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The *Interactive Lecture*: Teaching and Learning Technologies for Large Classrooms

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The *Interactive Lecture*: Teaching and Learning Technologies for Large Classrooms

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Abstract: Conventional lectures in large classrooms are connected to fundamental didactic problems due to a lack of interactivity and feedback opportunities. In an *interactive lecture* each student is equipped with a light-weight, mobile device that can be used to interact with the lecturer during the lesson, thus creating an additional channel of communication. These devices support new teaching and learning paradigms such as participatory simulations. In this paper, we present our experiences with the usage of mobile devices in lectures. After discussing the didactic benefits of interactive lectures, we introduce the software toolkits used in our scenarios, we highlight selected tools like a quiz tool or a support tool for participatory simulation, and present major results from six studies we have conducted.

Keywords: interactive lecture, participatory simulation, blended learning, ubiquitous computing

INTRODUCTION

Many new approaches based on emerging computer technologies were presented in recent years which support the learning of students in lectures. The aim of these approaches is the improvement of the quality and effectiveness of university teaching by using multimedia elements. With the help of appropriate new media teaching and learning procedures it is expected to achieve a better adjustment to individual learning needs, learning rates and time budgets of the students. For the instructors, a better flexibility of teaching is intended.

But despite the various multimedia projects and efforts on the part of dedicated instructors, the introduction of educational media only partially led to a modernization of the actual teaching scenarios. This is particularly evident when looking at the classical university teaching-learning scenario: the classroom lecture. Lectures in universities have profited from many technical advances over the last few years. Blackboards were replaced by overhead projectors which again were substituted by video projectors and electronic whiteboards (Geyer & Effelsberg, 1998). Most lecture halls nowadays are equipped with computers as well as video and audio systems, allowing the integration of every possible type of media into the lecture.

However, the basic teaching paradigm has remained largely unchanged throughout this time; one of the few exceptions are the scenario of the telelecture (e.g., Datta & Ottmann, 2001) or digitally recorded lectures (Zupancic & Horz, 2002). The main disadvantage of traditional lectures is the lack of interactivity: they can be characterized as situations in which a teacher presents new information to the learners without guiding their learning processes. The limited interaction possibilities in lectures cause a set of problems regarding students' attention and motivation, as well as a lack of quick adaptation of the lecturer's instruction.

Lecturers often attempt to overcome these problems by asking questions to trigger feedback on how well the students have understood the presented material, as well as to provoke them to actively participate. In lectures with a large audience this fact is problematic since only a few students are able to interact with the lecturer. The overwhelming majority will not profit from this form of interactivity. Additional problems arise if the lecturer wants to get feedback on how the lecture is accepted by the students, and what he or she can do to improve it. In lectures with a small audience the teacher can typically deduce this information from the students' reactions, e.g., looking bored. In large classrooms such information is usually gathered by handing out feedback questionnaires at the end of a lecture period. Unfortunately this approach is rather imprecise and does not allow the assessment of individual elements contained in a lecture. Furthermore, it is not possible for the lecturer to quickly react to problems.

Another form of interactivity are questions that are asked spontaneously by the students. This is difficult in large lectures. First of all, not all students are able to ask questions because of time constraints. Secondly, many students do not dare to ask questions in front of a large audience. Finally, if students can pose questions only at certain times, they will be out of context when finally speaking up. All these problems cause many students not to interact at all during the lecture.

Thus, despite the possible use of different media to illustrate the topics of the lecture, interaction is hardly possible in large classrooms. The resulting uni-directional communication leads to several motivational and cognitive problems:

From a pedagogic-psychological view, learning (in lectures) should be reconstructed as an active process (see e.g. Ernest, 1995; Jonassen, 1994; Honebein, 1996; Wilson & Cole, 1991). Interactivity represents an opportunity for the learner to take hand in shaping the informational, communicational and learning process rather than remaining a passive recipient. Thus, an active involvement of the learners has a great impact upon successful learning (Ramsden, 1992). As far as the learning success in lectures is concerned, empirical results state that lectures are not generally ineffective but not suitable for a global knowledge transfer (see for an overview Gage & Berliner, 1996; Peterson, 1979).

Directly connected to the problem of low interactivity is the lack of adaptivity of the teacher's behavior: During the lecture the instructor can only adapt a limited amount of contents or topics of his lecture to the learner's state of knowledge. On other hand, adaptivity is an essential tool in the instructional context to improve the learning process. The underlying rationale is to adapt explanations or curricula to the learners' current state of knowledge and attention, and thus to achieve greater efficiency and efficacy of instruction. Empirical findings reveal the effects of diverse learner-centered measures upon learning success (Sass, 1989; Cronbach & Snow, 1977; Bligh, 1971).

Finally, a fundamental problem in traditional lectures is the required continuous attention of the learner over 60 to 90 minutes. Usually, the attention span of a learner is only about 20 minutes (Smith, 2001). Subsequently, an activity change should take place in order for the students to keep their attention up (e.g., a change between lecturing and discussion phases). Studies show that a decreasing mental performance is responsible for the inferior knowledge acquisition (e.g., Siegel, Siegel, Capretta, Jones & Berkovitz, 1963; Bloom, 1953). However, in the traditional large classroom scenario, such activity changes are rare, and if ever done, the lecture elements depend exclusively on the specific ability of the lecturer (Ramsden, 1992).

But despite these didactic shortcomings, the classroom lecture still is an important and common teaching scenario since it has also advantages compared to other settings. Especially important is the economic aspect: Only in lectures an individual lecturer can impart knowledge to a large number of students at the same time. Furthermore, the classical teaching form is technically flexible and therefore easily adaptable to different audiences, topics, timetables and available technical devices. Also, a flexible integration into the curriculum without careful planning can be realized, which would not be possible with e.g. book-bound material.

We conclude that there are strong reasons to work on the improvement of the large-classroom scenario, in particular to create new (more interactive) version.

An innovative approach to improve interactivity and to realize a bi-directional, synchronous communication in lectures is to equip the students with small electronic devices such as handheld computers. To avoid cost-intensive modifications of the lecture hall, the handheld PCs and the server are connected by a wireless LAN. The handheld devices communicate with the computer of the lecturer and thus allow exchanging information with the lecturer at any time, without disturbing the lecture. The type of information exchanged can be arbitrarily complex, ranging from a simple "virtual hand raising" over detailed feedback to quizzes that may even be counted towards the grades of the students.

It is not only important to increase the communication between teacher and student, but it is also desirable to increase the activity, motivation and attention of the students. A *participatory simulation* is a new didactic concept, enabled by handheld computers and wireless communication, where students take an active role in a computer-based simulation. A dynamic and complex problem of the real world is mapped to a simulation model. The model is implemented in software on the computers. Students observe that system in the classroom and make decisions; they actively discover and understand the impact of their activities. They learn the processes of complex systems in the simplified model of the simulation.

