VR) technology way too early in the development. However, this is not an argument *against* VR: as teachers and learners assimilate the subsequent DLH components listed above, the use of augmented and virtual reality becomes increasingly beneficial. E.g., given the high actual cost and short innovation cycles of laboratories in high-tech domains, wide-spread access to costly experimental facilities (be it virtual access to real labs or entirely virtual labs) can be considered a crucial element of educational systems in the future, with respect to both budgets and equal educational opportunities.

Considering the above list of items, three self-evident points must be kept in mind: i) the synchronization of the milestones with feedback from teaching experience is crucial for the success of follow-on milestones – neglecting this principle is the general misconception of today's virtual university projects; ii) there is a shortage of innovative appropriate pedagogic/didactic concepts and, along with it, knowledge about how to use the technology in a suitable way (for the example of video capturing during class, cf. the peephole-effect vs. multi-perspective video as discussed later); iii) once appropriate pedagogic/didactic strategies evolve, the concept will have to be re-iterated. Even the underlying computing technology will be exposed to new requirements; thus the work described here is not considered an ultimate solution.

2. The Digital Lecture Hall

2.1 Overview and Architecture

In the remainder of this chapter, the design and implementation of the Darmstadt Digital Lecture Halls will be described. This description follows the possible evolutionary steps (and hence, the above-mentioned components) that lead smoothly from "traditional teaching going digital" (DigiMax) to different kinds of Internet/computer-assisted teaching. In fig. 1, these steps are related to a taxonomy of computer-supported cooperative learning (CSCL), showing that DLH covers all relevant areas of CSCL.

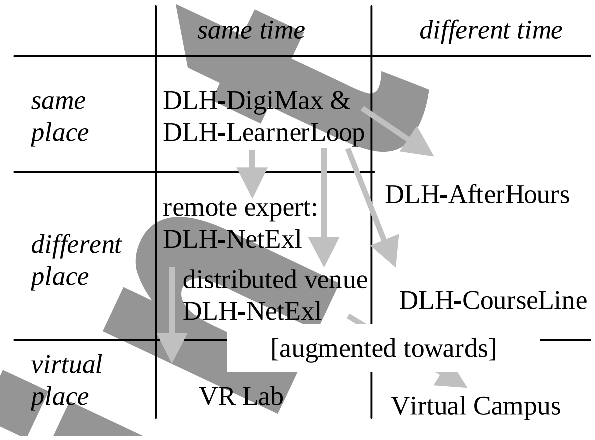

Fig 1.: DLH components related to CSCL taxonomy

A coarse architectural description of DLH is depicted in figure 2. It shows three basic layers of DLH, namely, hardware, components, and content i.e. course material. The hardware is further classified into four categories:

- Internetplus hardware i.e. Internet connectivity plus non common elements such as campus wide wireless connectivity and quality-of-service supporting routers;
- LearnerLoop hardware: handheld and laptop computers as described below plus local wireless connectivity;
- so-called learning appliances (cf. next chapter); and
- multimedia hardware for capturing / handling multiple media streams, see below.

The description of these components will be furthered only in the context of corresponding software functions. Among these, DigiMax is not only the first "step" of DLH use, it is also the "glue" for further components; in particular, most LearnerLoop functions are directly related to DigiMax subcomponents, and AfterHours is an extension to DigiMax for recording. NetExL extends the reach of DigiMax over the network and CourseLine accesses all other components. Fig. 2 also depicts a learner management system (LMS). Core LMS functions like firewall and group support are realized as part of the project, additional LMS functions are external to the DLH project. For the latter, DLH is prepared for integration with an external LMS. For the DLH implementations nearing completion or currently under way, the MTS2000 system [10] is integrated for learning management. For other projects planned, WebCT [21] and a confidential company proprietary LMS are considered.

The next four subchapters follow the stepwise approach of DLH components and provide more details about the respective subcomponents and functionality.

