

EXPLORING THE USE OF MULTI-DISPLAY-BASED ELECTRONIC
BLACKBOARDS AND PERSONAL MOBILE DEVICES IN
UNIVERSITY CLASSROOMS

Dissertation

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SELBSTÄNDIGKEITSERKLÄRUNG

Hiermit versichere ich alle Hilfsmittel und Hilfen angegeben und auf dieser Grundlage die Arbeit selbständig verfasst zu haben.

Meine Arbeit habe ich nicht schon einmal in einem früheren Promotionsverfahren eingereicht.

Cao, Bingyi
Berlin, 25.04.2017

Abstract

New technology always introduces new possibilities into the classroom. In the current stage of technological development, large digital displays and personal mobile devices have the potential to be widely incorporated into university classrooms. This study explores the feasibility and benefits of using multi-digital displays and students' personal mobile devices for university classroom teaching.

Compared with widely used computer-generated slides, the traditional blackboard offers advantages in terms of the size of the viewing area, information visibility and user-flexibility, etc. As such, the traditional blackboard is still favored by instructors from the departments of Sciences, Technology, Engineering and Mathematics. Large digital displays can provide an area of visual real estate comparable to the traditional blackboard, with great visual quality. This makes it possible to combine the advantages of both the traditional blackboard and digital systems to create innovative teaching tools. However, there is a lack of practical educational software to explore the potential of using these new tools for education purposes.

The first goal of this work is to design and develop a novel classroom presentation system which not only has the advantages of the traditional blackboard but also absorbs the features of digital systems, forging a more suitable tool for classroom teaching. This system has been implemented in the classroom as a long-term teaching practice that aims to understand the benefits of the multi-display-based electronic blackboard as an enhanced teaching aid.

At the same time, the widespread possession of mobile electronic devices among students has led to the possibility of promoting teacher-student interaction and changing the passive learning style of university lectures. I have incorporated network communication capabilities into the presentation system with the objective of providing a convenient tool to encourage students to engage in classroom interaction using their own mobile devices. This system has been deployed in both physical and remote classrooms to study its technical feasibility and users' acceptance, as well as the impact of its implementation on the interaction between teachers and students.

Based on the experience of the classroom practices, I have also summed up suggestions for future developers of classroom presentation systems, hoping to provide them with useful references.

Based on iterative development and long-term deployment in teaching practices, I have developed practical classroom technologies, studied their impact on classroom learning and the benefits that these new technologies offer to teachers and students. Additionally, I have evaluated feedback gathered from the students and made several suggestions pertaining to the design of new classroom presentation systems. My work provides a new point of departure for research on digital multi-displays and personal mobile devices for classroom application.

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1 Introduction

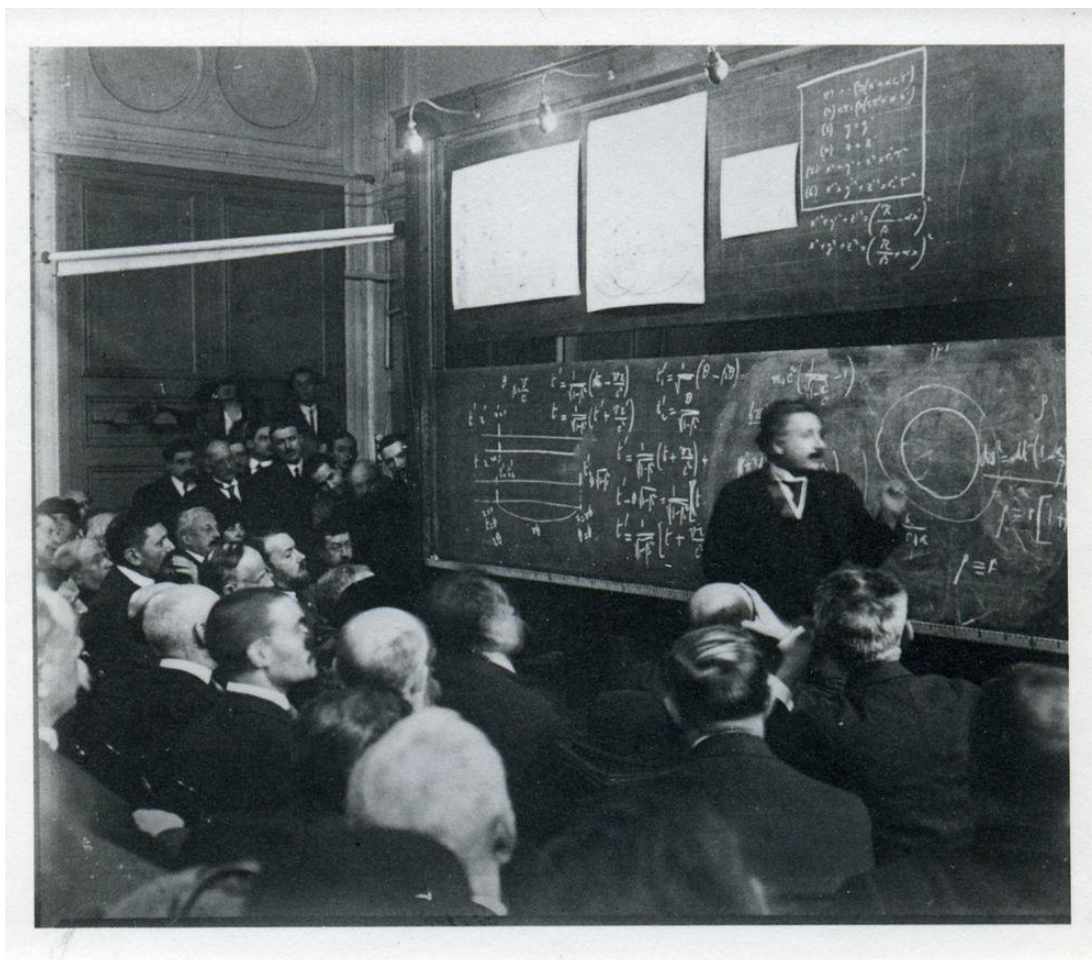


Figure 1.1 The famous physicist Albert Einstein using large sliding blackboards for his lecture. This shows that the blackboard can be used to effectively explain complex concepts.

1.1 Background and Research Problem

Back in the 1960s, during the mainframe era, computer scientists and pedagogy researchers began to explore the pedagogical value of computers [1]. Numerous teaching systems have since been developed to support classroom teaching and to progressively transform the classroom learning environments. Nowadays digital projection of slides is the most common form of teaching in university classrooms. Microsoft PowerPoint is the most prominent tool to make slide-based presentations. It was reported that 30 million PowerPoint presentations were shown every day [2]. The advantages of using slides include being able to structure material in advance, prepare high quality examples and illustrations, and the material can be easily reused [3].

However, the value of slides for classroom teaching is debatable. Researches show that teaching with computer-generated slides is no more effective than traditional ways such as blackboards, whiteboards or overhead projectors [4]. Critics point out that PowerPoint shows only the result but removes the process. The thought processes of the professors cannot be followed in PowerPoint lectures [5]. The users need to change their content to fit the display boundaries of slides [6]. And it has a rapid, sequential type of information flow that is well-suited for presenting products but inadequate for classrooms where complex reasoning and arguments are needed [7].

On the other hand, the traditional blackboard has been a basic teaching facility since the early 19th century when it was introduced into the classroom as an evolutionary tool [8, 9]. It is still widely used in STEM (Science, Technology, Engineering, and Mathematics) lectures. The blackboard provides an interface that is suitable for classroom learning as the visual area is large enough to ensure that information remains in sight to provide context for further discussion. The writing process shows the buildup of information instead of merely presenting the final results, as commonly seen with slide presentations [5]. It has also greater flexibility to work with examples, and modify the contents according to the responses and demands of the students. A study compared the use of traditional blackboard and slide presentations, concluding that blackboards supported more presentation techniques than slide software does, such as referring to previous content, displaying the full process of complex ideas, and supporting the delivery of dynamic non-linear lectures [10].

These studies and facts reveal that compared to computer-generated slides, the blackboard may be a more competent aid for classroom teaching. The digital systems have clear advantages in storage, reuse and multimedia capabilities. One of the main research questions of this thesis is how to combine the advantages of them and to forge a more suitable tool for classroom teaching.

In modern university classrooms, where digital slides are widely used, most students are passive learners. The flow of communications during a lecture is mainly one-directional (from the instructor to the students), only a few students actively participate in this learning process. The widespread use of mobile devices and the provision of campus wireless network are believed to have the potential to create an active classroom learning environment [11]. Wireless and mobile technology brings a lot of possibilities to teaching. For example, they make it easier for students to access information, and encourage students to participate in collaboration and interaction activities within the classroom [12-14]. Methods on making good use of personal mobile devices to improve the interaction between teachers and students, as well as to engage students in the learning process is also an issue that this work try to explore.

1.2 Research Objectives

- The first goal of this thesis is to design and develop a novel classroom presentation system that not only has the advantages of traditional blackboard but also absorbs

the features of digital systems, thus forging a more suitable tool for classroom teaching.

Firstly, we should understand the advantages and disadvantages of using both computer-generated slides and the traditional blackboard as teaching aids in the classroom.

Next, we need to solve the following questions: how to combine the advantages of the traditional blackboard and digital systems to develop a presentation system that will best support classroom teaching and learning? From the teacher's perspective, what affordances should such a system have for their teaching practices? From the perspective of the students, how receptive would they be to such a teaching system, and how useful to their learning process is the teaching system we designed?

- After completing the above objective, we focus on the extension of the system, trying to provide a convenient tool that enables the use of personal mobile devices in the participation of the students in classroom interaction. The issues to be addressed include how to eliminate the barriers that students encounter in the accessibility to such tools and how to increase their participation. We also want to find out whether such tools can improve the teacher-student interaction within the classroom. Lastly, we explore the feasibility of using this system for remote classroom teaching.

1.3 Contributions of the Thesis

The main contributions of this thesis are outlined here, while the more detailed elaborations will be provided in the summary.

1. We design and develop the Intellichalk electronic blackboard system. It is the result of a long-term iterative process of design, development, deployment, evaluation and redesign, through the adoption of the design-based research method. It is a robust, user-friendly and easily adaptable classroom presentation tool, which is designed for multi-display systems but can also be used in single-screen setups.
2. The features that a useful classroom presentation system should exhibit are summarized, based on the design and deployment process of the Intellichalk electronic blackboard system.
3. We implement the Intellichalk system using two different hardware configurations, a display wall with four electronic screens, and a single projection screen. Based on the analysis of data collected from teachers' classroom practices and feedbacks from students, we outline the benefits of the multi-display-based electronic blackboard for teaching and learning processes within the classroom.
4. We have developed the Classroom Interacter by extending the Intellichalk system. In addition to providing teachers with the full functionalities of the Intellichalk classroom presentation system, this also allows students to interact freely in the classroom using

their own mobile devices. The distributed architecture of the system enables more flexible deployments as it reduces the restrictions of time and location, supports teaching via portable devices, and enables remote teaching.

5. We have studied the user acceptance of the Classroom Interacter system and its influence on interaction within the physical classroom, as well as its use in remote classroom teaching.

6. In addition, we have designed and developed a system to assist instructors in the preparation of lectures. This tool is able to extract hand-written notes on paper and segment them into digital ink blocks. Instructors can use these ink blocks in the Intellichalk system via network storage spaces or removable storages. They can also be saved and used in other office and teaching software.

1.4 Outline of the Thesis

Chapter 2 presents literature pertaining to this research. Firstly, we present relevant pedagogical and psychological theories. The Design Based Research [15, 16] provides an important research method for our study. The multimedia learning theory [17, 18] and active learning theory [19] provide the theoretical basis for the design of the new teaching systems. Next, a description is given of other researchers' evaluations and studies of slides. Finally, we introduce existing classroom presentation systems and list them according to their main features.

Chapter 3 introduces the Intellichalk electronic blackboard system. The underlying design ideas of Intellichalk are first listed. These ideas are summed up from the design and implementation process. Then we introduce how we follow the design-based research method in the system design and development process. The next section then details the system, including the user interface and its formation, the modular system and the functionalities of the main modules, and the hardware setups for deploying the system in classrooms. The rest of this chapter introduces the lecture preparation system and the Intellichalk player.

In Chapter 4, we study the wall-sized electronic blackboard used in lectures in the university classroom. The Intellichalk system is implemented in two classrooms using different hardware settings. In one classroom, the system runs on a multi-display hardware system, which is an ideal setting. In the other classroom, only one projector is used, which is a very common hardware setting in university classrooms. The use of Intellichalk in both settings is then compared with an objective to understand the benefits of the multi-display electronic blackboard as a teaching aid in the classroom.