A major advantage of participatory simulations is the fact that the level of activity of the individual can be high even in large groups. A teacher starts with an introduction and explains the relevant theory of the complex problem. The students understand the possible activities available in the simulation. The exchange of experience and a discussion in small groups within or after the simulation help to inprove the understanding of the simulated system. Short simulations with a duration of a few minutes can be integrated into a lecture, but it is also possible to start a simulation at the beginning of a term and work with the same simulation for several weeks. The students choose their time to participate and the teacher discusses and visualizes specific features in the lecture.

Two departments at the University of Mannheim (Computer Science and Educational Science) are conducting the *Lecture Lab* project (Lecture Lab, 2004) to create a new form of multimedia-enhanced teaching along these lines: the **Interactive Lecture.** We have designed and implemented a full-featured software system and performed several major field studies to evaluate our concept. We work in close cooperation with the *Stanford Center for Innovations in Learning* in Palo Alto, California.

In this paper we describe the possible use of mobile devices in large learning environments, present the scenario of the Interactive Lecture as well as our own technology called WIL/MA (Wireless Interactive Lectures at the University of Mannheim). We illustrate how participatory simulations can support the teaching and learning and give an example of a stock exchange simulation for master's students in financial theory and a Internet packet routing simulation for students in computer science. We then discuss the results of two detailed case studies conducted with graduate students, focusing on the comparison between the use of PDAs and notebook PCs. We finally give an overview of the results of six experimental field studies which we have carried out in lectures of computer science and educational science in order to investigate the motivational and cognitive effects of our new teaching-learning-method.

MOBILE DEVICES IN LECTURES

A number of projects focusing on using mobile devices in lectures in order to enhance learning and teaching have evolved over the last few years. Most of the projects have specific ideas about what aspect of the lecture they intend to improve and how to cope with arising problems. Following is a short list of past and ongoing projects, along with a short description of the basic ideas behind them.

Classtalk (Abrahamson, 1999, 1998; Webking, 1998; Dufresne, Gerace, Leonard, Mestre & Wenk, 1996) is a well-known Classroom Communication System by Better Education Inc.. For the better involvement of every single student, the teacher "beams" three to four Classtalk tasks per lesson to the students' devices; these can be calculators, organizers or personal computers, and they are often owned by the students. A "task" can be anything from a simple question to a midterm exam, from a group exercise to a survey of class opinions. The results are displayed immediately on the teacher's notebook PC; the teacher can either keep them confidential or show them to the class. The class sessions can be archived for review, and can be analyzed and compared to other sessions. Additional features include feedback (from the teacher), tests and grading.

ClassInHand from Wake Forest University turns a PDA equipped with a wireless card into a web server as well as a presentation controller and a quizzing and feedback device for the lecturer (ClassInHand, 2004). Its major components are the Presentation Control and Web Server for the PocketPC. The clients need only a web browser. The Presentation Control allows remote control of the Powerpoint slides on the lecturer's PC. It also gives him the possibility to forward the quiz results to the class. The Web Server enables concept tests (quizzes), textual feedback, a feedback meter and easy document posting. The quiz feature enables the teacher to present a question with up to four answers and to view the results immediately on his/her PDA. These results can also be forwarded to the students' devices. The textual feedback component allows students to send their questions directly to the teachers PDA. Finally, the feedback meter enables students to submit numeric responses (range: -10 to 10).

Frequent key clicking can cause significant distraction in a lecture hall, in particular when the students annotate slides during a lecture. For this reason, the *"Classroom 2000"* project at Georgia Institute of Technology (Abowd, Atkeson, Feinstein et.al., 2000) decided not to provide the students' PDA's with a keyboard interface for note-taking at all, but uses a pen-based technology instead.

ConcertStudeo, a project of the Fraunhofer Institute *IPSI* uses an electronic blackboard combined with handheld devices (Dawabi, Dietz, Fernandez & Wessner, 2003). It offers exercises and interactions such as multiple-choice quizzes, brainstorming sessions, queries or role-plays. During a lecture, the teacher introduces the exercise and the learners enter their answers into their handheld devices. The collection, analysis, and presentation is done by the software.

Specifically designed for online feedback is *CFS* (the Classroom Feedback System) from the University of Washington (Anderson, Vandegrift, Wolfman & Yasuhara, 2003). It allows students to post annotations directly on lecture slides. The lecturer sees the annotations in real-time. The students use their notebook PCs to generate their feedback by clicking a location on a slide and selecting a category from a fixed menu (such as "more explanation", "got it", "example"). The teacher's screen shows the number of feedback requests for each slide, and shows the aggregated feedback with a shaded dot for each annotation at the actual presentation slide, The slides depict categorical information by color (e.g., red for "more explanation") and the slide context by location.

A different approach to improve the learning success and the motivation of students is based on *participatory simulations*. The idea to study complex problems of the real world is part of the system dynamics or system thinking research (Chen & Stroup, 1993; Senge, 1990). A participatory simulation is a role-playing activity that helps to explain the coherence of complex dynamic systems. Global patterns emerge in participatory simulations from local interactions of users. New teaching methodologies like participatory simulations are required because most students have problems in understanding the behavior of complex dynamic systems (Kahnemann et al., 1982; Mandinach & Cline, 1994; Resnick, 1995).

A major idea of participatory simulations is the concept of learning through doing. It is strongly related to role-playing games which have been used in many disciplines (Resnick and Wilensky, 1997). Students participate in an active way, analyze available information, make decisions, and see the outcome of their actions. This increases the motivation, and the learning success improves (Kafai and Resnick, 1996; Papert and Harel, 1991). Another goal of participatory simulations is to encourage creative thinking (Asselt et al., 2001).

Simulations were realized with paper and pencil in the past, but the technological advances now allow a new type of simulation. Hardware devices were developed to support participatory simulations. A physical interface called *System Blocks* (Zuckerman & Resnick, 2003a,b) was developed for young children to get a first understanding of dynamic systems. Each block is made of wood, contains some electronics and has a specific functionality (e.g., it plays a sound). The blocks can be connected with other blocks, and it is possible to create dynamic systems (such as a feedback loop) by connecting only a few blocks. Another participatory simulation is based on the so-called *Thinking Tags*, small name-tag sized computers that communicate with each other (see Andrews et al., 2003; Borovoy et al., 1996; Colella et al., 1998). A tag communicates with other tags, exchanges data and can visualize similar preferences of two persons.

Early software-based simulations were implemented with *Stella* (Roberts et al., 1983) or *StarLogo* (Resnick, 1996, 1995). *NetLogo* (Tisue and Wilensky, 2004a,b) in its current version 2.1 is a mature environment for the development of participatory simulations for PCs. A major advantage of this technology is that simulations can be re-played, analyzed and compared with previous simulations. With the rapid development of networking technologies, the NetLogo system was extended to support the participation of several human players. The extension is called *HubNet* (Wilensky and Stroup, 1999); it supports PCs and mobile devices for input and output. Mobile phones can also be used for participatory simulations (Lonsdale et al., 2004). Special channels for the communication are text messages triggering events or giving additional information. A typical example of a simulation that was developed with Net-Logo/HubNet is called "Gridlock" (see Wilensky and Stroup, 2000), it simulates the traffic situation in cities. The goal is to understand the complexity of traffic, the cause of traffic jams or accidents, and the effect of traffic lights.