2.2 DigiMax: Traditional Teaching Goes Digital

DigiMax realizes those computer-assisted features of a large-size auditorium which are related to the tasks of the

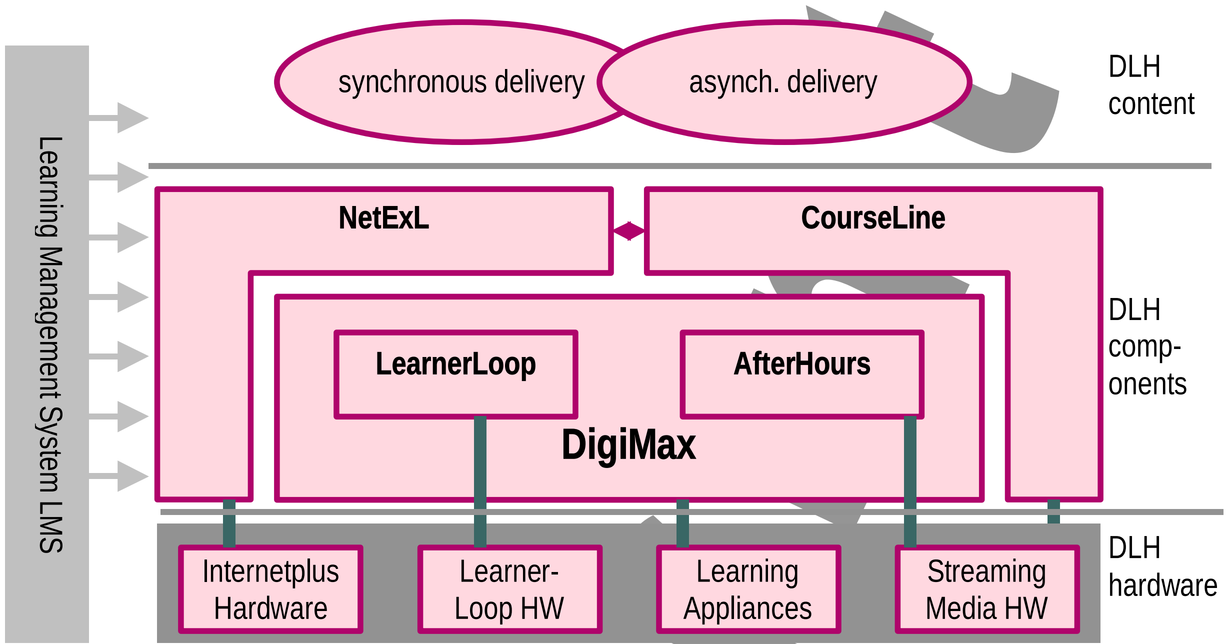

Fig. 2: DLH coarse architecture

lecturer. Thereby, minimal task change and minimal cognitive overhead are the key requirements for lecturers making the “analog-to-digital move”; lecturers already accustomed to computer-based teaching, on the other hand, should find maximum support for their advanced needs. The hardware setup comprises the following learning appliances – cf. fig. 3 and the top part of fig. 4:

- An electronic whiteboard (precisely, a SmartBoard™ manufactured by Smart Technologies as discussed, e.g., in [15][17]), rear-projected and mounted such that the auditory has maximum visibility and the lecturer has easy access (considering the other appliances he must reach, too).
- A pen-based LCD tablet positioned like an “analog” overhead projector; this interactive device is configured via DigiMax as an alternative to the SmartBoard at any time during the lecture; it can be configured such that either both devices display the same screen or the Pen-LCD-Tablet hosts additional functions not to be seen by the audience (room control, presentation control, previews, etc.). If using the tablet, the lecturer can more easily keep eye contact with the audience – a feature and aspect considered crucial by many teachers today and a main reason for many to move from blackboards to overhead projectors.
- An array of beamers mounted on the ceiling which are adjusted such that a large seamless display area is created; for the first DLH realization on campus, we used three beamers based on D-ILA technology in SVGA resolution (1024x768 each), yielding a display area of about 9 meters times 2½ meters.

All learning appliances are connected to a central presentation server located in the DLH. The software subcomponents of *DigiMax* comprise the novel *Virtual Multiboard VMB* and *ScreenRecorder* sub-components discussed below as well as less original subcomponents like *PresentationControl* and *RoomControl*, the latter of which is mapped onto the room control system (by AMX) installed in the lecture hall; these two rather straightforward sub-components will not be discussed here further.