Chapter 5 describes an extension of the Intellichalk system called "Classroom Interacter" for the support of interactions between students and instructors. The Classroom Interacter allows students to use their mobile devices to give teachers feedback and to participate in the learning process. The student client of the system is based on the browser. Therefore, it requires no installation of any software or plug-ins. The

distributed system structure makes Classroom Interacter very flexible to deploy. In addition to supporting tablet teaching and BYOD (Bring Your Own Devices) classroom, this system can also be used for remote classroom and distributed classrooms.

Chapter 6 is divided into two parts. The first part introduces the use of Classroom Interacter in the physical classroom. It mainly studies the students' acceptance of the system and the level of its helpfulness in promoting classroom interaction. The second section describes how the system is used in a remote classroom.

Chapter 7 summarizes the work and original contribution of this thesis and suggestions for future work.

2 Related Work

Developing a teaching system involves multidisciplinary theoretical and practical knowledge. In this chapter, we first introduce the relevant pedagogical and psychological background. The design-based research provides us with an important research method. Theories of multimedia learning and active learning provide the theoretical basis and direction for our research. Then, studies and criticism on slides in classroom settings are discussed. Finally, we introduce the existing classroom presentation systems and list their main features.

2.1 Design-Based Research

One of the most important aims of our work is to develop a practical tool for classroom teaching – different from the experimental types of system that is developed solely for testing in the classroom and that is not feasibly used after the conclusion of the experiment. Our study utilizes the methodology of design-based research. Through the iteration of design, implementation in actual educational context and collection of feedback to improve the design, we aim at creating a practical system that refines design principles to provide useful references to both educational researchers and educational system developers.

The design-based research was first introduced in 1992 [15, 16]. In Ann Brown's view, the classroom is a complex system that, nothing can be studied independently without the classroom running smoothly. Thus, rather than isolating all the various factors that impact learning as in traditional studies, researchers in learning science should embrace the complex system as a whole [15]. The classroom activity participants, the course curriculum and the technology etc should be seen as inputs into the working whole (Figure 2.1).

Barab and Squire pointed out that design-based research is not a single approach but a *series* of approaches [20]. These approaches are designed to create new theories and practices to interfere learning and teaching in naturalistic settings.

Meanwhile, Terry Anderson is of the opinion that a quality design-based research is defined by the following characteristics [21]: (1) being situated in a real educational context; (2) focusing on the design and testing of a significant intervention; (3) using mixed methods; (4) involving multiple iterations; (5) involving a collaborative partnership between researchers and practitioners; (6) evolution of design principles; (7) comparison with active research; and (8) having a practical impact on practice.

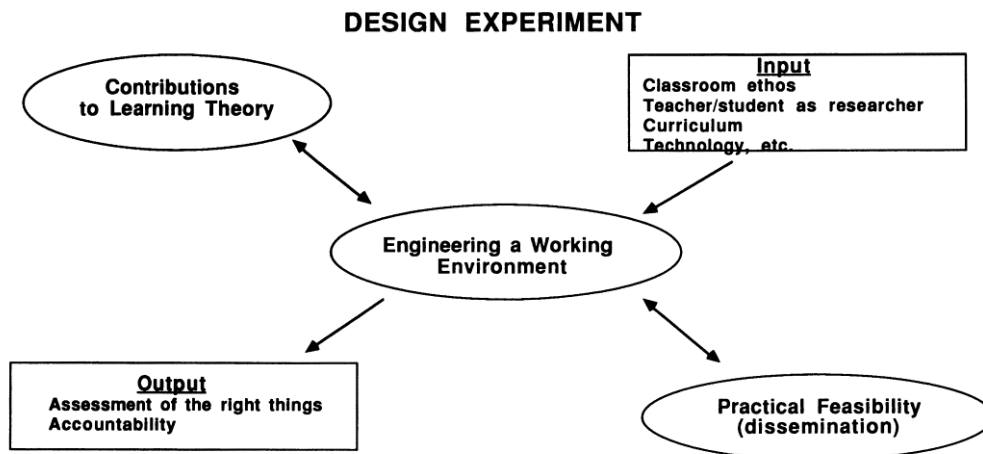


Figure 2.1. The complex features of design experiments. Picture from [15].

Wang and Hannafin [22] say that the design-based research methodology is systematic but also flexible. Researchers apply this methodology with the aim to improve educational practice through an iterative process of analysis, design development and implementation. It requires researchers and educators work together in the real educational settings, and potentially leads to design principles and theories that are contextually sensitive in nature.

Our thesis aims to provide teachers with a better classroom presentation than the commonly used digital projection of slides. To achieve this objective, we employ a variety of research methods, including literature research, questionnaire survey, interviews with teachers and students and data analysis, to help in the design and development of Intellichalk, a new tool that assists classroom teaching. The system was gradually improved over years of study based on an iterative process according to design-based research.

2.2 Multimedia Learning Theory

Richard Mayer [17] proposes multimedia learning theory based on the cognitive load theory [23, 24], working memory model [25], and dual coding theory [26]. There are three main assumptions in his theory. First, human beings process visual and auditory information with two separate channels (*Dual channels*). Second, each channel can process limited amount of information at one time (*Limited capacity*). Third, human beings organize information into coherent mental representations and integrate them with other knowledge when engage in active learning (*Active processing*) [27].

According to the dual channels theory, people can use both channels together to enhance learning. However the processing capabilities of the channels are limited and there is a risk of cognitive overload if they are overwhelmed with information.

One of our design ideas is to develop a blackboard-metaphor based presentation system

which supports multiple displays so that it shows the buildup of information and presents relevant information at a glance. According to the multimedia learning theory, this method has lower risk of cognitive overload since the writing process naturally slows down the pace of the lecture, while the larger visual area can be used to link the information spatially rather than temporally. This may reduce the cognitive load.

2.3 Active Learning Theory

Active learning is generally defined as any instructional method that engages students in the learning process [28]. Bonwell and Eison, the pioneers of learning theory, claim that active learning requires students to do meaningful learning activities and think about what they are doing [19]. From this perspective, they introduced a variety of ways to promote active learning. Many researchers came up with different teaching strategies and guidelines for teachers to implement active learning in the classroom [29, 30], some introduced how to use technologies to assist in the active learning process [31-33]. Studies have found that incorporating activities into lectures can significantly improve the recall of information and the benefits of student engagement have extensive study supports [28]. One of our goals is to promote teacher-student interaction within the classroom to engage students in their learning process. This is greatly beneficial to the students' learning, according to the active learning theory.

2.4. Slideware

Slide presentation has become increasingly common in university classrooms in the last two decades. Microsoft PowerPoint is the most prominent tool to make slide-based presentations. It was reported that 30 million PowerPoint presentations are shown every day [2]. However, although PowerPoint (the judgments about PowerPoint apply to all kinds of slide software) has certain advantages, including the ability to structure material in advance, prepare high quality examples and illustrations, and easily reuse material [3, 34], in terms of delivering lectures with slides, this software has been frequently criticized. Parker [5] points out that PowerPoint shows only the result but removes the process. The thinking processes of the professors cannot be followed in PowerPoint-styled lectures. Farkas [6] points out that slides have strong display unit boundaries compared with book, and electronic documents, which may causes authors to change their content to fit the display boundary reluctantly. Tufte [7] investigated thousands of slides and concluded that inherent defects of PowerPoint preclude it from communicating information properly and adequately. He claimed that slides supported a sequential type of information flow that is suitable for the presentation of products but inadequate for instruction within a classroom, where complex reasoning and arguments are commonly required.

Others who hold conflicting views argue that the effectiveness of PowerPoint is user-reliant and that slides can be an effective instructional tool if the user knows how to

properly use it [35, 36]. However, it remains indisputable that the use of slides has encountered a growing number of criticisms, from both experts such as Tufte, as well as ordinary teachers, as it becomes commonly used. Beside these non-scientific essays that are largely based on personal opinions and experiences, there are many experimental studies about the use of slides in the classroom [37]. These studies cover a wide range of disciplines and mainly focus on the students' reactions and learning outcomes, trying to find out the difference between using and not using slides. These studies report a generally positive attitude of students towards the use of slides, and they hope to continue the use of computer-generated slides in the classroom. However, in terms of learning outcomes, most studies reported that computer-generated slides do not demonstrate an impact on improving the student's learning outcomes. The students' performances in class examinations generally do not improve when the learning with slides, on contrary to when the material is presented using traditional blackboards or overhead projectors. Although a few studies reported that using slides result in better learning outcomes, these study results were said to be debatable [4]. In general, there is no strong evidence to illustrate that slide presentation is a better teaching tool than traditional ones.

2.5 Classroom Presentation Systems

To improve the quality of lectures and provide teachers with better teaching tools, a variety of technologies have been employed to enhance teaching and learning processes. Digital ink was believed to have great potential for supporting a more dynamic style of teaching, and encouraging interactions within the classroom. The literature review shows that digital ink has become a basic function of most classroom teaching tools. In fact, Microsoft PowerPoint also supports basic digital ink writing. While various digital ink systems have been developed to assist both teachers and students, some of them integrate public classroom notes with each student's private or shared annotations in their personal devices [38, 39]. Others provide teachers with free-hand writing functions on desktop screen, slides, or images [40-43]. The digital whiteboards benefit more from the digital ink technology since the flexibility of direct interaction is one of the key features of digital whiteboards and the digital ink provides strong support for this feature.

2.5.1 Slide Based Classroom Presentation System

A great number of presentation systems have been developed by educational technology researchers to address the existing limitations of slides. These systems are either developed based on slide software or use slides as information media. They either add new functions or modify existing features to address one or more problems. Some systems added a private view for the teacher, which is different from the public display [41]. Some systems work as plug-ins of slide tools, offering new features such as the recording of courses or a platform allowing students to give feedback [44]. Other

systems enable users to use interactive paper to control the slide presentation and annotate on the handouts [45], or allow users to control the presentation with handheld devices [46].

Classroom Presenter

The Classroom Presenter [47] is a classroom presentation system that combines the digital ink technology and PowerPoint. Slides can be imported to the system and presented in the form of static images. The size of the slide images can be reduced so that the instructor has more space for annotating and explaining. The system also provides teachers with a different view from the one that the students see. A set of annotating and editing tools are provided on the instructor's screen for freehand-inking on the slides (see Figure 2.2). The extended version of Classroom Presenter also allows students to receive lecture slides, add notes and send feedbacks to the teacher using their own laptops and tablets.

Lecturnity

Lecturnity [44] is a PowerPoint-based presentation system. The most important feature of this system is the automatic recording of the lecture during the presentation. It is also tablet-and-PC-friendly. Besides the automatic recording function, a set of digital ink tools are also provided for writing, highlighting, and pointing (see Figure 2.3). This is a lightweight method to record PowerPoint presentations. The lecturer will not even notice that the lecture is being recorded. Lecturnity also allows users to add the speaker's video or voice comments to the recorded video with the use of an editing tool.

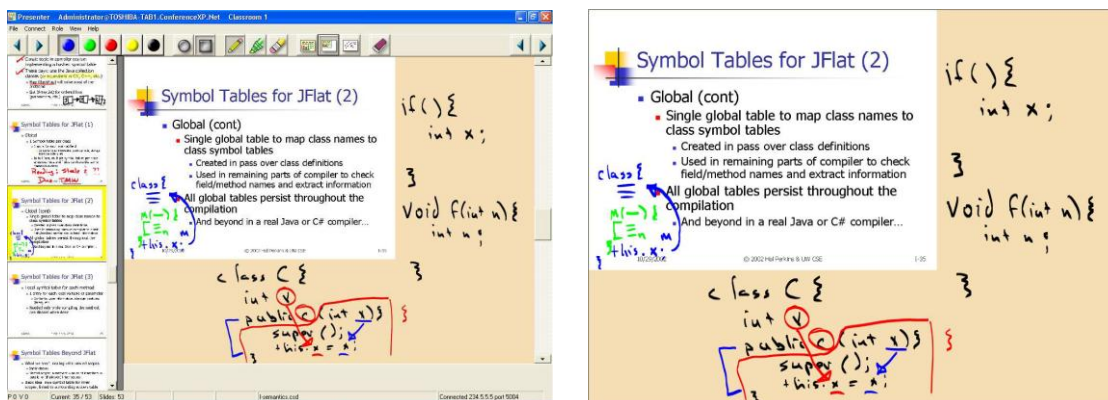


Figure 2.2. The instructor's view of Classroom Presenter with navigation and pen controls (left). Projector view showing only slide (right). Pictures from [47].