Besides the education of students, participatory simulations were used in software engineering to support the development of complex software systems (Ramanath and Gilbert, 2004). In these experiments, the end users of the system were much more involved through all phases of the software development process.

THE WIL/MA SOFTWARE

As discussed above, there are many different ways to take advantage of mobile devices for improving interactivity in the lecture hall. Most of the earlier work has focused on specific issues, such as quiz only, online feedback only or annotations only. Furthermore, the software is often designed to run on a particular hardware device. Our software tools attempt to solve these problems: the same basic software architecture can accommodate many different interactivity services ranging from quiz tools to participatory simulations. Our system is written in Java and portable to almost all modern mobile devices.

System Architecture

The WIL/MA system is designed as a classical client/server application (see Figure 1). As the central part of the architecture, the server provides all the fundamental functionality: management of the connections, users, and services. *Connection management* establishes connections to the clients upon request, processes incoming and outgoing data, and monitors the registered connections for broken links. *User management* identifies individual users via password and stores personal information for internal and external use. *Service management* dynamically loads a requested number of plug-in service modules, informs clients about the availability of certain services, and controls the data flow between the services within the server structure itself and between clients.

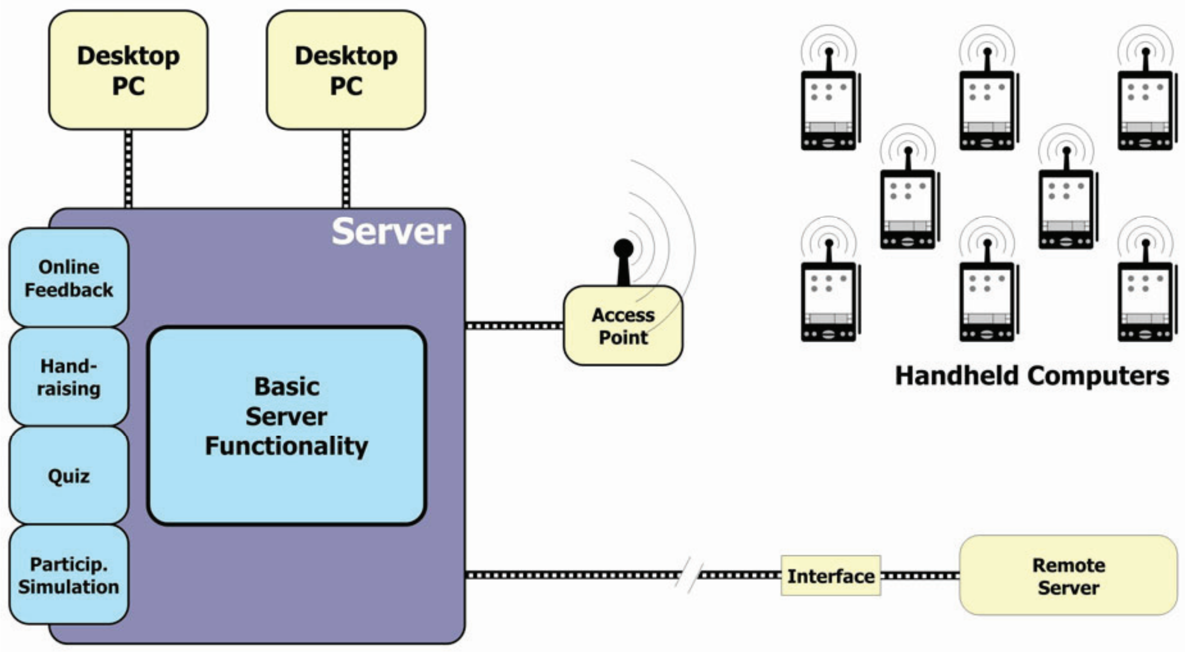


Figure 1: The WIL/MA architecture

All functionality which is visible to the users is bundled into services. Services are built as independent modules which are loaded by the server and the clients at start-up time; for each service there is a server-module, a teacher-module and a student-module.

The server-modules are the central part of a service. They have to aggregate all incoming data, analyze the information and broadcast trimmed data packets in various ways back to the teacher and each individual student. A sophisticated messaging system to do this is provided by the server software. All other modules are loaded into the clients of the students and the teacher. While the teacher-module focuses more on editing various aspects of the service as well as the display of analyzed data, it is more important for the student-module to display prepared material appealingly and to provide an intuitive user interface.

The client for the lecturer runs on a machine typically connected to the server via a wired network, all other clients use the wireless LAN to connect to the server. By means of interface utilities, multiple servers can be connected to extend the range of an interactive lecture to other lecture halls easily without overloading the network in between. It is also possible to create interfaces to other similar software systems to share data of common services.

Beside the already discussed functionality, the server software also provides several tools to easily manage a larger amount of students' devices. The two most important features are a DHCP server, allowing the configuration of all network related parameters centrally, and a Java class server. Thus, only a very small footage of classes has to be installed on the students' computers and all other classes are loaded automatically at start-up. The class server can also be used to update all mobile devices when the software is changed (e.g. new releases, updates).

Implemented Services

Several services are implemented so far, e.g., a quiz tool, an online-feedback tool and a call-in tool. Participatory simulations are supported with the WIL/MA system, too.

The *quiz tool* allows the teacher to pose questions (that possibly include graphics or animations) about actual lecture contents and “beam” them via wireless LAN to the audience. The students work on them and send their answers back to the lecturer’s computer. After a timeout, the cumulated results are presented graphically on the projector. In this way the lecturer and students gain a representative feedback on the newly acquired knowledge. Apart from two different multiple choice question styles (only one correct answer, multiple correct answers), we integrated other optional question types into this service, which can be automatically analyzed. To give some examples: Clickable images can be used to ask the student to point into a certain area of a picture as an answer (for example: "point at the location of Moscow on a map of Russia").

Fill-in questions make it impossible for the student to accidentally guess the right answer of a mathematical exercise.

The *feedback tool* delivers direct and systematic feedback to the lecturer about different aspects of the lecture from all students, who can then instantly adapt his/her presentation style to the new situation. An aspect – or category – could be the speed or the level of the lecture, so students can ask the teacher during the lecture to progress more slowly or discuss a certain topic more detailed. Also, technical issues can be used as a feedback category; for example, video or audio distortions in telepresence scenarios can be discovered much sooner or the students can be asked to complain, when their learning environment is suboptimal (because other students are too loud in the last rows or bright sunlight makes it impossible to read the projected lecture slides).