Virtual Multiboard VMB: the VMB subcomponent is one of the two unique software-related features of *DigiMax*. Its design is inspired from traditional “analog” use of lecture halls – following the major DLH goal to assimilate such analog forms as much as possible. In traditional large audiences, lecturers will not use a single blackboard. For instance, university lecturers teaching mathematics are known to “consume” a handful of blackboards for a single proof. These multiple blackboards are usually all together visible to the audience – even for more loosely related series of blackboards, it is a key feature of the “teaching technology” that several blackboards “in the history” remain visible – e.g., in order for learners to quickly review this history (such re-iterations are proven to considerably improve retention rates) or as a buffer mechanism when students lack behind with their note-taking or re-reading.

In order to support this “teaching technology” on the digital side, VMB can be configured to hold a number of blackboards from “history” and to display them on the large seamless display realized with the array of beamers. Fig. 3 shows a configuration where VMB displays the so-called “backslide#0” in large size in the middle, “backslide#1" and "backslide#2" in quarter size to the right, and backslides #3 and #4 to the left (backslide#0 is the one actually displayed on the Smartboard and the LCD tablet; VMB may alternatively display backslides starting with #1 i.e. omit the actual one). Other configurations are possible, where "older" slides may or may not be displayed at smaller size. Part of the VMB display space may also be configured to hold the output of any other software such as the NetExL component which might project a remote expert, lab, or peer DLH. Note that Smartboards themselves can not be arbitrarily extended in size and/or height since their display is interactive i.e. must remain in the reach of a lecturer's hands.

ScreenRecorder: many TeleTeaching settings (cf. chapter 3) feature "electronic whiteboard" software (usually no SmartBoard-like hardware) that integrates recording functionality. Annotations made by the lecturer are recorded and can be played back during (asynchronous) rehearsal. In advanced settings, slide presentations may be uploaded to remote sites upfront and local presentation control as used by the lecturer is remotely mimicked to drive the pre-loaded presentations. Such approaches must restrict presentations to predefined formats (the ones supported by the specific software, e.g., Postscript™ or Powerpoint™) and restrict recording functionality to the "whiteboard scribbling". In our approach, recording is supported for arbitrary software and comprises both software I/O and annotations (added using, e.g., the SmartBoard™ annotation functionality). Note that arbitrary animations, dynamically created output, and output from remote software (cf. X11, RDP, or T.128 sessions) are supported and audio output is captured, too.

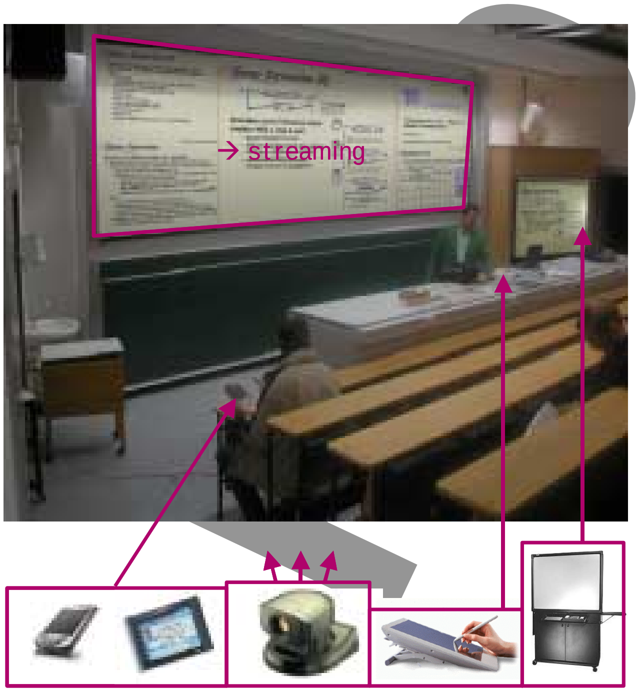

Fig. 3: Augmented photograph of DLH, showing a VMB display (red box), PTZ cameras and the learning appliances Pen-LCD-Tablet and SmartBoard™ (right) as well as the learner appliances PDA and WebPad (below).

In order to couple *VMB* and *ScreenRecorder*, a standard button or pen gesture or a software specific function (such as the "next slide" function in Powerpoint™) on the SmartBoard and Pen-LCD-Tablet can be configured such that the actual screen output is transformed into a snapshot which is handed over to VMB where it becomes "backslide#1". To take Powerpoint™ as an example, it may depend on the lecturer's "teaching style" or even on the actual situation whether she wants to create a new backslide just with each new slide projected, or at some key points within an animation (which belong to a single slide), or for the virgin and the annotated slide, etc.