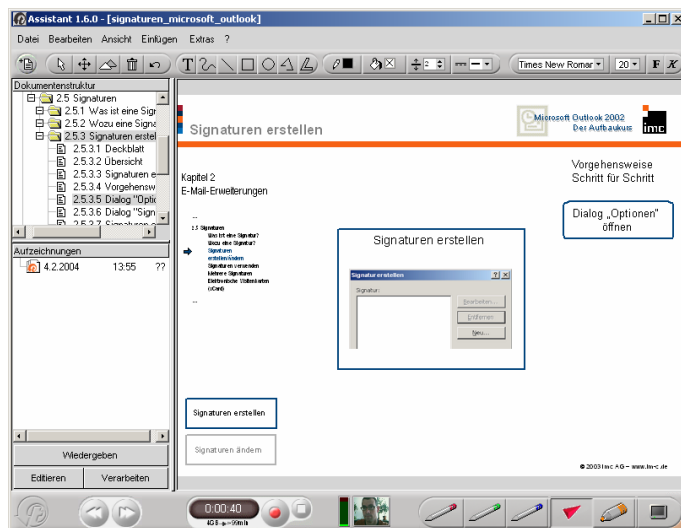


Figure 2.3. The LECTURNITY presentation software used by the lecturer during the live event. Picture from [44].

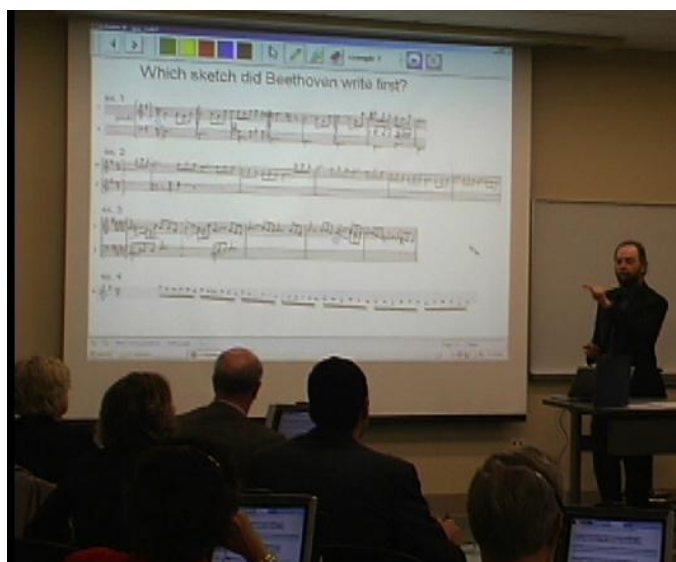


Figure 2.4. A professor uses eFuzion in a music class. Picture from [42].

eFuzion

eFuzion [42] is a tablet-based classroom learning environment. The instructors can use the presentation tools of eFuzion to add notes and examples onto slides that are prepared in advance (Figure 2.4). These annotations can be sent to students' devices, and they can add their own annotations to the lecture notes and save it as a personal copy. The system uses XML to present the ink strokes and sends them to clients via network. Different types of client devices have different solutions to represent the ink information. It also supports interaction between teachers and students in the form of quizzes and interactive polls.

2.5.2 Non-Slide Based Presentation System

One of the most frequently criticized characteristics of slide presentations is that the information is presented in a linear manner, which is unsuitable for classroom teaching, especially for courses in which complex reasoning and arguments are required [7]. Researchers also find that many teaching techniques supported by traditional blackboards, such as the comparison of two objects and back-references to previous information become difficult to carry out on a linear slide presentation [10].

To address the problem of the linear sequencing of slide presentations, some researches adopted the Zoomable User Interface [48], which allows navigation and presenting different levels of information, thus allowing students to understand the structure of the talk. Fly [49] added a visual structural aid to all presentations based on Mind Maps in order to show the structure of the lecture contents. Some systems completely abandon the slide metaphor so as to support non-linear and dynamic style of presentations.

Prezi

Prezi [50] is currently the most popular non-slide based presentation tool. According to the latest (2016) official statistics, Prezi currently has more than 75 million users and 260 million presentations around the world. The software allows the user to add images, videos, texts and slides to an unlimited scalable and movable panel. The user can move between different content, zoom in to present details and zoom out to show the structure and links of the presentation. This animation of moving, rotating and zooming creates a strong visual impact to the audience.

The advantage of Prezi is that it changes the linear delivery method of the lecture, effectively showing the links between ideas via “path” and displaying the structure of knowledge by zooming. However, there are several limitations in this software. The language support is currently limited. Visually, the audience may become dizzy if the switching effects of viewpoints and perspective are not properly used. In fact, this is quite common among Prezi presentations and is called “Prezi sickness” [51] by the users. Additionally, another weakness of Prezi is the extent of its visual effects, which may cause the audience to focus on the display but ignore the speech itself.



Figure 2.5. The Prezi web editor. Picture from [50].

Collage

Collage is a software tool specifically designed for making digital presentations in K-12 classrooms in India [43]. It is different from general-purpose tools such as PowerPoint. Collage focuses on presenting the paper-based teaching materials (mainly textbooks) in a digital format. It can be viewed as a simple media viewer which can display images and scanned textbook materials, while providing several editing tools that enables interaction between the user and the material (Figure 2.6). Compared to PowerPoint, Collage has a clear and purposeful design that also shows off a streamlined functionality. Therefore, it is easier to use and is preferred by the target users.

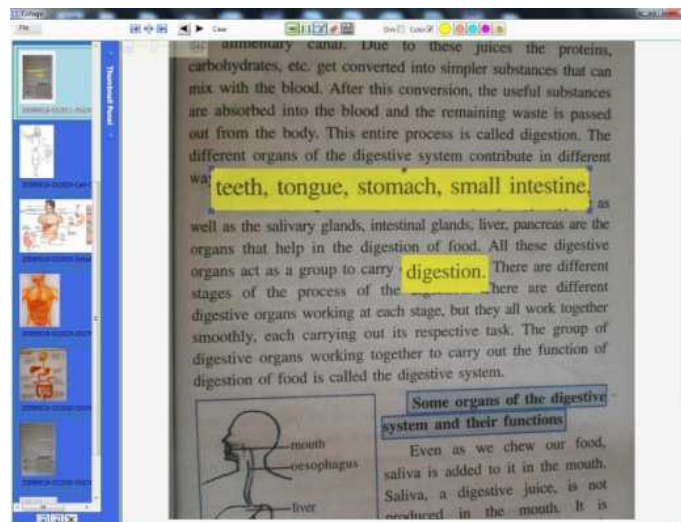


Figure 2.6. Screenshot of Collage. Picture from [43].

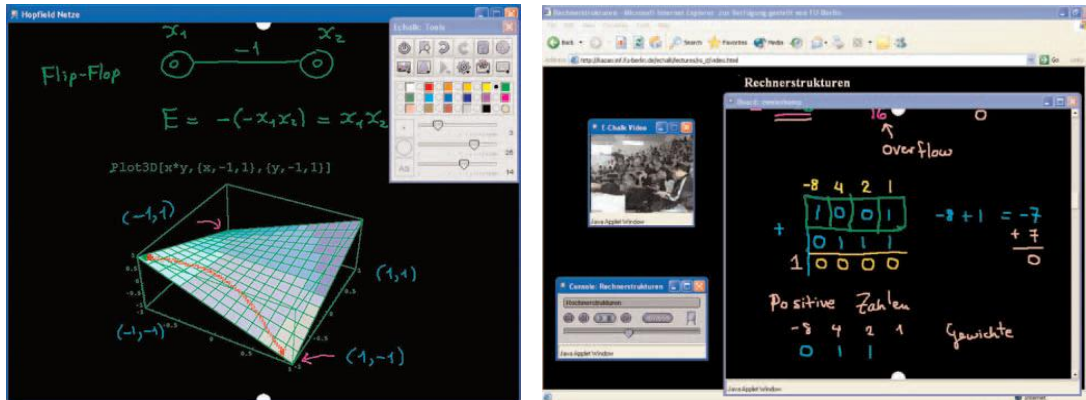


Figure 2.7. The user interface of E-Chalk (left) and the replay of the lecture on a browser (right). Pictures from [52].

E-Chalk

E-Chalk [52] is a non-slide based classroom presentation system that provides teachers with a familiar, blackboard-like teaching interface as seen in Figure 2.7 (left). It does not require other pre-authoring except preparing images or applications for the lecture. When using the E-Chalk system, the instructor spontaneously talk and write on the screen with great flexibility, in a style very much similar to using a traditional blackboard. Most features of the system can be controlled with the stylus instead of the mouse or the keyboard. The lecture can be transmitted or asynchronously replayed via the Internet for remote learners. Figure 2.7 (right) shows the playback of a lecture with audio and video using a web browser. E-Chalk is based on blackboard-metaphor which refers to a kind of board-like user interface. It gives users the flexibility to arrange and, extend the working space according to the users will, unlike the slides with strict boundaries.



Figure 2.8 Interactive Whiteboard using LED panel displays. Picture from [53].

IWB

Interactive Whiteboards (IWB) are large interactive displays connected to a computer initially designed for business meetings of small groups [54]. Now, however, they are perceived as more of an educational product and are widely used in the classroom, especially in primary and secondary schools. An IWB typically uses a projection screen on which the users use pen-based input to interact with the displayed content. Most IWBs are supported by different kinds of software. They can be used for the presentation of slides, free drawing of notes, as well as other classroom activities. As the display technology develops very quickly, some newer versions of IWBs utilize high resolution digital displays instead of conventional projectors. These offer better visual clarity and readability than projector-based IWBs. See Figure 2.8 for example.

2.5.3 Presentation Systems with Multiple Public Displays

Tufte's essay reports that a single medium-resolution screen limits the amount of information that can be presented, making it difficult to explain complex concepts [7]. Sweller [24] also states in his cognitive load theory that physically integrated sources have lower cognitive load than split learning sources sequentially presented over time. Researchers tried to resolve this problem by introducing more displays into teaching systems.

Dual-projector systems double the area of visual aid in the classroom and have the advantages of being cost-effective and requiring only basic computer skills from the instructors. Therefore, numerous studies use dual-projectors systems to explore the impact of increased display area [55-57]. Two of the most frequently reported benefits of increasing the visual area are an improvement in the learning effectiveness of students and a reduction in the cognitive loads [55, 56, 58].

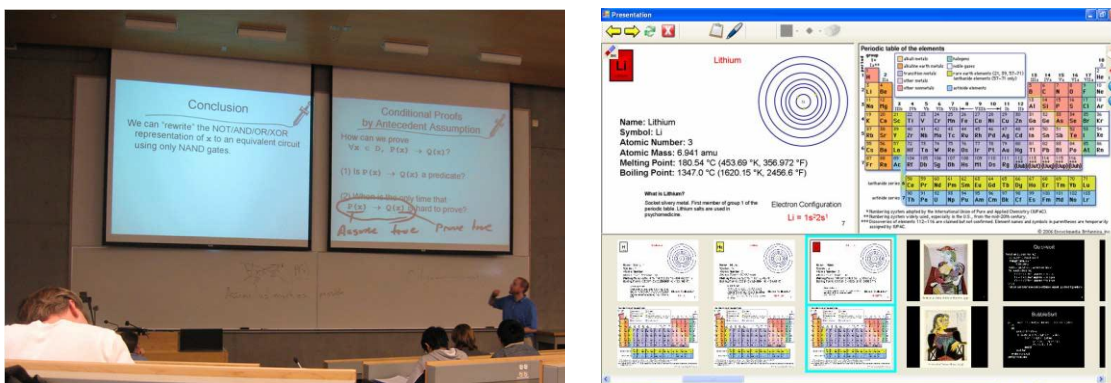


Figure 2.9. The instructor's view of MultiPresenter during presentation (left). The system is in use with two public displays (right). Pictures from [57].

MultiPresenter

The MultiPresenter [57] is a lightweight solution for dual-screen teaching in classrooms. It is also a slide-based presentation system. As shown in Figure 2.9, the MultiPresenter provides the teacher with a private view where she can decide which slide to be shown on which screen. The display order and position of the slides can also be prefixed during the preparation of the lecture. It also allows the teachers to annotate the slides using digital ink. Its original design idea was to use the advantages of dual-screen to address the limitations of common single-screen slide teaching with the objective of enabling non-linear teaching techniques to be used in the presentation. The extra screen space can be used to display previous slides and to make it more convenient for information comparison. The MultiPresenter system increases the flexibility of slide presentation to some extent to benefit the students' learning.

Dual-projector systems have been accepted and widely used in classrooms due to their light-weight solution. The advantages for using these systems were demonstrated compared to a single projector. However, the information that can be present on a dual-projection screen is still less than that of a typical traditional blackboard. Some other studies concentrate on the use of multi-displays and display walls as visual aids for teaching. The common aim is to understand the benefits of using larger display areas.