The call-in tool forwards spontaneous text questions to the teacher at any time during the lecture. The questions are stored in a list and can be dealt with in three ways: Using the software, they can either be answered individually, or the answer can be sent to all students if the question is of general interest (of course, the anonymity of the original student is maintained). In these cases, FAQ lists can be created, which are then put on the Web for the next generations of students. The third way is to integrate questions or remarks from students into the lecture. A selection of screenshots from the teacher's client as well as from the students' client can be seen in Figures 2a-e.

Group Support

From the software engineering perspective, there are three types of group support to be considered in an interactive lecture: device sharing, working groups and distributed working groups.

Device sharing is particularly interesting in lectures, where many students want to participate but only a limited number of devices are available. In this case, the software could allow multiple students to log in and then select their name before accessing a certain service. This way, each student in a group still acts as an individual from the server perspective. In quiz rounds, for example, the students could work on their answers on a piece of paper and then use the device only to send these answers to the server. The ConcertStudeo software is one of the few projects supporting device sharing.

Most projects - including WIL/MA - do not, because of some severe problems of device sharing (e.g., the second student in a row can easily copy the answers of his predecessor). Furthermore, the second type of group support is an easy but feasible alternative: A group of students collaborates using a single device. The software has not to support this explicitly, because there is little difference between a working group and an individual student when using only one log in.

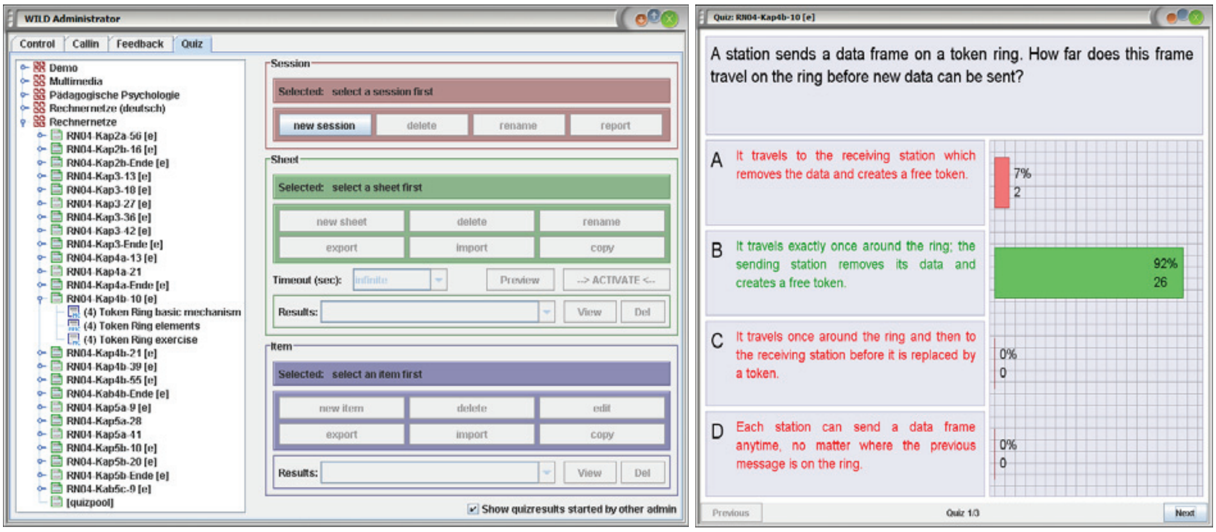
The third type of group support is much more interesting, because it offers a wide range of possibilities. In this scenario, students are able to form groups or are put into groups, but still have their own individual device. This way they can still act individually in some services (feedback or call-in). In other services (quiz or online brainstorming, for example) the individual input is specifically aggregated by the server to form a homogenous group input.

By this technique, it is possible to form groups over wide distances, between students who don't know each other, or in crowded lecture halls, where group members can often not sit next to each other. The group building process is also much more interesting: students can advertise their skills in a list, and can be invited by a group that is missing these skills. Or groups can be formed automatically, using various heuristics, thus bringing together students of equal or complementary knowledge.

Obviously, this kind of group support has high demands on the software system. First of all, the students in a group have to be able to communicate. The communication must be easy to handle, must not disturb other students and should be blended into the standard screen of the service as much as possible. During a quiz, for example, the students would see little colored dots next to the answers which their fellow group members think to be correct. The brighter the dots are the more confident is that group member with his or her selection. Whenever there is a disagreement, the students can switch back to a VoIP or chat screen to discuss the final answer.

Handling unresolved disagreements is a second demand on the software. The single analysis step of a system that only supports individual input has to forego a pre-analysis step, where heuristics decide the final input of a group in case of discrepancies.

Figures 2a, 2b, 2c: Screenshot of the students' client showing a quiz, feedback and call-in



Figures 2d, 2e: Screenshot of the lecturer client and a typical quiz result

Support of Participatory Simulations

A participatory simulation follows the general structure of the WIL/MA system and therefore provides server and client functionalities for students and for the lecturer. The task of the teacher is to configure the general simulation, e.g., in case of a stock exchange simulation to define data such as market information or securities. The main menu of the stock exchange module of the lecturer is illustrated in Figure 3. On the left-hand side, the available companies and securities are depicted. The right-hand side provides the lecturer with the sub menus to create new companies or securities, or to modify existing ones. This menu cannot be accessed during a running simulation to avoid data inconsistencies. Instead, a smaller interim menu is made available so that the lecturer can modify market and company data to make index or security prices move into a certain direction. Optionally, a message can be broadcast with a modification which informs the participants about market or company news. In that way, the students can immediately see the effect of the new information on the security prices. Figure 4a illustrates possible modifications for companies.

The WIL/MA server accepts requests from any number of participants and lectures. By starting the simulation, a server process is initiated which is responsible for simulating the stock exchange based on the configuration parameters. During the simulation, the server repeatedly computes new market data and security prices.