VMB may display live output from arbitrary sources as discussed, but displays backslides only as static snapshots. In terms of displaying several backslides simultaneously during a synchronous lecture, this is obviously the only reasonable approach; imagine several backslides on display, all showing dynamic (e.g., animated) output – this would clearly distract the audience from the actual course of action i.e. from the actual display on the Smartboard and optionally shown in backslide#0 if correspondingly configured. We will describe the use of ScreenRecorder data in the AfterHourse component further below; in that context, the dynamics of the original output are conserved and can be reviewed (see section 2.4).

Lecturers who need or want to use their own equipment (e.g., a Laptop with a computer specific licence of a software to be shown) can either use T.128 (or another screen sharing software) with full DigiMax functionality or hook to a restricted version of DigiMax with no ScreenRecorder and limited VMB support.

2.3 LearnerLoop: integrating local learners

A major goal in DLH is the tight integration of learners into the digital teaching/learning process. This has been a goal in other projects as well, be it TeleTeaching setups or electronic classrooms; DLH emphasizes smooth evolution and large venues again in this context.

Teleteaching setups usually support audio connections to students for question-and-answer phases of the lecture; in this respect, the multiple pen-tilt-zoom (PTZ) cameras installed in DLH as well as the microphone / speaker installation – all described in the context of AfterHours and NetXeL below – provide already a level of sophistication that goes beyond common approaches.

Ambitious electronic classroom projects (see chapter 3) have equipped learner workplaces with computers which were carefully designed for integration in the computer-assisted teaching process; computer-equipped learner workplaces are central to DLH, too, but with three major differences:

Firstly, computer-equipped learner workplaces are supported and recommended, but not mandatory: use of video/audio communication is offered as an alternative.

Secondly, our years of experience with the electronic classroom "CCF" in Linz [14] brought evidence that computer-equipped learner workplaces may lead to learner distraction and social and cognitive disintegration of the class: quite often, the individual access and high degree of freedom provided by typical per-workplace user interfaces, together with the cognitive overhead and level of concentration required by that user interface, leads to a large number of individual "learning threads". E.g., some learners may go way back in the teaching "history" for rehearsal; a worse but very commonly observed example of distraction yields from the fact that learners who want to raise a question or issue need to interact shortly but intensely with the system in order to input their issue (while other learners do the same for a different issue); as one such issue is raised and discussed among the teacher and one learner subgroup, other learners still "prepare" their issue; once prepared, they have a high interest to raise their issue (in order for the preparation effort to pay off), but quite often this issue is orthogonal to the one currently discussed. For CSCW software and group meeting rooms, this observation (and other similar ones) has led to the recommendation to even avoid per-workplace computers. In our case, it has led to the "minimal distraction" requirement which materialized in the *TVremote* subcomponent of *LearnerLoop* described below.

Thirdly, In our vision of virtually every lecture hall of a university or organization being DLH-like, we imagine learners to come and go and to switch venues quite often; given the high level of deployment of mobile computing equipment among todays and tomorrows learners, it seems quite natural to support learner-owned equipment (the era of public ubiquitous computer notebooks laying around everywhere is yet too far out to be relevant for our project). This assumption has far-reaching consequences which make DLH much different from electronic classrooms again: i) the four categories of learner devices considered reach from SmartPhones via PDAs and WebPads to Laptops; ii) wireless connectivity is the only feasible connectivity approach for a number of reasons (e.g., this approach scales up to an online campus vision where students can access all kinds of resources on the move); iii) LearnerLoop has to accommodate a whole performance range with respect to both the learner device and the communication bandwidth.

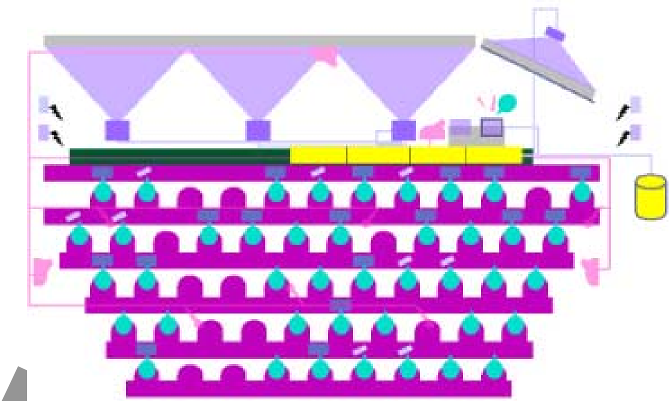

Fig. 4: Schematic drawing of a DLH configuration with Smartboard™, beamer array, and Pen-LCD-Tablet (purple, upper part); server and recording hardware (yellow); PTZ cameras and microphones (light pink); wLAN / PAN network and learner appliances