Classroom 2000 / eClass

Classroom 2000 [59] project (later known as eClass) focused on the capture of in-class activity for later review and also tried to enhance group interactions in the classroom. In this project, the researchers used three display screens to show the current slide, history slides and / or Web pages. The three projection screens created a public display area roughly equivalent to a traditional blackboard.



Figure 2.10. Three projection screens were used in the classroom 2000 project. Picture from [59].

Although this project did not focus on the benefits of multi-display, it is nevertheless an early use of the multi-display (three or more) system for education. The survey results showed that most students thought the use of this technology made lessons in the classroom more interesting and they highly preferred this method.

Virtual MultiBoard

Virtual MultiBoard [60] is inspired by sliding blackboards. The researchers of this project pointed out that traditional lecture rooms had several sliding blackboards on which the educator could spread out the lecture content. The multiple sliding blackboards, therefore, present both the current content and the “history” of the lecture together for the class. The Virtual MultiBoard system uses two more display screens to present the latest two slides. The authors claimed that this setting benefited both students and educators, especially since three quarters of the students reported that the presence of the previous slides helped in their understanding and learning. This study pointed out one drawback of computer-generated slide teaching in comparison to the traditional blackboard and developed a multi-display system to compensate for this short-coming. It is the main design idea of the Virtual MultiBoard system. However, The Virtual MultiBoard still uses slides to display information, showing three slides at a time instead of one. It does not consider other benefits of the traditional blackboard, such as the free use of visual area and the display of information chain.

In addition to the systems introduced above, there are other classroom presentation systems which utilize three or more display screens. ModSlideShow [61] proposes a presentation system on which users can use a gestural interface to manipulate the flow of slides on multi-displays. Polyvision Thunder [62] is an electronic flipchart that can display several electronic views at the same time. It was initially designed for corporations, but was later adopted for education purposes. Another study [63] also presented a teaching system that utilized three display screens and claimed that the multi-display teaching system could significantly reduce cognitive load. These infrastructures shared some common idea: they all organized the display screens separately, and used slides in the presentation of information. The extra projection screens were used to display history information or other environments such as a browser window.

2.5.4 Classroom Interaction Technology

Lectures are the most common form of teaching in universities. The typical features of lectures are a large audience, lecturer-centered and very little interaction. In such a lecture, only a few students are able to actively participate. Asking questions is the primary way to participate, however, for various reasons many students do not ask questions. Some students are too shy to ask questions. Some students view asking questions as a challenge to authority [64]. In an alternate situation, the classroom is dominated by a few students who answer all the questions asked by the lecturer. In most

lectures, only a few students are involved while the majority remain passive. From the perspective of the active learning theory and constructivist, however, learners construct their own knowledge and understanding, which requires active participation in the learning process [19, 65].

How to promote the interaction between the lecturer and students and create an active classroom environment is an important research question in educational science. Numerous studies have suggested a variety of teaching strategies, such as collaborative learning and blended learning to foster students' engagement. Meanwhile, other researchers commit to the development of new teaching tools to create a dynamic classroom environment. CRS (classroom response system, also called audience response system, clickers, voting system or personal response system) is one of the most popular tools for engaging the students in large classrooms. Its first use can be traced back to the 1960's [66, 67]. A number of studies [68-70] have demonstrated positive evaluations towards CRS. Moreover, over the past decade, another tool for enhancing classroom communication called the Digital Backchannel attracted the attention of scholars with its effectiveness in assisting classroom teaching practices [71, 72].

To promote classroom interaction, researchers have integrated interactive features into classroom presentation systems. Early projects include Classtalk [31], which allows teachers to send questions to students, and ActiveClass [73], which enables students using their wireless computing devices to ask questions, response to polls from the teacher. The presentation systems that have been introduced above such as Classroom Presenter, Virtual MultiBoard and eFuzion also have the ability to collect feedbacks from students.

Dyknow

Dyknow [74] is a commercial classroom presentation and management tool. The system allows the instructor to prepare material using freehand drawing or keyboard input and send them to students over a network connection. Students, on the other hand, are also able to send part of their work space to the teacher. Besides, the instructors can also send and receive files, as well as send polls to the class. Dyknow also has features that monitor students' devices and restrict the use of certain types of software.

At the end of this chapter, we list the previously mentioned presentation systems in Table 2.1 and identify their main features.

	Digital Ink	Slide based	Instructor's View	Teacher-Student Interaction	Multiple Public Displays	Replay Support
Classroom Presenter	✓	✓	✓	✓		
Lecturnity	✓	✓				✓
eFuzion	✓	✓	✓	✓		
Collage	✓		✓			
Fly		✓				
WriteOn	✓					
Prezi						
E-Chalk	✓				✓	✓
Multipresenter	✓	✓	✓		✓	
Classroom 2000	✓	✓			✓	✓
Virtual MultiBoard	✓	✓	✓	✓	✓	
ModSlideShow	✓	✓	✓			
Polyvision Thunder		✓			✓	
Classtalk			✓	✓		
ActiveClass			✓	✓		
Dyknow	✓	✓	✓	✓		✓
T-Cube		✓				✓
AOF	✓		✓			✓
Ubiquitous Presenter	✓	✓	✓	✓		

Table 2.1. The presentation systems and their available features.

3 Intellichalk: An Electronic Blackboard



Figure 3.1 Authoring is lecturing, the Intellichalk system supports the traditional “chalk and talk” teaching style, but also combines the advantages of digital systems, forging new capabilities for classroom teaching.

This chapter introduces Intellichalk, a novel classroom presentation system inspired by the traditional blackboard, but enhanced with multi-media technology and artificial intelligence [75]. In a usual classroom setting, the instructor shows up for class with lecture notes prepared beforehand or empty-handed if she is familiar enough with her topic, and then creates lecture content on the Intellichalk system using the pen-based input devices. Prepared images, texts or multimedia resources from the Internet can be added to the presentation at any given point in time during the lecture. The intelligent assistants are readily available to enliven the class (Figure 3.2).

As an innovative classroom teaching tool, the Intellichalk system itself is a contribution of this thesis to technology enhanced classroom learning. Furthermore, we adopted the design-based research method to implement the system in an iterative process of design, deployment, evaluation and redesign. Experiences and lessons gained from the implementation process, as well as insights gleaned from real classroom practices, have contributed to the design of similar classroom teaching systems, while this innovative technology enhances the learning environment within university classrooms.

Compared to using computer software, writing and sketching with paper and pen is a convenient, intuitive, and natural way to express and record ideas, and is still favored by many teachers and researchers. The advantages of pen and paper are even clearer when

the content includes mathematical derivation, engineering sketches or algorithmic structures, all of which are difficult to create and edit using computer software. However, the content written on paper is difficult to reuse and inconvenient to store compared to digital content. We developed a tool to enable teachers to prepare lectures on paper. The handwritten content on the paper can then be electronically extracted and segmented into digital ink blocks. Teachers can use these ink blocks in the Intellichalk system or in other office and teaching software as images. This lecture prepare tool provides convenience to teachers who are accustomed to preparing lectures using pen and paper. They do not have to re-write the content again in the lecture and can digitize and save the manuscripts for later use.

As an additional feature of the Intellichalk presentation system, the Intellichalk player was developed to replay the entire lecture. During an Intellichalk lecture, all the instructor's actions and speech are automatically recorded with timestamps for later replay. The production of online learning materials often requires a lot of time and resources, but when using the Intellichalk system, the online teaching materials are created as by-products and no operation on the instructor's part is needed. Actually, the instructor may not even realize that the online learning materials are being generated during the lecture.

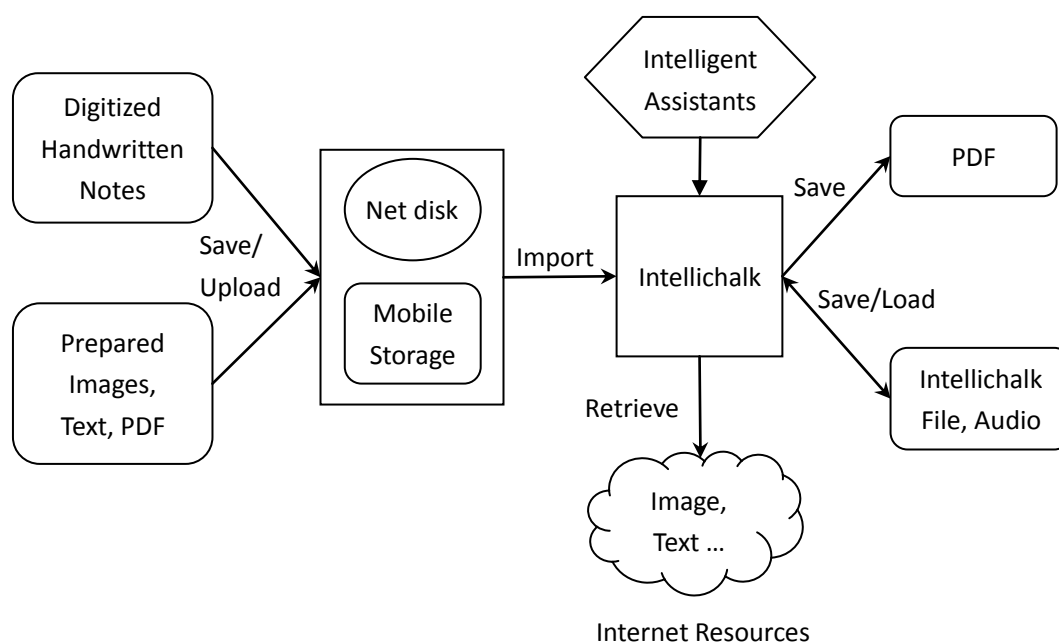


Figure 3.2. The instructors can use the Intellichalk system like a traditional blackboard. Prepared pictures, PDF files and other multimedia files can be used to assist their teaching. Handwritten notes on the paper can be extracted out as digital ink blocks and added to the Intellichalk presentation system. Moreover, the instructors can paste pictures and text from the Internet at any time during their lecture. The intelligent assistants are readily available. After class, the lecture content can be generated as a PDF file and distributed to the students, and the Intellichalk file together with the recorded audio can be used to replay the entire lecture.

In this chapter, we first introduce the underlying design ideas behind Intellichalk. The principles we present here were identified during our long term design process and real classroom deployment. Then we briefly introduce how we followed the design based research methodology to design the Intellichalk system. In subsequent sections of the chapter, we describe the system in detail, starting with the user interface and the evolution of its design. Then we introduce the highly modular and extendable system architecture and the functionalities of several main modules. After the description of the system, we briefly introduce several ways to deploy the system in the classroom. At the end of this chapter we introduce the handwritten note extraction tool and the main features of the Intellichalk player.

3.1 The Underlying Ideas

The blackboard metaphor

In contrast to electronic slides which have been popularized in the last two decades, instructors have been using blackboards to present and explain complex ideas for over two centuries. In this section, we present our new electronic blackboard system called Intellichalk. We share the same motivation as E-Chalk [52]: we believe that the traditional blackboard offers many advantages for teaching, not available when using digital slides. For example, the information stays available for further thinking and discussion; instructors can use arrows and circles, and underline to emphasize certain details and attract students' attention. Our idea is to combine the advantages of both the traditional blackboard and the digital systems. We reproduce the features of blackboards with digital technology and provide teachers with an easy to use and familiar environment. The teacher and students can interact as if using normal blackboard.

The aim of Intellichalk is to enhance the traditional blackboard with the benefits of a digital system, making it a more suitable tool for teaching. It can be viewed as a blackboard enhanced by multimedia and artificial intelligence, which makes it surpass the traditional blackboard in many ways.

Separation of views

Writing directly on the screen is more natural and intuitive. But wall-sized touch screens are still not that affordable and the use of interactive whiteboards is limited by their visual quality and size. They are not our current choice. The separation of views, on the other hand, has many benefits for classroom usage.

The public display contains only information about the lecture contents, preventing the waste of screen real estate on unused software controls. The separation of screens keeps the instructor's manipulations with the system's tools out of the public screen. The benefit for students is that the operations do not distract their attention. For the instructor, this means that she can avoid operating the computer under the observation of the whole class. Moreover, one professor mentioned one benefit of the system during

his interview. He said working on a graphical tablet, he could face the class and keep eye contact with students, rather than turning his back to them. It gave him the opportunity to observe the students' understanding status.

Supports dynamic teaching styles

In contrast to linear slide presentations, lectures with traditional blackboard are often more spontaneous and dynamic. We want to inherit these advantages of traditional blackboard. To be specific, we list the techniques we want to achieve as follows:

Support for flexible teaching styles: In a slide-based lecture, the content is premade, and the delivery sequence is also planned before the lecture. With our system, the teaching contents are dynamically added to the teaching canvas, it gives the users great flexibility to develop their own teaching styles.

Work on examples: With digital ink, the instructor can easily work on examples to explain her idea or to clarify questions raised by students.