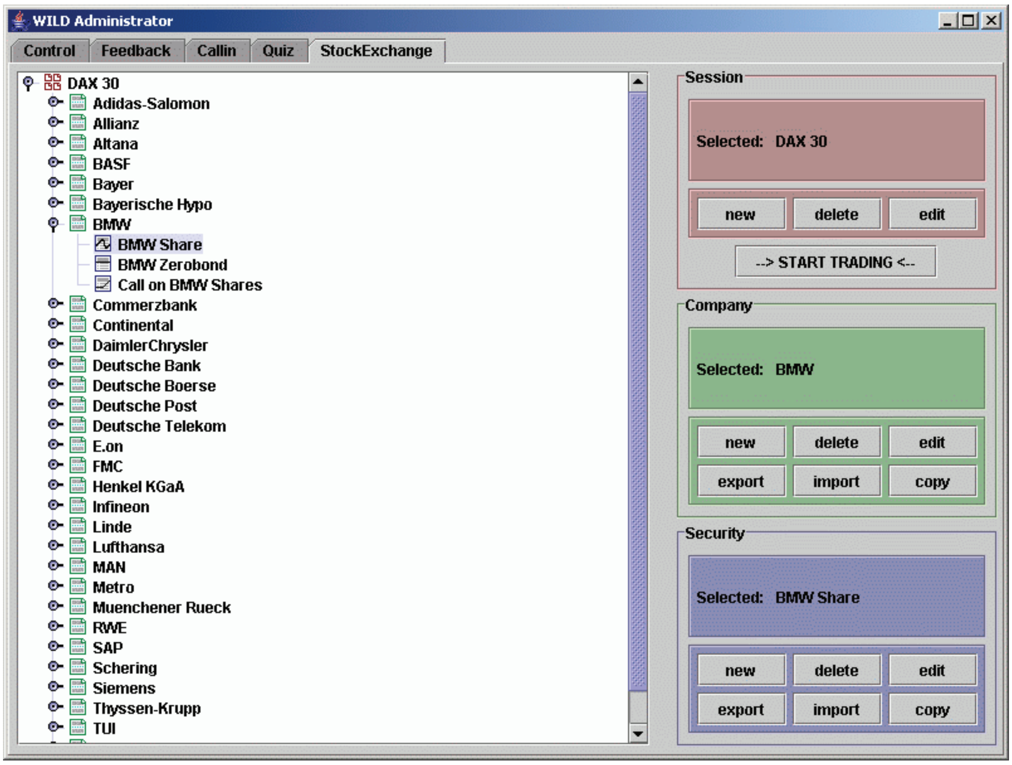


Figure 3: Example of a participatory simulation: lecturer screen of a stock exchange

The client provides an interface that allows the users to act as private investors. Figure 4b shows the basic client menu with all the available options. Viewing the account balance, users can see the amount of cash and the list of securities in their portfolio, including the number of stocks and their total value. In the account statements, all the security transactions are listed, such as orders, dividend or coupon payments and maturity payments. The market information option provides the user with all the information available about the market, specific companies and their associated securities. The information given should be the basis for the order decisions of every user. The students can decide whether to buy or sell a security. If all order data is correct and the server accepts the order, the transaction is performed.

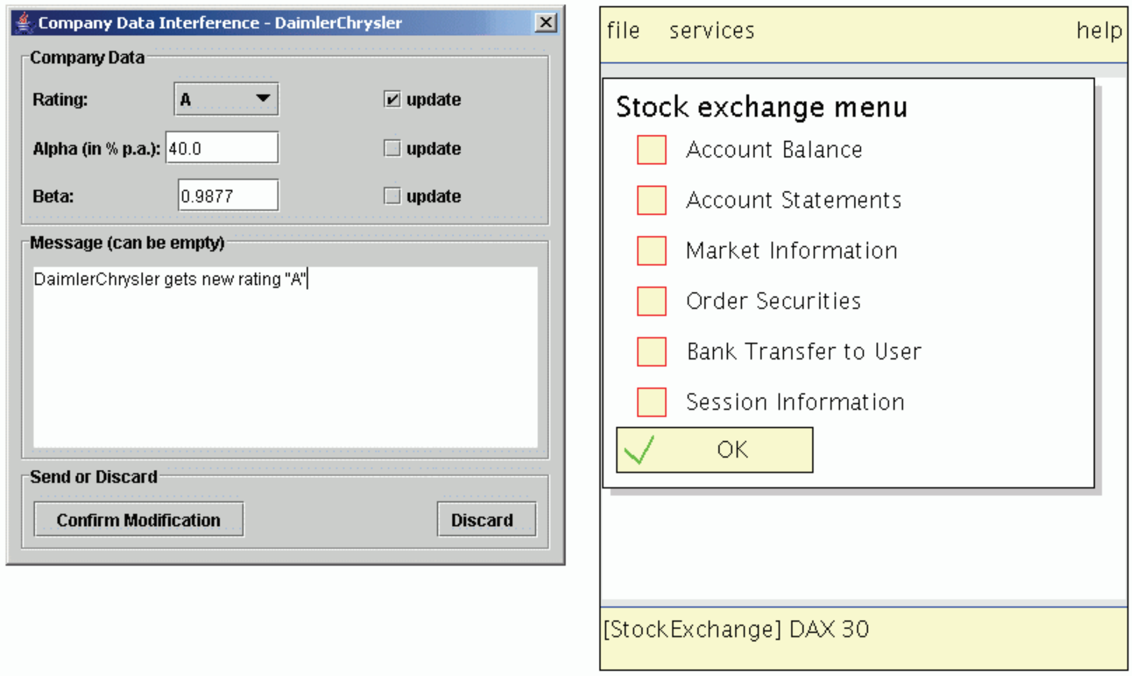
The idea of bank transfers is to introduce a group component to the simulation. By permitting bank transfers to other users, it is possible to play in teams: the players try to maximize the team's performance, not necessarily their individual portfolio value. By limiting the tradable securities for specific users, team play can be forced. This can be done by a risk class setting associated with each security as well as a maximal risk class for each user. At the end of the simulation, a ranking is sent to all users, showing all participants with their current portfolio value. The economic competition is a major motivating factor for the students.

Using the Tools in an Interactive Lecture

To dispatch an interactive lecture, only three devices are needed: A single wireless LAN access point is usually sufficient to handle the connections of more than 100 students. The server software can be run on any computer running Java; a standard notebook is sufficient. This computer is usually used for the teacher software as well. Finally, a data projector is needed to display the aggregated results of several services (primarily the quiz service) to the audience.

Since many modern lecture halls are already equipped with projectors or large-screen monitors, all the equipment needed for the Interactive Lecture fits into one notebook carrying case. It is usually installed and started in less than 5 minutes before the lecture begins.

Of course, it is quite time consuming to hand out dozens of PDAs to students who do not own a mobile device. This requires some assistance, but in our experience, the students are quite disciplined, and the devices are treated very carefully. In the future, we expect that more and more students will own a PDA or Java-enabled mobile phone, or would like to use their notebook computer in the lecture anyway; it is likely that having to hand out large numbers of mobile devices will not be an issue anymore in the very near future.



(a) Company interference (b) Main menu of the client

Figure 4: Interface of the participatory simulation with WIL/MA

Once the software is started, the students begin to login. In our case, the services *feedback* and *call-in* are started right at the beginning and are thus accessible continuously. Quizzes are scheduled approximately every 30 minutes. In our 90-minute interactive lectures the students thus had two breaks for the quiz rounds. A good practice may also be to start with a short quiz to see what the students have learned in the last lecture. The quiz questions are prepared before the lecture and "beamed" to the students at an appropriate time during the lecture. Depending on the difficulty of the questions, the students are given three to five minutes to answer them; the discussion of the results usually takes another five minutes.

The teacher introduces the relevant theoretical parts before the start of a *participatory simulation*. The students should understand the problem at hand, and the capabilities of the software. Like the quiz, a participatory simulation may take only a few minutes. Additional time should be reserved after the simulation for analysis and discussion. It is also possible to start the simulation at the beginning of a term and use an ongoing simulation for several weeks.