As to the hardware, the four device classes envisioned were mentioned above; the wireless network currently supported is an IEEE 802.11b standard wireless LAN (wLAN), to be complemented by a PAN (personal area network) standard in the future. For the sake of space, we can not discuss the rationale behind our networking choices in detail; to mention just a few considerations: PAN standards such as Bluetooth, DECT, and HomeRF emphasize frequency hopping (FHSS) transmission technology which is still maturing with respect to power constraints, scalability within a single venue, and performance; standards are competing and only about to settle, and device costs are not yet reasonable for a thousands-of-students scale. As of today, the use of public cellular networks (GSM, UMTS) is not cost-efficient. wLANs are still expensive to deploy, but e.g., at the time of this writing, PDAs with a CompactFlash slot and CompactFlash based wLAN cards are emerging on the market promising considerably lower prices; hence PDAs can be reasonably well supported.

Until a feasible and scalable wLAN / PAN approach is widely available, we have applied a policy at our department which successfully led to a high degree of wLAN connected student devices: we equipped DLH (and other venues on the campus) with wLAN access points and offered a complementary loaning program for wLAN PC cards; since most students in our department own Laptops but would not readily invest an additional (roughly) $200 for wLAN connectivity, this policy helped to boost wLAN usage; following positive experience, students tend to consider buying their own cards. In order to finance this policy, we redirected the budget for PC pool renovation; in turn, we encourage students to complement our pool PCs with their wireless connected laptops.

The *LearnerLoop* component is comprised of four major subcomponents as follows:

TVremote: as the name suggests, TVremote provides minimal functionality for the learner to "control" the digital lecture taking place. Following the minimal distraction requirement, the functions are usually mapped onto soft keys of the device, such that "pressing a single key" suffices for operation. The main function of TVremote is "tagging": by pressing a *tag* key on her device, a student expresses particular interest in the current phase of the lecture (she may either mark the beginning and end of a relevant section or indicate interest in "what the lecturer just said / presented"; in the latter case, the marker is set slightly back in time). Technically speaking, such tagging results in an entry in the student's personal annotation file which points at the audio/video/presentation recording (cf. AfterHours) centrally stored. In a future version of DLH, tagging will influence the "aging" process of the recording (depending, e.g., on whether or not a student copied the marked parts to her private workspace).

Another important *TVremote* function is "RaiseHand", a function which queues the student for question. The lecturer may (immediately or later) call upon the student using corresponding DigiMax functions; in the latter case, DigiMax calls VMB to display the backslide that was actual at the time of "hand-raising". While hand-raising is supposed to lead to immediate reaction by the lecturer for smaller audiences and local-only lectures, delayed calling-upon for questions is supposed to be common for very large audiences and distributed lectures.

Assignment: the *Assignment* subcomponent offers a standardized means for lecture-initiated interaction, task assignment, and exam. Questionnaires, assignments etc. are modeled by the system as computer-based forms. Customizing this model, the lecturer can, e.g., employ online questionnaires and exams during the lecture. These questionnaires can be simple yes-no questions or more complicated multiply choice, gap text, or free text question / answer forms. The lecturer may perform the evaluation right on the spot, defer it to a later time or delegate the work to tutors. Another option in the *Assignment* subcomponent is the ability for students to submit online questions to the lecturer. The related queuing and calling-upon functions for the lecturer are variants of those mentioned for *TVremote* above, but the submitted questions are displayed via VMB (instead of establishing an online channel to the student who called "raise-hand" as is the case with *TVremote*). An *anonymous* option exists for questions and questionnaires; anonymous participation is supposed to facilitate participation of students who are scared in open contradictions with the lecturer. Exams, on the other hand, are of course authenticated (tamper-proof authentication for official exams is still under development with our IT security research group).

The implementation is based on OpenSource technology (Cocoon XML-Server with an PostgreSQL backend; HTML-only or integration into a group annotation utility for Laptops, WebPads, and PDAs; a WAP version is prepared for future SmartPhone support).