Adjust content: The system provides a set of editing tools to add, delete or modify lecture content according to the teacher's strategy or students' reaction. All operations on the electronic blackboard can be completed with the stylus. An undo button allows users to undo any operation.

Comparison: The instructor can present relative concepts or content on different displays in parallel for comparison.

Tradeoff of reuse

The content of slides is completely reusable. Old slides can be used repeatedly without modification. The disadvantage, as we discussed before, is that they directly display the result and ignore the process. Since content on a traditional blackboard is non-reusable, the teachers need to rewrite the lecture contents every time. The content on electronic blackboards is partially reusable. We believe this approach will help teachers save time on trivial writing and allow them to spend more effort on complex reasoning and explaining.

For descriptive content, such as definitions and lists that do not contain reasoning or the explanation process, it is not as worthwhile to write everything stroke by stroke. This content, as well as that which is repeatedly reused, can be defined as "Macros" in our system. We suggest that teachers reuse those contents. These fragments can be prepared and imported to the system before the lecture and can be added to the teaching canvas whenever needed, with the selected color. In our opinion, neither complete reuse nor non-reuse is the best teaching practice. We propose the partial reuse of lecture contents in order to improve the efficiency of teaching while retaining the benefits of the blackboard. Lecturers can save valuable lecture time for theories and derivations which require detailed explanations.

Intelligent assistants

Information and Communication Technology and Artificial Intelligence make it possible to create interesting tools to aid teaching and enhance classroom experience. We aim to develop various types of programs running as services to assist the lecturer's teaching. For example, working with a handwriting recognizer, we have developed a program to interpret hand written lambda calculus. A logic circuit simulator can recognize and evaluate logic circuit drawn on the board. We call these programs intelligent assistants. We are attempting to work with a variety of third-party software to develop more intelligent assistants. They can make the lecture more interesting.

Reduce students' cognitive load

Meyer states in his multimedia learning theory that we use two separate channels to process visual and auditory information. However the channels have limited processing abilities. If overwhelmed with information, we risk cognitive overload [17, 18]. With slide presentations, lecturers tend to delivery lectures at a fast pace since they are familiar with the content on the slides, and the omission of writing saves time. This may make it difficult for students to understand the classroom content. Teaching with an electronic blackboard, the teacher is slowed down when she explain the complex content step by step. It gives students time to follow the lecturer thoughts. The persistency of previous information also eases the cognitive load of the students because they do not need to remember the old content.

3.2 Design Process

One of the most important aims of our work is to develop a practical tool for classroom teaching – different from those systems solely developed for research purposes, which will disappear when the experiments have been finished. We therefore adopted the methodology of design-based research. Through the iteration of design, deployment in real educational contexts and collecting feedback to improve the design, we aim to create practical systems and refine design principles to provide useful references to both educational researchers and educational system developers.

The process of achieving this goal is broadly divided into four steps as shown in Figure 3.3. The first step was to frame a preliminary design of the system. We first analyzed the limitations of existing classroom technologies. The widely used computer-generated slides are heavily criticized [5-7]. We have studied many classroom presentation systems that are designed to address one or more limitations of slides. Some systems introduce digital ink functions to improve the flexibility of the teaching systems [41-43] so the instructors can adjust the teaching content according to their needs. They also have the flexibility to draw freehand annotations or work on examples. Other systems use non-slide methods of organizing and delivering the lecture content to break the linear sequencing of slide presentations. They are able to express the macrostructure and internal links of knowledge [48, 49]. Also some systems use multiple displays to

increase the visual area of the teaching systems [57, 60]. The extra visual area can be used to present the history information, compare different content, etc. The benefits of these improvements for teaching have been verified. Therefore, it is necessary and wise to adopt the strengths of these ideas in the initial design of our innovative teaching system.

Related research indicates that computer-generated slides are not superior to traditional methods of classroom teaching [4]. One study [10] shows that traditional blackboards support many more teaching techniques than slides. The Virtual MultiBoard [60] and E-Chalk [52], which are based on the idea of blackboards, combine the advantages of traditional blackboards and electronic systems to a certain extent, and have become a popular teaching system for teachers and students. Moreover, the E-Chalk system was the former study of our system. Although the system was developed ten years ago, and both the hardware and software are out of date, we still share the same motivation as it. We believe that the traditional blackboard has many advantages for teaching, not available when using digital slides, especially in STEM disciplines where complex reasoning and interpretation is needed. Combining the advantages of both traditional blackboards and digital systems, we will be able to create a more suitable system for classroom teaching.

Suggestions from teachers are also essential to designing the teaching system, as teachers are the direct users. And whether they are satisfied with the system determines whether it has a chance to be deployed in the classroom. Although classroom technology should try to use the latest technology and exploring the possibilities it brings, the technology should not be the driving force. Instead, the classroom technology should be user-oriented, and the needs of teachers and students should drive its development. We were therefore concerned about the actual needs of teachers during the first phase of Intellichalk implementation. Recommendations from teachers were considered thoroughly and adopted in the initial design of the system.

After forming the preliminary system design, the second step of the study was system development and features realization, aiming to create a prototype of the presentation system which could be deployed in the classroom for further evaluation and improvement. Considering future extensions, feature modifications and cross-platform capabilities, we designed a highly modular system architecture based on the OSGi framework. The system modules are divided into three categories, which are basic modules, intelligent modules and plug-in modules. Each type of modules can be extended by the developer. The vast majority of the implementation in this phase was completed by the author of this thesis. Three undergraduates were involved in this process and each of them contributed one functional module as his graduation project.

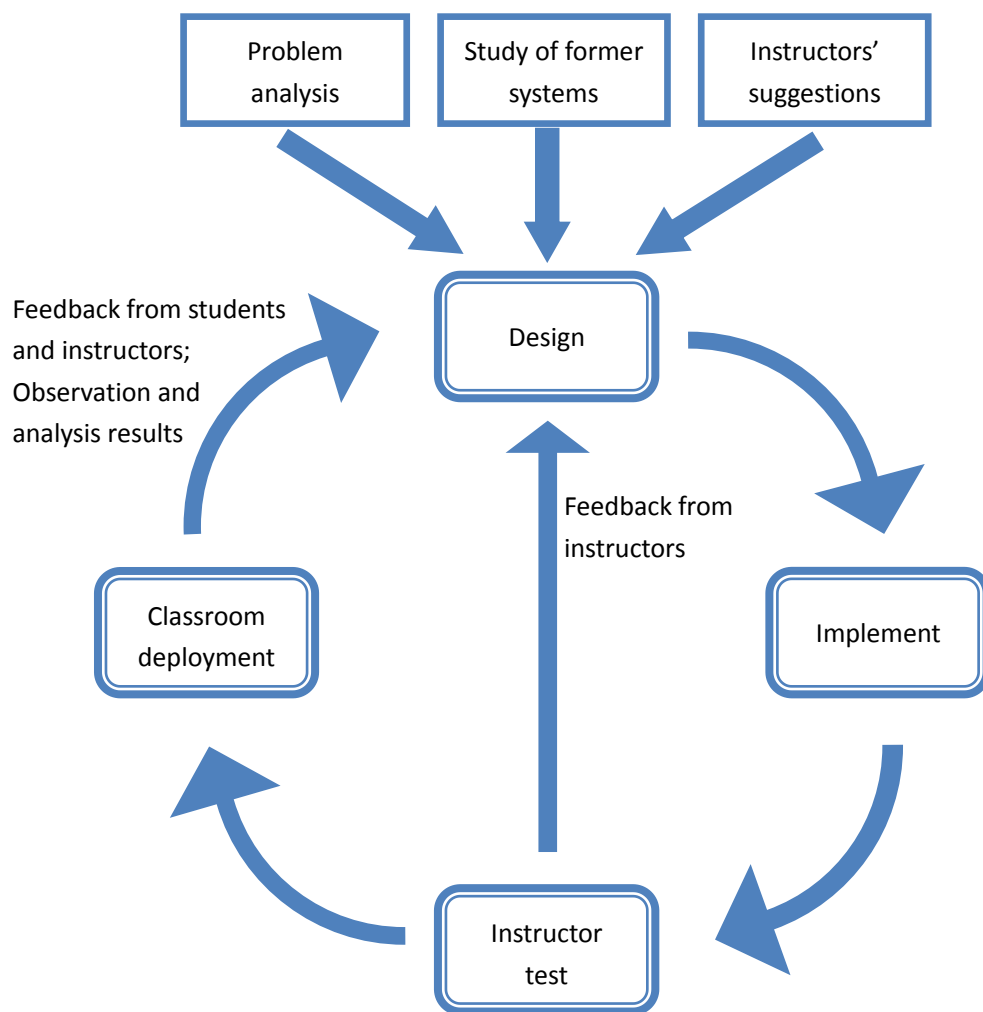


Figure 3.3. The design process of Intellichalk system.

The third step was a long iterative process of teacher evaluation, deployment, classroom evaluation and redesign. At the beginning of a new iteration, the system with new features or improvements was tested by the instructors first before classroom deployment. If they were satisfied with the system and agreed to use it in their lectures, the system would be deployed in the classroom and evaluated by the instructor and students. Otherwise the system needed to return to the design and development step for improvement. When the system was used in the classroom, we sent questionnaires to students. We designed a questionnaire according to the Technology Acceptance Model (TAM) [76, 77] to investigate students' acceptance of the system. Open questions were asked to collect students' opinions about the strengths and weaknesses of the system and their suggestions for improving the system. After actual classroom deployment, we again asked the teacher's advice. We then analyzed the feedback from teachers and students, kept the advantages, designed the new features and improvements according to users' requirements and then started the next round of development and improvement.

It seems that the third phase can go on indefinitely, since teachers are always able to put forward new requirements and it is unlikely for a teaching system to satisfy all students. But a research project cannot carry on indefinitely. When the preset goals had been reached, it was time to enter the last phase of the research. After several years of continuous improvement, the classroom presentation system we proposed has matured and can provide support for teachers in their lectures. Students also rated the system highly, finding it helpful to their learning, and wanted to continue using it. Our initial goal was to design and develop a practical and more suitable presentation system for classroom teaching, and it was achieved after the earlier phases of work. In the fourth and last phase, we summed up the experience and lessons learned from the design and development process, concluded the principles for designing such innovative classroom presentation systems, providing useful reference for other researchers and educators.

3.3 User Interface of the Intellichalk System

3.3.1 Description

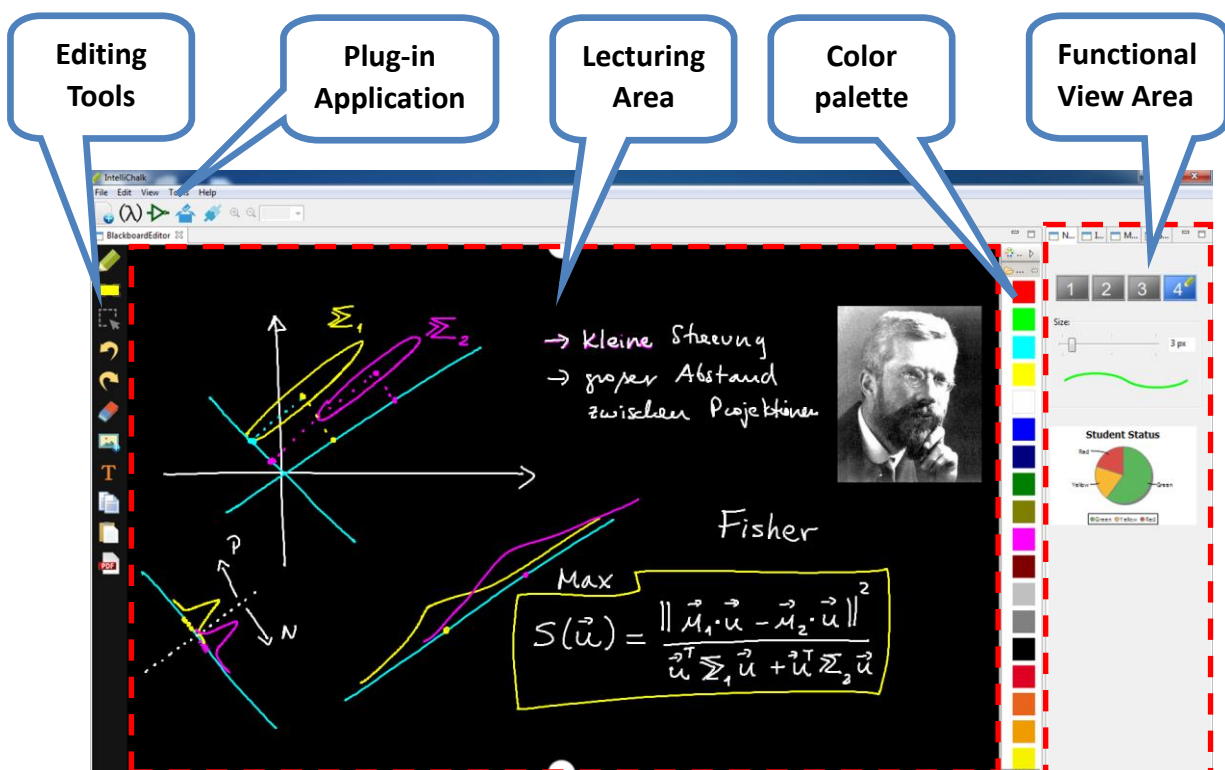


Figure 3.4. The user interface of Intellichalk system.