The results of all services are stored on the teacher's machine in a portable XML-based format so that the teacher can analyze the information he or she was not able to grasp during the lecture any time later.

Choosing the Best Device

In our experience, the best devices for the Interactive Lecture are modern, light-weight notebooks (alternatively TabletPCs) and PocketPCs. Notebooks are capable of running almost all software designed for modern computers. Unfortunately, in an interactive lecture, they are almost too efficient, leading to distraction of the owner and the students in his or her vicinity. On the other hand, they can be used for more sophisticated group exercises, e.g., working with applets that need a large screen.

PocketPCs are favored by most students because they are very small and easy to carry, and do not take up as much table space as a notebook computer so that printed scripts, etc. can still be used. Also, they are very unobtrusive and usually do not lead to distraction in any way.

Although often praised in the literature, we think that mobile phones are not ready yet to be used in interactive learning scenarios. Featuring only very small screens and either very expensive or very limited connectivity, today's mobile phones can only be used for the most basic services. We expect that this will also change in the near future, as cell phones and PDAs are merging rapidly (for a more detailed discussion, see Scheele, Seitz, Effelsberg & Wessels, 2003).

EXPERIMENTAL FIELD STUDIES AND EXPERIENCES

We have conducted six experimental studies in order to investigate the effects of mobile devices in lectures with respect to motivational and cognitive impact. Four of the studies were carried out in computer science lectures and two in educational science lectures. A sixth study (in educational science) is still running. We now give an overview of the results.

Interactive Lectures in Computer Sciences

At the very beginning, a test trial of the interactive lecture scenario was carried out in the winter semester 2001/2002 (Wessels, Fries, Horz, Scheele & Effelsberg, submitted). In an experimental study a first prototype of the WIL/MA tools was technically and empirically tested in a computer science lecture by comparing two wireless LAN-supported sessions with two conventional lectures of the same topic. The 44 students of this lecture participated in an interactive and in a conventional lecture session, and the groups were compared with respect to acceptance of the teaching method and success in learning. Regarding the acceptance, the interactive condition was evaluated significantly better than the conventional one. Besides, students reported higher levels of assumed attention, activity and estimated learning success in the interactive condition. Objective measurements indicated better learning results in the interactive condition, though the values fall just short of significance. And finally, there was no measurable distraction in the interactive lectures. Overall, the results were very encouraging.

As the next step, in summer semester 2002, a long-term integration of the system was realized as well as an application of the scenario within a tele-lecture (Scheele, Mauve, Effelsberg, Wessels, Horz & Fries, 2003). The computer science lecture was transmitted as an MPEG-stream via the Internet to a lecture hall at another German University. Just like the students in Mannheim, the students at the remote location were included into the scenario and the study. The lecture was split into a conventional and an interactive phase, the latter consisted of eight consecutive sessions. For all 99 students the acceptance of the two teaching methods and their learning increases were quantified. We could replicate the good acceptance scores of the first study: again, the interactive sessions were rated very well and were superior in their acceptance compared to the conventional lecture. Regarding the knowledge acquisition in the respective lecture, the use of the interactive elements/tools had a highly significant effect: The participants in the interactive lecture had a higher and also faster learning success (see Figure 5).

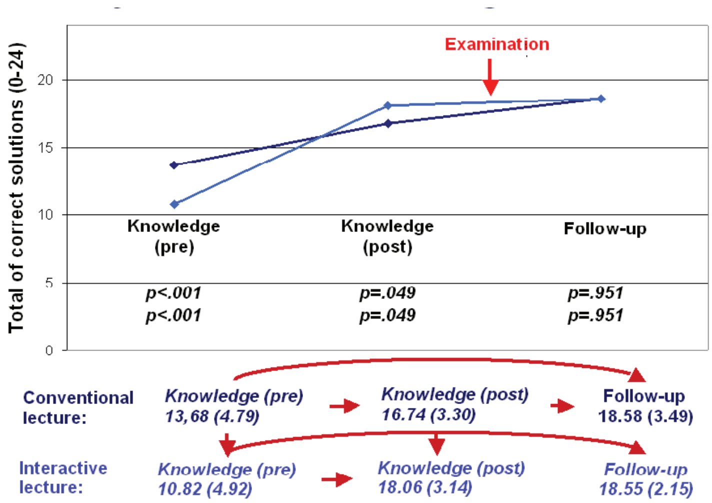


Figure 5: Study during Summer Semester 2003: learning increase
Note: arrows represent significant increases; read: mean (standard deviation)

In the next summer semester (2003), a variation of feedback to the quiz rounds (i.e., the discussion of the results) within an interactive computer science lecture was performed (Wessels, Fries, Horz & Hofer, 2003). The investigated computer science course was realized as a series of interactive lectures over the entire semester, and was again transmitted as a tele-lecture to our partner university. Within the series of lectures a systematic variation of the information capacity of the quiz feedback was realized. There were three conditions; in each condition the verbal feedback to the quiz rounds by the teacher varied, it became more and more informative over time. The 56 students were compared with respect to acceptance of the lecture and the three feedback methods and their respective learning increases. The results of the study show that again that the interactive lecture was very well accepted. Besides, the students prefer an elaborated feedback to the quizzes which is related to information about the correct and incorrect solutions. Regarding the learning increase in the conditions, the highest increases could be seen when a feedback was given which included further information about the solutions (an informative feedback, see Figure 6).

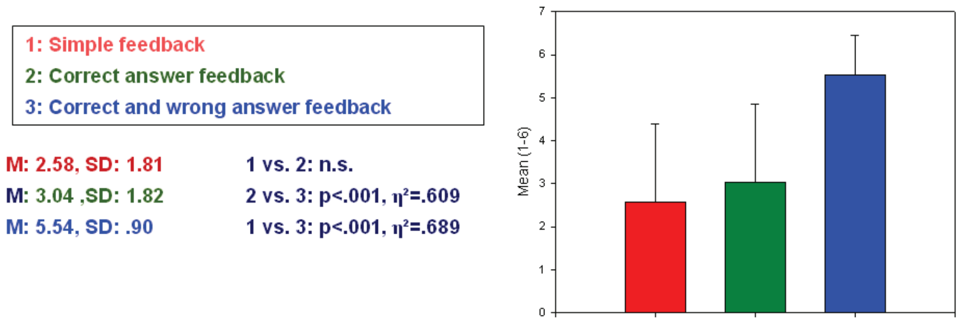


Figure 6: Study during Summer Semester 2003: acceptance of different feedback conditions
Note: M: mean, SD: standard deviation, n.s.: not significant

The aim of the fourth interactive lecture (summer semester 2004) was its realization within a computer science course as close as possible to the everyday reality in higher education. Therefore, the accompanying evaluation was kept to a minimum: just at the beginning and at the end of the semester, measurements with respect to the knowledge and acceptance of the scenario and the tools were carried out. Furthermore, we tested the WIL/MA group support tools for the first time. In contrast to the other studies, the 69 students were equipped with mobile computers which they kept until the end of the semester. First results indicate a replication of the good acceptance of this scenario as well as a better learning success for the students who participated in the lecture in comparison to the students who did not participate (i.e., just studied with the lecture recordings). Especially, the students who participated in the interactive lecture in groups reached better examination results at the end of the lecture.