ToGather: for a higher level of student involvement and for group work during lecture, we release the "minimal distraction" requirement in the context of the *ToGather* subcomponent. This subcomponent currently supports Laptops, WebPads, and PDAs, but not SmartPhones. Learners have the possibility to form (secured) groups and to perform group annotation. Their devices receive a live stream from the lecturer's input via *ScreenRecorder*. Learners can annotate this stream and see the annotations of other group members. Since local storage (e.g., on PDAs) is considered rather limited, these annotations are by default stored on the central server and related to the centrally recorded *ScreenRecorder* stream for *AtferHours* retrieval.

Upload: To prevent misuse of the network infrastructure, DLH is equipped with a firewall, which is part of the DLH specific LMS and allows access to be configured to the exact needs of different lectures. In this context, the *Upload* component provides learners with the possibility to access third-party virtual lab software during the lecture, based on access rights granted by the lecturer (Linux firewall software, Cocoon, PostgreSQL, LDAP, and Win32/WindowsCE are used as software platforms for the implementation).

2.4 AfterHours: Authoring on the Fly

Following the principles established by the "AOF" (authoring-on-the-fly) research group at the University of Freiburg, entire lectures are recorded and stored on the DLH server systems. In comparison to known AOF approaches, the DLH approach adds several unique features:

- ScreenRecorder captures arbitrary presentation software and courseware as described in 2.2; the time-dependent (non isochronous but event based) stream generated by ScreenRecorder is integrated with audio and video as described for the MediaCorder component below.
- MultiPerspectiveVideo is considered crucial, see below
- Teacher annotations, learner tags (cf. TVremote above), and learner annotations (cf. ToGather above) are all integrated with the recording and used by the Memorize subcomponent for a-posteriori functions.

The following hardware and external software is currently used in the subcomponents described below: a dual Pentium III 1Ghz based computer with 4 Winnov AV/PCI graphics cards running Windows2000™, RealProducer™ and RealServer™ software, 4 Sony EVI PTZ Cameras. The functions developed on top of this basis as part of DLH are briefly described in the context of the three *AfterHours* sub-components below.

The *MPV* (multi perspective video) sub-component follows observations first published by Ramesh Jain and used in his MPIvideo products [13]. In contrast to common practice for TeleTeaching, Jain advocates the use of multiple cameras. He refers to the cognitive process by which humans settle in an environment by subconsciously taking “snapshots” from different perspectives and view angles and points out that common practice for the transmission of live events (such as sports games) mimicks this human behavior by offering views from different cameras spread over the venue under different zoom/pan settings. He claims that most of the “uncomfortable” feeling expressed by remote lecture participants comes from the peephole effect, which in turn comes from single-camera transmission and which inhibits a comfortable level of telepresence impression.

In the case of DLH, our *MPV* subcomponent provides multiple (in the current implementation, four) camera inputs, all fed into MediaCorder as described below. Pan/tilt/zoom (PTZ) functions of the cameras are available via MPV software controls and made accessible to authorized personnel. A prototype automatic “PTZ & Cut” control software is available; this software takes over the PTZ functions if no human has control over it; it delivers a single audio/video stream (called MainStream) by switching between the cameras; the sophistication of both the automatic PTZ and the automatic cutting is planned to be considerably improved in the next DLH version.

MediaCorder: this subcomponent combines the four camera input streams, the *MainStream* (as a derived medium, see above), *ScreenRecorder* output, and optionally learner annotations into a so-called *LectureStream*. Student tagging and private annotations refer to the generic time-/eventstamp mechanism used for random access into the *LectureStream*.

Memorize: Currently, round-robin storage of *MediaCorder*-generated *LectureStreams* is supported: *LectureStreams* are usually kept for two weeks; interested students are supposed to copy interesting parts (usually, the *ScreenRecorder* stream plus selected audio and/or video clips) into their private storage (a more sophisticated “aging” policy is planned for future versions). In addition, *Memorize* supports functions for statistical analysis and relevance feedback, both automatic i.e. based on the statistical analysis and based on student ratings realized via the *Assignment* subcomponent of *LearnerLoop*.

2.5 NetExL and CourseLine

Since the NetExL and CourseLine components exist in prototype versions yet, their description will be summarized here with a lesser degree of elaboration.