Figure 3.4 shows the user interface of the Intellichalk system. As it adopts the traditional blackboard metaphor, the instructor can directly author content in the system during the lecture. This is the instructor's view which cannot be seen by students. It has five parts, the largest area in the middle is the lecturing area on which the instructor creates lecture content, which will be mapped and displayed on the public display for the class. The lecturing canvas can be scrolled up and down vertically, providing the lecturer with a virtually unlimited surface to write on.

The editing toolbar and color palette are positioned on each side of the lecturing area. The editing toolbar provides various editing tools to control or edit strokes, pictures, text and other visual elements. According to our design, each visual element is an operation object, which means that all the operations such as select, move and delete are applied to the whole visual elements. Compared to pixel-based operations, object-based operations are more convenient and flexible. The color palette remains active, allowing the user to easily change the pen color with a single click. The lecture area together with the editing area and the color palette constitute the *focus area* of the presentations system, most operations of the user take place in these areas.

On the right side of the Intellichalk system is the functional view area, which is an extendable and configurable area and the user can decide which functional views to display there. *Navigation View* is the default view for this area. When running on multi-display hardware settings, it displays the active screen on which the user is currently editing. The user can switch the current editing display by mouse clicking or pressing functional keys on the tablet. Users can also set and preview the size and color of the pen tool, and it displays the overview of the students understanding status, which is part of the interactive system and will be introduced in detail in chapter five. Another functional view is the *Image View* which shows thumbnails of images in a selected directory, the lecturer can pick and place the images in the lecturing area with a given size and position. *Macros View* shows the previously extracted digital ink blocks from the paper and can be added to the lecturing area at any time during the lecture. For teachers who are used to preparing lectures on paper, we provide an independent tool for extracting the content they write on paper and automatically segmenting it into digital ink blocks. This tool will be introduced later in this chapter. *Shapes View* provides some basic shapes such as circle, rectangle, and coordinate systems as vector graphics to assist teachers for their lectures. *PDF View* and *PPT View* are used to import PDF files and PowerPoint files as static images and list them in the image gallery.

Plug-in applications toolbar lists the plug-in applications we developed to enhance classroom experience. Available plug-in applications: handwritten lambda calculus interpreter, hand-drawn logic circuit simulator, voting system and server connection, which enables teacher-student interaction via network. Developers can add their own tools to assist classroom learning.

3.3.2 Design Ideas of the Intellichalk User Interface

Our aim is to develop a practical classroom system, and therefore we adopt design-based research to iteratively improve the functionality of the system. As important as the functionality is, the user interface directly affects the user experience and the user's perception of the system. Gradually improving the user interface was also an important task during the study process. The layout and functions shown in Figure 3.4 were designed based on user feedback, analysis of collected usage data. For example, the analysis of collected lecture data illustrate that the most frequently used operations are writing, switching colors, scrolling, and undo. Therefore, we must ensure that these most commonly used functions work properly and are easy to use.

Switching color is the most frequently used operation except writing, so the color palette is arranged on the side of the lecturing area and kept available. Various colors are easy to access with a single click while the color selection functions of other software often require more manipulations. One more click can be distracting for teachers who are focusing on their lecture content and may lead to teachers to avoid using this feature. Therefore, we try to minimize the interaction between teachers and the system, saving their time for lecturing. According to our statistics, the most commonly used colors are white, green, cyan and yellow which have high contrast with the black background color, so we put them in easily accessible locations. Because the colors are very convenient to access, teachers use a variety of colors and frequently switch them in their lectures. They use a variety of colors to help the expression of their ideas which could help students to understand. The lecture content in Figure 3.4 is an example.

In order to make it easier for teachers to move the lecture canvas, we use two drag handles in the top center and the bottom center instead of a scroll bar on one side. The drag handles are designed for stylus operation. Compared with the commonly used scroll bar, they are closer and easier to reach, wider and easier to locate, and users can intuitively control the drag distance. Unlike with "hand" or "grab" tools in other software, one does not need to switch tools. The user can move the lecture canvas while writing without a tool switch.

Changing the pen size is a less frequently used function. It is placed outside the focus area of the interface, in the navigation view. In the previous design, we used a round shape to present the current pen size, as with other software. But an instructor reported that the round shape does not intuitively tell them the thickness of the stroke. He needs to test several times before finding his desired stroke size. We then showed a preview of a stroke drawn with the current stroke size and color and the teacher could immediately judge the thickness and color of the stroke made by the stylus.

Erasers in common software clean the specified area based on pixels, which not only requires adjustment of the eraser size, but also needs precise control of the contact location. This can be very disruptive to teachers during the lecture, and they have to interrupt their thoughts to deal with writing mistakes. Our eraser tool was also

developed through continuous testing and feedback. It is object-based and can be used in two ways. A single click will remove the visual element under the touched point with a small tolerance. If the user drags a rectangle with the eraser, the elements in the rectangle will be cleared. During our study, we observed that all teachers were restrained in their operations interacting with the system, particularly with those operations requiring accurate position control. This explained why teachers prefer the current object-based eraser. However, we still observed that some teachers preferred to clear a block of strokes and redraw when they found just one wrong stroke, rather than clicking and deleting that wrong stroke. When they want to remove the most recent content, the undo function is more popular than the eraser because it needs only a single click without precise location control or a tool switch. And we often observed that the instructor clicked undo five or six times to clean the previous mistakes and rewrite them rather than using the eraser to locate the specific wrong stroke. The psychological reasons behind these behaviors deserve deeper analysis, but that is beyond the scope of this thesis.

The highlighting tool is also generated from actual use. When learning with a multi-display or very large display teaching system, students easily get confused about which content the teacher is referring to, due to the large amount of information on the public display. Most teachers naturally use circles, underlines and other attention marks to attract students' attention. But the lecture notes will be saved as a PDF file and sent to students after class. Teachers and students complained about the readability when there were too much attention marks on it. And these marks have no meaning for students without the speech since the context is lost. The normal highlighting tool in other editing software cannot solve this problem, so we implemented this highlighting tool which shows a bright block with a given size and location under the emphasized visual elements. The highlighting block is not persistent. It disappears when the instructor switches back to the pen tool to continue writing. It is particularly useful when using a projector or teaching remotely, as physical gestures are not convenient.

Teachers have different habits when using pictures and other multimedia resources. For those teachers who write a lot and only used pictures occasionally, they can open and add pictures from the local storage or use the clipboard to add pictures from the Internet. For teachers who often use a lot of pictures to assist their teaching, they can use the *Image View*, one of the functional views, to open an image directory. The image view presents all the images in the located directory in the form of an image gallery. The teacher can choose pictures she needs from the image gallery and add it to the lecturing area with a given size and position. For teachers who want to use PowerPoint or PDF files for teaching, they can open the needed file in PPT view or PDF view. Each page of the file is converted to a static image. The converted file contents are also displayed in the form of an image gallery. Teachers can add the needed pages to the lecturing area, combined with annotations and explanations to achieve a flexible and creative teaching style.

Moreover, the Macros, assistant shapes and other functions are developed based on the

actual needs of teachers and gradually improved through the iterative study process. They provide practical functions for teachers.

3.4 The System Architecture and Features of Intellichalk

The Intellichalk system is inspired by the idea of blackboards. It has a full-featured editor on which users can not only write and draw fluently but also add a wide range of multimedia material resources from the Internet or local disks. Digital ink blocks can be used whenever needed during the lecture. Unlike prepared slides, this blackboard-like system shows the instructor's thought process. The Intellichalk system can be viewed as an electronic blackboard enhanced by multimedia and intelligent technologies. It provides lecturers more possibilities in the form of teaching, gives students chances to follow the thoughts of the teacher. The highly modular structure ensures that it can be easily configured, extended and upgraded. The system runs on top of OSGi runtime environment [78]. It has three types of modules, the basic modules provide the basic functions of the system, the intelligent modules offer advanced features for further development, the plug-in modules extend the functions of the system. Every kind of module is extendable. Figure 3.5 shows the architecture of the Intellichalk module system.

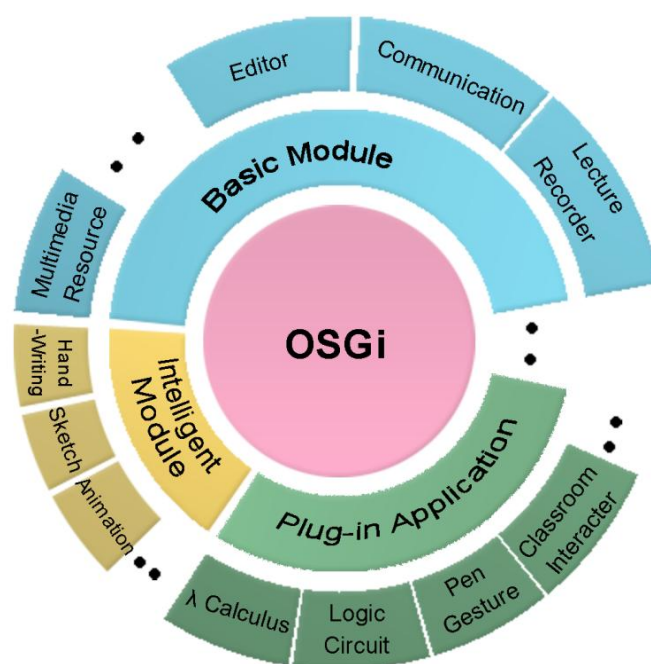


Figure 3.5. The Intellichalk model. It has an extendable, highly modular structure.

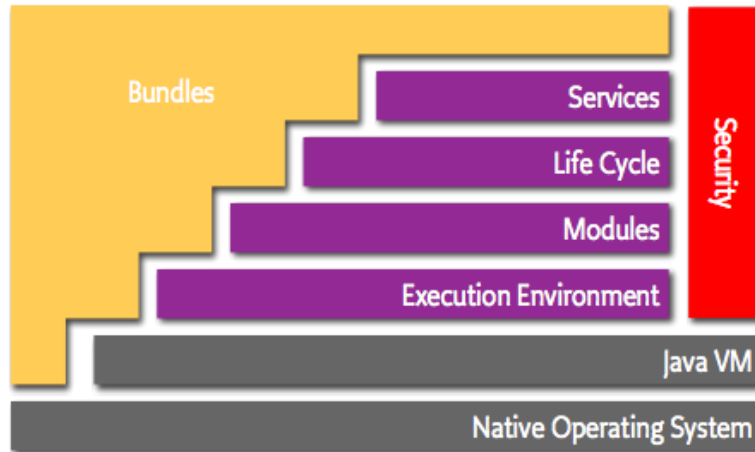


Figure 3.6. The OSGi layer model, picture from [78].

OSGi and modular design

The OSGi technology is a set of specifications that define a dynamic component system for Java [78]. These standards enable different components of a software system hide their implementations from others. They communicate with each through services, which are specific objects shared between components. Figure 3.6 shows the layer model of the OSGi framework.

The *service layer* of OSGi framework simplifies the development and deployment of service bundles by decoupling service standards and its implementation. It allows developers to bind their services using only their own interface specifications, so the implementation of the interface can be decided at the runtime. More detailed description of the architecture and mechanism of this framework can be found on OSGi Alliance website [78].

The service-based function organization method makes both development and use of the Intellichalk system very convenient. For example, the user can use pen gestures on the editor to trigger the intelligent assistants, the plug-in modules developed to assist teachers with their teaching. Both the handwriting recognition based λ -calculus interpreter and the hand-drawn shapes recognition based logic circuit simulator can be triggered by the same gesture ($\leftarrow \downarrow$), as shown in Figure 3.7.

The two plug-in modules are registered as the same type of service. At runtime, the pen gesture bundle does not need to know which bundle it is calling. All services responding to execution gesture ($\leftarrow \downarrow$) can be called to provide their functions. The advantage of this mechanism is that the system can dynamically activate different services to provide the corresponding functionality. Logic circuit simulator, λ -calculus interpreter, and pen gesture bundles do not need to know each other. The module that provides service and the module that invokes the service cooperate with each other through the service type.