In summary, our results with interactive lectures carried out with computer science students show that:

1. The interactive lecture is highly accepted by the students.
2. There is an increased learning efficacy through the use of the interactive tools.
3. Regarding the feedback of the quizzes, an informative feedback of the quiz rounds (which includes further information about the quiz solutions) is preferred by the students and leads to a higher learning success.

The next step was to carry out interactive lectures with participants who are not as technical experienced as computer science students. Therefore, we implemented the scenario within an educational science lecture in order to generalize previous findings and to extend the research by investigating a technically less experienced sample.

Interactive Lectures in Educational Sciences

In our first educational science lecture (winter semester 2003/2004) the focal point of our research was the question if and how a variation of an individual feedback to the quiz performance would affect cognitive and motivational variables. 69 of the 214 participants of the lecture were equipped with mobile computers. The other students participated in the interactive sessions with a paper-and-pencil procedure. Additionally, the users with a mobile computer received a personal feedback on their mobile devices about their scores in the quizzes. This feedback was systematically varied with respect to the effects of different reference norm orientations (individual vs. social vs. none).

With respect to motivational factors, the first results show a very good acceptance of the scenario, independent of the type of user participation. Furthermore, all students were concentrated and rated the actual lesson as more interesting than the average.

With respect to the learning outcome, first results show a significant learning increase in both groups which was stable over a period one month after the end of the lecture. Concerning the quiz performance, a computer-based participation in the quizzes led to a higher learning success. Besides, the learning increase measured by a pre/post measurement, was also higher when a PocketPC was used. However, the variation of the reference norm orientation on the quiz feedback does not show a preference in favor of one feedback type regarding the learning outcome, although both feedback variations (individual vs. social oriented references) were well accepted by the students and superior to a feedback with no reference information. In general, this study shows that an integration of an interactive lecture is also possible in a non-technical discipline. Furthermore, our first results confirmed the motivational and cognitive effects of the interactive lecture scenario.

In order to replicate and extend the results of the last study, we are currently carrying out a second study in educational science (N = about 200 participants). The aim of the study is the investigation of the effects of online student feedback to the lecturer about the lecture's current quality (by using the online-feedback tool of WIL/MA) on acceptance and learning success. Since this study just began in October 2004, no results are at hand so far. The study will be completed in February 2005.

Participatory Simulations

In addition to the Interactive Lecture scenario, three different participatory simulations were implemented and tested. The first simulation is based on the WIL/MA software architecture and implements a stock exchange that was designed for master's students in financial theory. The complexity of the simulation can be reduced (e.g., by decreasing the number of parameters or securities), so that it is suitable for high school students. The participants get market information and have the possibility to trade different kinds of securities. Each student manages a securities account and tries to increase its value; this is done in competition with the other students. The simulation aims to increase the understanding of the pricing of stocks, bonds and options.

The competition is a major factor for the motivation of the students. They have to be active to increase their profit and can benefit from analyzing market information and understanding basic factors about the pricing. Although the students can see the success of their investment strategy on the changing value of their portfolio, the more profound experience gain is based on a discussion of their strategies in groups. A teacher defines market, company and security data before starting the stock exchange simulation. He can also influence the market or specific company data during the simulation.

The motivation of the students in our experiment was very high. We used an older PC as the server (Pentium, 133 MHz) to test the functionality of the WIL/MA system and measure possible performance problems. Stocks, bonds and call options of 30 companies (DAX) were added to the system. During one simulation, nearly all prices of the stocks rose (bullish market). Students who bought call options during the first part of the simulation could increase their portfolio value significantly. Despite the bullish market, some students even lost a small amount of money due to the transaction costs.

We developed a second stock exchange simulation based on NetLogo/HubNet (Wilensky & Stroup, 1999, Tisue & Wilensky, 2004a) in order to compare it with our WIL/MA system. The full functionality of the WIL/MA system could not be re-implemented due to missing features in NetLogo such as dynamic screens, menus or limited possibilities for interaction. Stocks are traded by artificial or human agents. The teacher defines a specific strategy for each artificial agent based on the readiness to take risks. It is possible to select agents that get additional insider information about the expected development of the prices of one stock. A screenshot of the NetLogo client is depicted in Figure 7.

The behavior and the decisions of the artificial agents in NetLogo were analyzed. 139 simulations with several artificial clients were carried out. As expected, the standard deviation and the average total asset at the end of the simulation are higher for the agents that take higher risks. Artificial agents that receive (and use) insider information could increase their assets even more.

One of the major strengths of NetLogo is the interface builder: Elements of the client window can be arranged by *drag and drop,* and it is very easy to add code to the elements. A graphical visualization for histograms or plots is integrated into the system, and the network support for the clients works quiet well. A major disadvantage of the interface is its limited flexibility. For example, it is not possible to use more than one window or change/rearrange the items in the window. The input on the clients is limited to sliders, choices or buttons. The internal use of lists and the lack of an exception handling mechanism is a problem: The program crashes if the teacher enters a character where the program expects a number.