NetXeL is currently realized as an outbound and an inbound subcomponent. The *Outbound* subcomponent makes the *MediaCorder* based *LectureStream* available on the network. Corresponding to the available bandwidth to the remote site(s), several Quality-of-Service options exist: for high-bandwidth access, e.g., on campus, the remote site receives all four video streams and may interactively control the preferred camera i.e. stream. For lower bandwidth, either the *MainStream* or no video stream at all may be selected. In future versions, continuous scaling and the integration with Internet-QoS research at our group are envisioned. The *Inbound* subcomponent places arbitrary inbound streams (camera input from remote experts, remote learners, or remote DLH sites) onto a VMB subscreen and optionally (via Upload) onto learner workplaces. Connections have to be manually set up (i.e. require human intervention), this functionality must be augmented for further versions; e.g., as the lecturer calls upon learners for Q&A (either following a *RaiseHand* command or an *Assignment* based submitted question), she is to be auto-connected to the VMB remote-learner-subscreen.

Within *CourseLine*, we explore two paths towards advanced teaching: i) the possibility to start from recorded *LectureStreams*, furthering the above-mentioned AOF (authoring-on-the-fly) approach; ii) the possibility to use the sophisticated DLH venue for a seamless introduction of advanced instructional strategies (for overviews, see [4,12,20,22]).

For introducing new pedagogic/didactic strategies, we start from the observation that novel computer and Internet specific teaching styles are still in their infancy, despite four decades of unsatisfying behaviorist-style courseware and three decades since Intelligent Tutoring Systems (ITS) came up. Therefore, we intend to work in a fairly experimental setup for several years to come, exploring novel approaches in the context of our lectures. The DLH *CourseLine* component emphasizes, as one of the goals, group- and network-centered asynchronous learning concepts which strengthen learner skills like autonomous knowledge working and responsible cooperation. The current experiments comprise, among others:

- the integration of applet-based simulation modules into the course of DLH based lectures (about multimedia communications)
- the use of (six) interactive games in the context of IT security related lectures
- the use of multimedia modules in civil engineering lectures, exploring flexible run-time adaption of the module sequencing policy to both different instructional strategies and different learner styles, based on the L3 authoring tool,
- the use of Web based open explorative group learning strategies, again using civil engineering subjects, in an attempt to teach “soft skills” like “Knowledge Working”, “Internet/Web Literacy” and “Group Working” as orthogonal subjects to the primary subject matter.

For all the experimental attempts described, we intend to distil methods, skeleton courses, and tools for widespread use of novel instructional strategies.

3. Related approaches

Related work has been discussed in the course of this paper. A few general observations and comparisons shall be added at this point, comparing DLH to electronic classrooms, to virtual labs, to virtual universities, and to teleteaching efforts.

Electronic classrooms: of course, the project reported here is not the first digital teaching venue ever built. For advanced examples, see [1,2,14,3,6]. However,

- other such venues were mostly built with only some of the above-mentioned milestones in mind
- even very advanced projects such as "Classroom 2000" at GeorgiaTech or the "Classroom-of-the-Future" project at the Ars Electronica Center in Linz, Austria (headed by the first author) are restricted to classroom size, i.e. some 20 or some 30 participants.

However, some key goals and concepts of these electronic classroom projects are common with those of DLH. As a consequence, tools developed in the context of these projects resemble in part those presented in this paper. As discussed in chapter 2, major differences between electronic classroom tools and DLH tools for synchronous delivery concern,

- the interactive presentation support: DLH-DigiMax supports the virtual multi-board VMB and arbitrary input from electronic Whiteboard and LCD tablet – such functions are not present in electronic classrooms – and
- the learner integration: DLH concentrates on supporting large numbers of students, on integrating a spectrum of learner-owned devices, and on minimal distraction; the former is not relevant in electronic classrooms and the latter two have not been a major goal in electronic classrooms yet (to the best of our knowledge).

Virtual labs have been mentioned as an ideal complement to DLH, their integration is supported via NetExL. Nevertheless, virtual labs remain an issue and pedagogical approach in its own right, focusing ubiquitous availability on one hand and experiment-centered learning (learning-by-doing) on the other hand. They span from remote access to physical experiments to true VR "lab spaces" [5, 7,11,16, 19]. As to university teaching and tertiary education in general, classroom based (and lecture hall based) lessons are usually rather decoupled from laboratory hours in present curricula. The integration of virtual labs with DLH offers a chance to reintegrate the theoretical and the practical side of the curriculum.