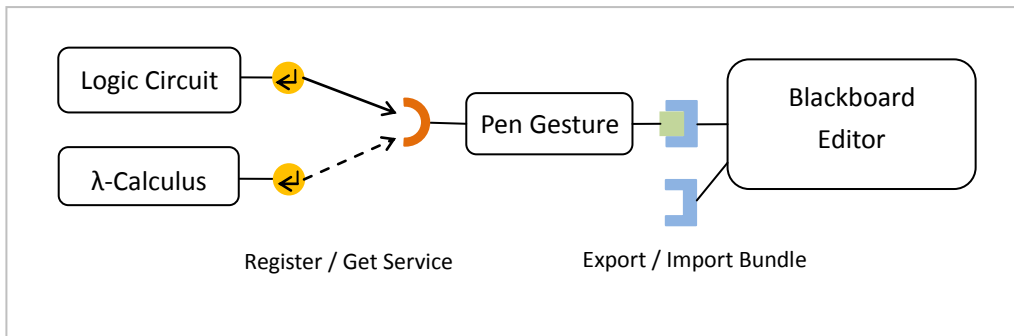


Figure 3.7. The collaboration mechanisms between bundles. A number of bundles can be registered as the same service. Bundles need to explicitly export or import the parts they want to share or use.

This approach provides lazy loading, hot plugging, dynamic switching features and good scalability. When we need to add more functions called by the execution gesture, such as calling other third-party software and plug-ins, we only need to register them as the same service while the existing services bundles, the service invocation bundle, and the service type itself do not need any modification. The lazy loading feature makes sure the services are created only when they are called. It is likely that the system will run several times without the less commonly used services being created. This mechanism can effectively reduce system overhead when the system is gradually expanding and has a large number of services.

The main functional modules of Intellichalk can be divided into three categories, the basic modules, the intelligent modules and the plug-in modules.

Basic modules

Basic modules are the most basic modules and support the most commonly used functions. The basic modules are listed as follows:

- *Editor module*

This is the Interface between teachers and the Intellichalk system. We have described the user interface layout and functionalities of each part. It provides teachers with a familiar blackboard-like environment. As the digital ink technology is the base of an electronic blackboard system, the writing experience was the top priority during the design phase of this system. With a high quality graphical tablet, it offers a smooth and flexible writing experience as if the user were writing on real paper.

According to our design, each teaching element is a Java object, so users can easily move it, change its size, delete or store it. All the teaching elements are stored with time stamps and location information for further use such as online handwriting recognition and pen gesture recognition. At the end of the lecture, a PDF file of the lecture notes is generated and sent to the students for review.

- *Multimedia resource management module*

Intellichalk enables teachers to use a variety of media elements for teaching. Multimedia resource management module organizes the multimedia files and provides them to the user, including images, PDF files, PowerPoint files, digital ink blocks and geometric shapes. These files can be present in an intuitive and convenient way in the corresponding functional views. Teachers can use them flexibly during their lecture.

- *Lecture recorder module*

The lecture recorder records all the actions made in the editor and the audio of the lecturer's speech. The whole lecture can be replayed after class. Each operation in the lecturing area, such as writing, adding pictures, editing a visual element or dragging the lecture canvas will generate a record with start and end timestamps as well as operation type, operation object, position, and other attributes of the operation. Therefore, the archived classroom files can be played back for online teaching or students' review after class.

- *Screen management module*

The public screen is the interface between students and the system and acts as a visual information exchange media. The Intellichalk system supports teaching with a number of different displays. The screen management module helps the user to control and switch between multiple screens. Regardless of the hardware configuration on which the Intellichalk system runs, it provides teachers with a consistent way to use multiple screens.

Intelligent modules

In order to improve the usability and functionality of Intellichalk, three intelligent modules were added to the system. Developers can use these intelligent modules and basic modules to develop interesting teaching tools.

- *Handwriting recognition module*

A great advantage of digital ink is that it naturally collaborates with handwriting recognition technology. With the help of handwriting recognizers we can make the blackboard look "smart". The handwriting recognition tool we use in the system called "Lipitk" was developed by HP Lab India [79]. The purpose of this handwriting recognition module is not to develop a recognizer with the world's leading recognition rate, but to create a lightweight and fast recognizer to support the development of interesting tools.

- *Sketch recognition module*

The sketch recognizer can identify geometric shapes such as triangles, ellipses, and arrows. It is designed for a more natural form of human-computer interaction.

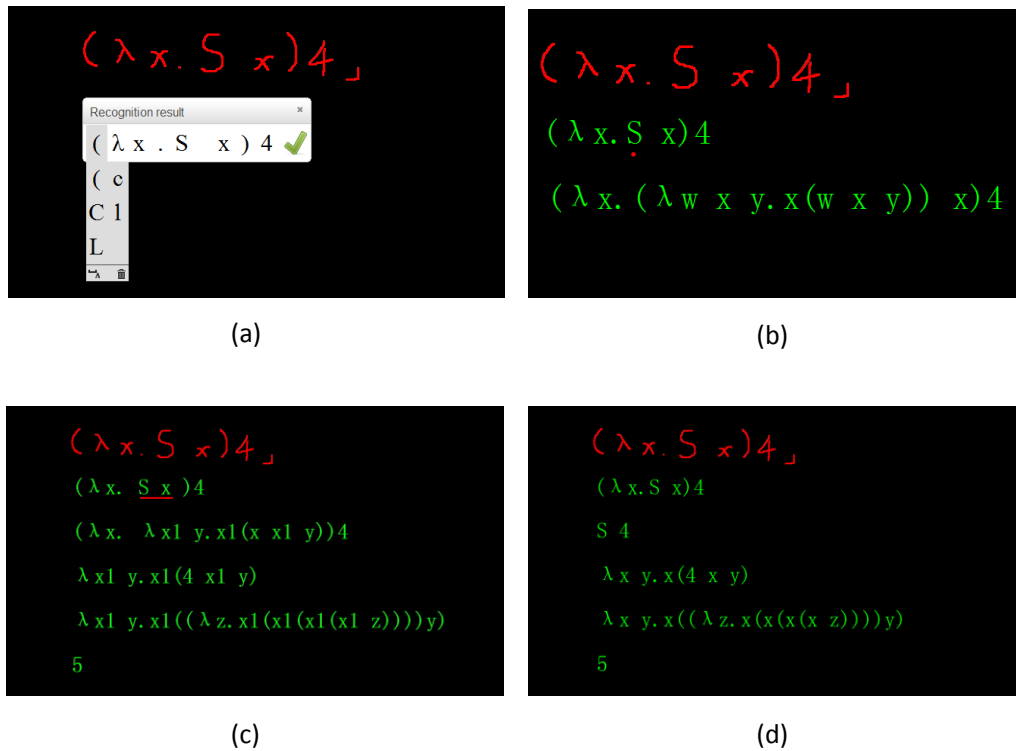


Figure 3.8. The handwritten Lambda calculus Interpreter plug-in.

- *Animation module*

Intuitive animation is a great tool to explain theories and processes in various disciplines. We defined basic animation actions in this module. It can be used to develop teaching aids such as algorithm animation.

Plug-in modules

Our system structure makes it possible to develop pluggable components for learning. We have already developed three interesting tools using basic modules and intelligent modules.

- *Lambda calculus*

This is an interesting Intellichalk plug-in application that we developed using a handwriting recognizer. An undergraduate student developed the lambda interpreter as his graduation project and we combined it with the handwriting recognizer and the editor module to implement this application. The handwriting recognizer identifies the hand-written inputs, and sends them to the lambda calculus interpreter. The interpreted results are shown line by line in the form of text. Figure 3.8 shows the interface of this application. Users can replace incorrect recognition results with alternatives.

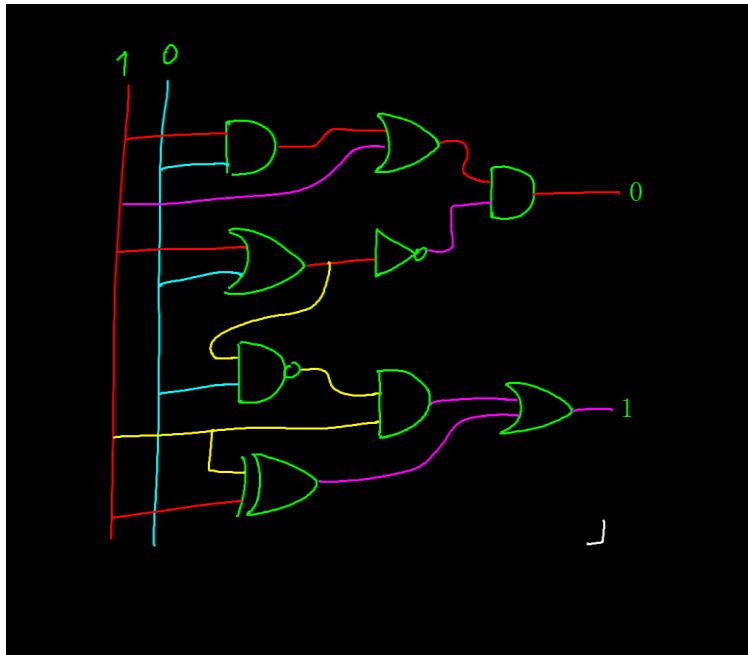


Figure 3.9. Logic Circuit simulator.

They can use the “enter” and “backspace” keys to control the interpretation steps. Underlines and dots are used to specify which clause or symbol to expand in the next step. These features are designed for detailed explanation of lambda calculus and the plug-in application was developed for a functional programming course which is open to first year computer science students.

- *Logic circuit*

A logic circuits simulator was developed for teaching computer science. It can simulate hand-drawn logic circuits. Users sketch digital circuits on the editor and assign the input with “1” or “0”. Recognizers run in the background to identify the gates and inputs. The outputs are given after simulation (see Figure 3.9). It can recognize seven types of logic gates and zero and one as inputs. An undergraduate student developed this simulator with the intelligent modules of Intellichalk. He conducted a user test, and reported that the overall recognition rate of the simulator is around 96%.

Including the handwritten lambda interpreter and this hand-drawn logic circuit simulator, we developed these intelligent applications to support classroom instruction while making the lecture more interesting. We call these applications intelligent assistants. We plan to collaborate with more third-party software to develop more intelligent assistants to support classroom teaching. These applications provide more natural human-computer interaction. The handwritten inputs will be processed by a variety of background services and output the results to the editor.

- *Classroom Interacter*

This module was developed to collaborate with a server and student clients to facilitate voting, present student status information and receive questions from students. In collaboration with the server and the student clients, it constitutes a distributed interactive system with a wider range of usage scenarios. It supports classroom interaction with audiences' own mobile devices and can enable distance learning, a remote class can receive the lecture with a web browser. We will introduce the extended version of this system and its use in later chapters.

3.5 Hardware Setup

Two basic devices are required to run the Intellichalk system: a computer with a pen based input device is needed to collect input from the instructors, and one or more public displays to present the lecture to the students.

The lightweight setup: A pen input device with a projector

This is a cost-effective deployment. Current university classrooms are usually equipped with computers and projectors. Only one more pen input device is needed to use Intellichalk in the classroom. In this setting, the Intellichalk system works as an electronic whiteboard. Teachers can still benefit from the easy-to-use user interface, multimedia resources capabilities and the intelligent assistants. However, due to the limited display area, a lot of advantages we inherit from traditional blackboard cannot be expressed, which limits the potential benefits of the Intellichalk system for classroom teaching.



Figure 3.10. Intellichalk equipped in a multimedia classroom with four large screens.

The medium setup: A graphic tablet with two projectors

Using two displays, the instructor can display the old information so that students can still see the previous screen when the lecturer is writing on another one. They can compare different content on two screens, and refer back to previous content to support their explanations. These are important teaching techniques used with traditional blackboards, but which are not supported by single screen slide presentations. As more and more lecture rooms in universities are equipped with more than one projector, new software suites are needed to make efficient use of them to enhance classroom learning. The Intellichalk system is designed to support multi-displays and display walls.

The ideal set up: digital display walls

Compared to digital projection screens, LCD screens have many advantages. They offer better visual quality and contrast, are easier to calibrate, and do not require dimming the classroom lights. Figure 3.10 shows Intellichalk equipped in a multimedia classroom with four large screens. It gives the users adequate display space. This is our ideal hardware setup as it can fully express our underlying design idea for the system. As the display technology develops rapidly, large high-resolution displays are becoming increasingly affordable. It is highly likely that in the near future, LCD walls will be used in more classrooms.