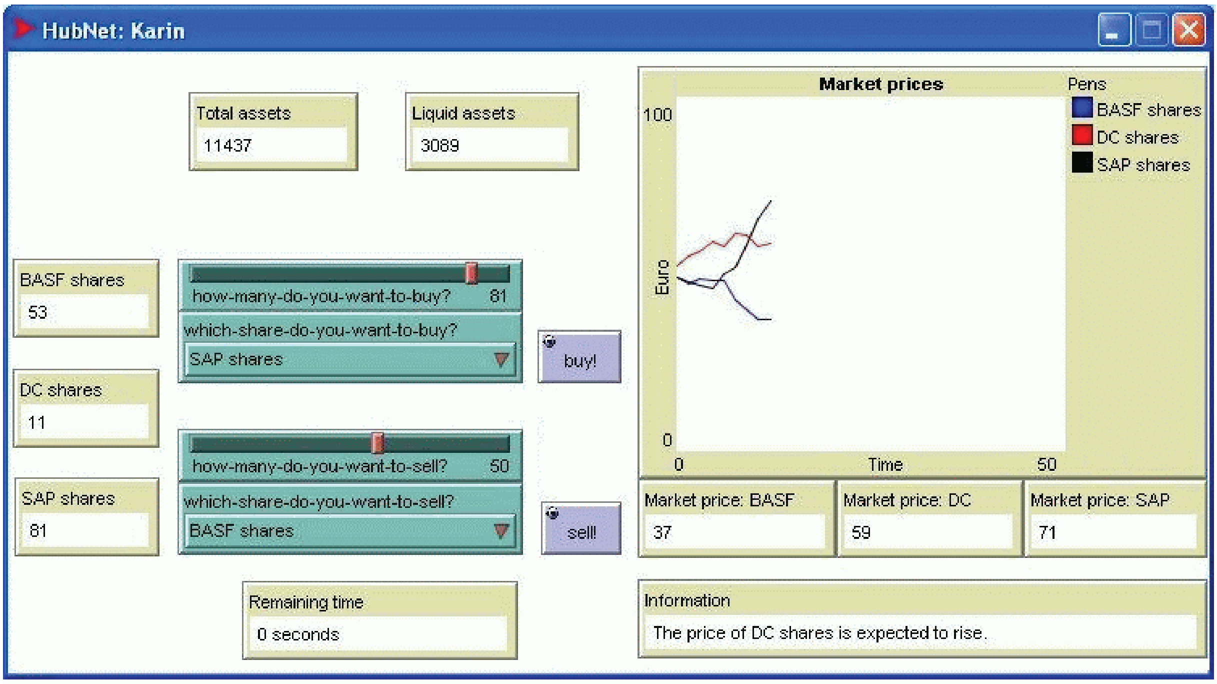


Figure 7: NetLogo client of a stock exchange simulation

The complexity of a real-world stock exchange is very high. The functionality of NetLogo – especially the fact that everything must be visualized in one static window – is not sufficient to create complex simulations. In comparison, an advantage of the WIL/MA architecture is that the teacher can make changes during the simulation, stop/pause or continue it, send messages to selected users or modify the value of market parameters (e.g., the exchange rate of the dollar or the oil price). On the other hand, the effort to create a new simulation is higher in comparison to NetLogo. We found that the creation of the client window via drag and drop and the visualization of dynamic graphs or histograms are important features that are missing in the WIL/MA architecture.

The motivation of the students that used the NetLogo simulation was very high although only stocks were supported. Even before the final release of the NetLogo simulation was finished, several students tested the simulation and tried to develop strategies to maximize their assets. NetLogo is particularly useful if the number of parameters and interactions is not too large.

In a third simulation, students in a high school learned algorithms for the routing of packets in the Internet. Each participant took the role of a router, received packets and forwarded them to his/her neighbors. The mobile devices were equipped with GPS to get the current geographical position of the participant and WLAN to communicate with the server. The topology of the network depended on the current positions of the students. The individual position was visualized in the simulation. Three network protocols were supported: *flooding, RIP* and *OSPF*. Figure 8 displays two example screenshots of the client during the routing simulation.

CONCLUSION AND OUTLOOK

Conventional lectures in large classrooms incur a number of serious didactic problems with respect to the cognitive and motivational conditions for learning. The main disadvantage is the limited interactivity between teacher and students and among students. The students' attention, activity and motivation (and, as a consequence, their learning success), as well as the teacher's ability to react to the current mood in the classroom are severely restricted.

In order to optimize education in mass lectures, we are conducting the LectureLab project. The idea is to support interactions between students and teachers by the use of mobile computers in a wireless network. The students are equipped with handheld computers and use several wireless interactive learning services which provide the possibility of giving feedback in both directions.

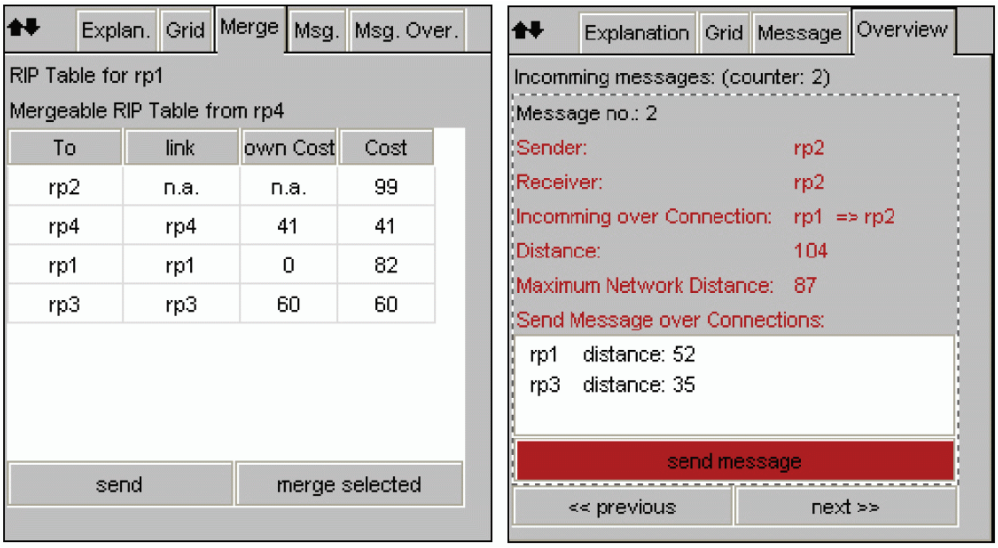


Figure 8: Client screen of a participatory simulation of a routing protocol

Our experiences show that with respect to the technical realization an interactive lecture is very easy to implement. Concerning the use of different mobile devices within this scenario, we have a strong preference for PocketPCs and Notebooks.

The experimental field studies show that a large interactive lecture involving the use of mobile computers significantly strengthens the learning process in higher education. Wireless networks, together with an appropriate didactic concept, are a new and promising possibility to actively integrate the students into the process of learning. Apart from promoting the attention and motivation of students, a key point is that this scenario also supports the learners' knowledge acquisition.

For a long term into the future, lectures in large classrooms will not become obsolete in higher education for cost reasons. Thus, an enrichment of this teaching method around interactive and adaptive elements will be a persistent optimization. Using the technology to transform traditional lectures into interactive lectures is possible in all educational institutions as long as the learning content can be mediated in lecture methods. Because of the flexible application of the hard- and software as well as the adaptive didactic concepts, no structural changes in the educational system are necessary. By an immediate integration of interactive lectures in different disciplines, presence teaching can be strengthened by the creation of an individual flexible model. By means of an interactive lecture, it is possible to integrate new media into higher education directly in a didactically meaningful and economical fashion.

Group support will be a major issue for the next releases of the WIL/MA software and in the following field studies. The first steps in that direction was made with an early prototype for collaboration in quizzes and participatory simulations. A major advantage of participatory simulations is the fact that students learn to see patterns and understand coherences much easier. Also, the fact that they become part of the simulated world intensifies their learning experience. At the same time, informal communication and discussion is always an essential part of the learning process. We believe that especially in the case of complex systems under study, the emerging field of participatory simulations can improve the learning success of students significantly.

In the longer term, flexibility of teaching and learning can be achieved with tele-medial availability of home learning techniques. The described problems of reduced interaction possibilities have gained even more importance over the last years by the rapid growth of synchronous distance education. With an intended spatial expansion of the interactive lecture scenario the technical requirements as well as the human implications and didactic demands and conditions for interactive telepresence scenarios can be specified and optimized.

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