Virtual universities have been discussed several times in the present paper. DLH was positioned as an alternative approach in the sense that a smooth path from current to "digital" universities was proposed in contrast to the "leap" into virtual venues; on the other hand, it was discussed how virtuality can come in naturally as a (comparatively late) feature in the evolution steps of DLH: as virtual labs in the context of NetExL, as virtual university like features mostly in the context of CourseLine. At this point, it should be added that no commonly agreed definition of virtual universities exists and that other terms such as "corporate university" and "virtual campus" are used with an overlapping meaning. Some of the corresponding projects concentrate on organizational and management issues, the technical aspects of these are largely addressed by learner management systems like WebCT. Most virtual university projects offer on-line material for self-paced training – few of them go far beyond on-line versions of the lecture notes and/or classroom teaching material. True VR aspects are rarely addressed but if so, are very promising in the long run [18, 20]. The "right-paced" approach of DLH does not exclude or counter such efforts yet tries to offer a step-wise concept where virtuality can come in at the right time and for the right reasons.

Teleteaching: Lecture halls have been augmented with networking and computing equipment for teleteaching. Among the many setups and projects worldwide, only few are directly related to computer-assisted learning research and development activities like the activities at the Universities of Mannheim and Freiburg [8]. The work of these has brought forth a noticeable requirements document contrasting the status and vision of teleteaching [9]. This work also includes a description of the major scenarios to be supported, called 'remote lecture room', 'remote interactive seminar', 'interactive home learning', and 'individual learning with CBT'. The overlap of these goals and concepts with the DLH project are obvious, yet these projects have different foci, mainly i) the support of large remote groups via sophisticated multicast and adaptive video, and ii) the furthering of interactive whiteboard software (which has roots in the mBone tool wb and was furthered for teleteaching first in Freiburg, then in Mannheim, both in Germany; note that Unix workstations, not Smartboard-like devices, were targeted by these projects at the outset). Such aspects, which are at the core of computer-science related TeleTeaching research, are of course relevant for DLH, but not considered the primary focus. Rather, DLH concentrates on issues such as, e.g., large (virtual multi-board) projection and intuitive (multiple interactive device based) input (cf. DigiMax), minimal distraction and ease-of-use (cf. LearnerLoop), and maximum telepresence (cf. NetExL) – as discussed in more detail above. In a project just proposed to a national funding board, DLH and other German projects seek cooperation and mutual fructification.

In summary, the research domains discussed in this chapter are complementary to DLH in focus, partly even have a different world view (virtual universities), but all of them can be regarded as steps of the evolutionary process of digital lecturing proposed and supported in DLH.

4. Lessons learned and summary

Despite the many virtual university and TeleTeaching projects worldwide, many issues are yet to be resolved and many leapfrogging attempts may be questioned as to their sustainability and to their effect on the “masses”. The Digital Lecture Hall project described takes a step-wise approach and offers an easy start for ‘the average teacher and learner’ with virtually no need for behavioral change and with minimal cognitive overhead. The paper has introduced the major components which support these steps, called DigiMax, LearnerLoop, AfterHours, NetXeL, and CourseLine. It was shown how major known teaching and learning approaches can be accommodated by DLH. The first lessons were taught in the prototype DLH realization in summer 01. Although at the time of writing some subcomponents of the production version are still under construction, standard all-day DLH based teaching is planned to start in fall 01.

The state of the project may be considered a bit early for a discussion of lessons learned, yet a number of consistent and sound lessons can already be recorded. There have been quite a number of similar concerns that the very low “entry threshold” for lecturers might be a temptation not to change the teaching process at all. These concerns did not turn out to be justified: average lecturers quickly learn to appreciate the additional possibilities offered by a digital environment, such as the ability to mix prepared, pre-sketched, and empty slides at will. They will not switch to a different technology for technology’s sake or by curiosity, such as the “elite” gathered in virtual university projects – but this supports basic assumptions of DLH: virtual university projects are still too much “in vitro”, and teaching will only change on the large scale in the pace dictated by pedagogic / didactic improvements. All in one, the first lesions learned strongly support the assumptions made at the outset of the DLH project.

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