3.6 Handwritten Notes Extraction and Segmentation System

During lesson preparation, teachers often need to edit a formula, add a mathematical symbol or draw a diagram to express their ideas. Tools like Microsoft Word, PowerPoint need a lot of work and time to complete this task. When a sketch is needed, neither drawing with a mouse nor combining basic shapes provided by the editing software can easily achieve the desired result. In this case, users are likely to miss the convenience of drawing with pen and paper. If a tool can extract the hand-written shapes and symbols out from the paper, we believe it will provide great convenience to lecturers who work in mathematics, physics and engineering etc. disciplines. Therefore, we designed and developed this lecture preparation system to provide such functionality.

The lesson preparation system includes a camera with bracket and an independent program. Users only need to put their prepared paper under the camera and click a button, content written on the paper will be extracted out digitally (Figure 3.11). Content can be segmented as digital ink blocks by drawing a straight line between two parts. The resulting descriptive or conceptual digital ink content can be used later in the Intellichalk presentation system. Users can adjust the size and change the color of these ink blocks freely.

Figure 3.12 shows the handwritten notes extraction steps, including image capture, grayscale, binarization, noise reduction and segmentation. The most important steps are binarization and ink block recognition.

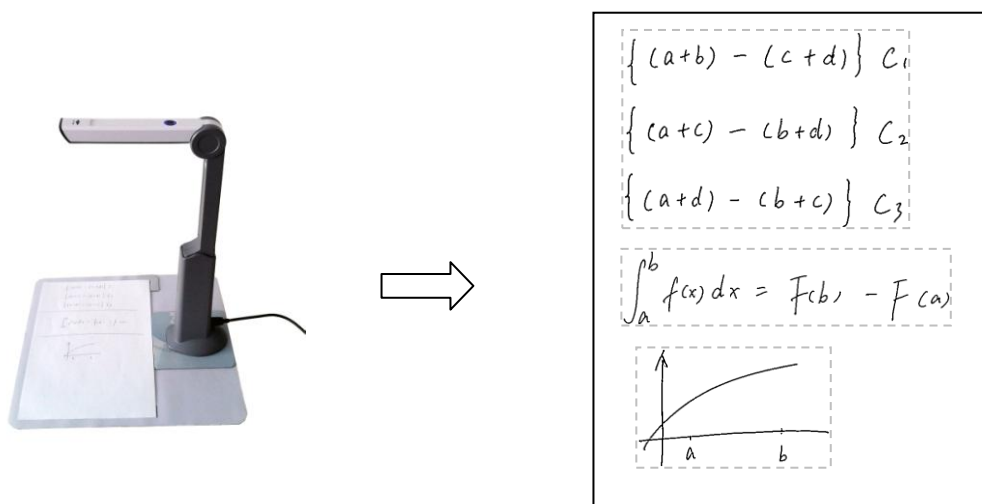


Figure 3.11. A camera with bracket is used to generate digital ink blocks from hand-written text on paper.

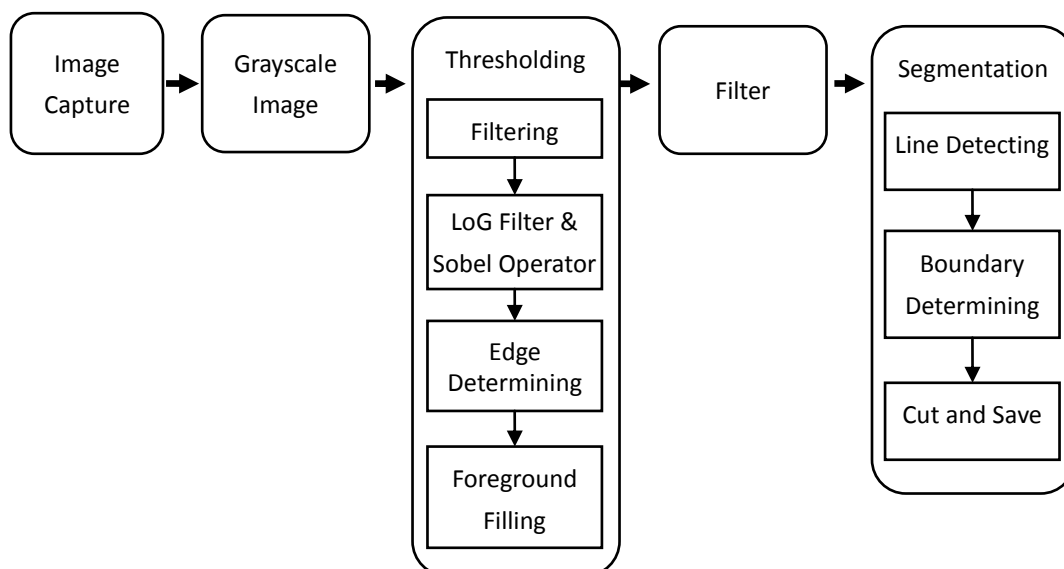


Figure 3.12. The processing steps of the ink block extraction system.

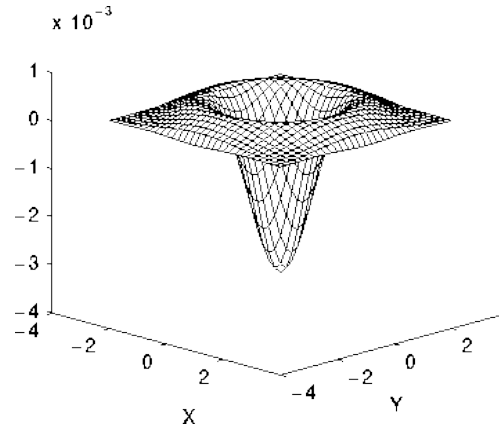


Figure 3.13. The Laplacian of Gaussian (LoG) function.

Binarization is an important issue in image processing and image analysis, and it is a common operation in graphics and image applications. The results of binarization directly affect the performance of the application system. At present, there are many binarization algorithms, which can be divided into global threshold methods and local threshold methods. Global threshold methods, such as the histogram method and Otsu's method use a single threshold for the entire image. As our system will be used in real life at any time, uneven illumination and low lighting environments are very common. The global threshold methods that we tried are sometimes unable to distinguish the foreground and the background well. Local threshold methods choose thresholds according to local gray values, so they are able to work with uneven lighting conditions. Such algorithms include the Bernsen algorithm, LEVBB (Local Extreme Value Based Binarization) algorithm and so on. We also tried these algorithms, but the results were not accurate when the paper was wrinkled, or the text was written in pencil which causes color differences within each stroke and does not provide strong contrast with the background color. The results of these algorithms show intermittent or sticky strokes, or identify the foreground incorrectly. After several attempts, we finally used the Laplacian of Gaussian (LoG) operation to detect the edges of images (Figure 3.13), then binarized the image based on the edges detected. We describe how we used this method to binarize images as follows.

$$\text{LoG}(x, y) = -\frac{1}{\pi\sigma^4} \left[1 - \frac{x^2 + y^2}{2\sigma^2} \right] e^{-\frac{x^2 + y^2}{2\sigma^2}}$$

(1) Since the LoG algorithm is sensitive to noise, we first smooth the image $f(x, y)$ using the $3 * 3$ mean filter. The output image is denoted by $f'(x, y)$.

(2) Then we use the LoG algorithm with $\sigma = 0.7$ and window width $w = 5$ to

approximately apply to the image $f'(x, y)$. An output LoG (x, y) is obtained.

(3) We use the Sobel operator to calculate the horizontal and vertical edges of $f'(x, y)$.

$$\text{Sobel}_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} * f'(x, y) \quad \text{Sobel}_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} * f'(x, y)$$

(4) When $\text{LoG}(x, y) < 0$ and $\text{LoG}(x-1, y) * \text{LoG}(x+1, y) < 0$ and $\text{Sobel}_x > 40$ or

$\text{LoG}(x, y) < 0$ and $\text{LoG}(x, y-1) * \text{LoG}(x, y+1) < 0$ and $\text{Sobel}_y > 40$, the pixel (x, y) is on the edge, otherwise it is an undetermined pixel. The output image is $L(x, y)$ after this step.

(5) The value of the undetermined pixel is decided by the pixel values within $3*3$ ranges around it. A binary image $A(x, y)$ with separated background and foreground is generated after the steps above.

After the binarization, the next step is to recognize the dividing lines and crop the image.

First, we use a simple search window to identify the dividing lines. Within the range of the window with a height of w , the maximum continuous pixel length L in the horizontal direction is calculated. When L is greater than or equal to the given threshold ε , it is determined that this window contains a dividing line. We set $\varepsilon = 0.75 * W$, where W is the width of the image (see Figure 3.14). Compared with Hough Transform, the commonly used line detection algorithm, our method is fast and effective, since the dividing line is defined as a substantially horizontal direction, it is unnecessary to consider image rotation. Furthermore, the Hough Transform algorithm cannot recognize hand-drawn lines well, especially in a block with lots of content where discontinuous pixels may be identified as straight lines by the algorithm. The method we use in our application has clear advantages over Hough Transform in terms of computational efficiency, recognition rate and implementation complexity.

Then we need to identify the actual range of the ink blocks. After recognizing the splitting lines, the image is segmented into several blocks, each with the same width as the original image. The exact size of each ink block is confirmed according to the distribution of the histogram in both horizontal and vertical directions, as shown in Figure 3.15. The darker blue area in the center is the determined ink block area.

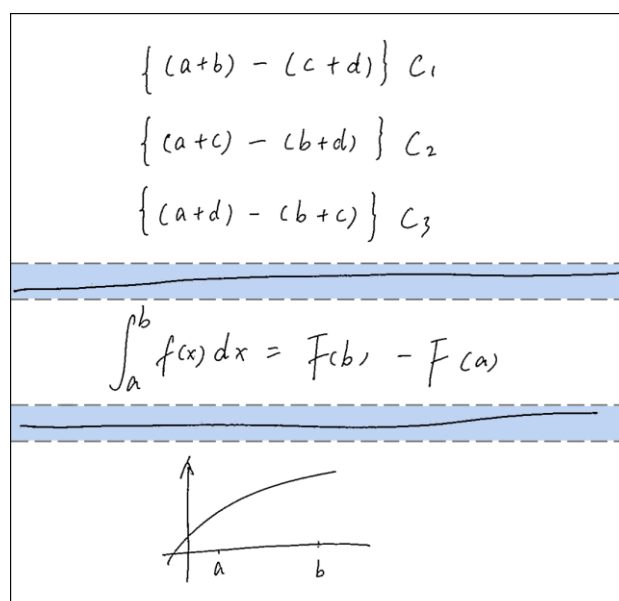


Figure 3.14. The scanning window is used to detect the splitting lines.

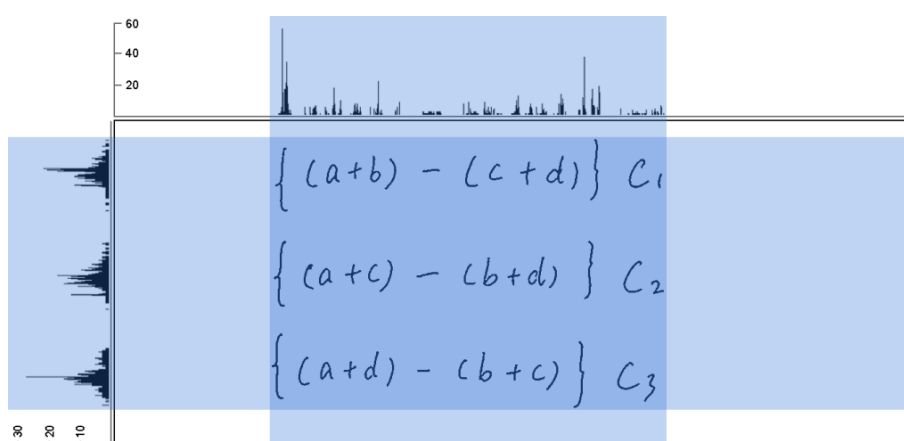


Figure 3.15. The histogram of both horizontal and vertical directions are used to determining the boundaries of ink blocks.

The benefits of this handwritten notes extraction tool for teachers can be outline as follows:

- They can use pen and paper to prepare their lectures, this natural way of writing is more convenient and will not interfere with their thoughts.
- With a single click, contents written on the paper will be extracted out digitally and organized as digital ink blocks according to the user's intention.
- Digital ink content can be easily reused to improve the efficiency of lectures, or used in other teaching software as images.

3.7 Intellichalk Player

We have introduced that in the lecture recording module, all the actions on the editor and the instructor's speech are recorded automatically during the lecture. A player was developed to replay the entire lecture (Figure 3.16). It was implemented by an undergraduate student as his graduation project.

The recording of a lecture gives students opportunities to review the lecture and reinforce what they have learned. The recorded lectures can also be put online for distance learning. Several applications can record the lecturer's desktop during lectures, such as AOF [44] and Dyknow [74]. However, the computer desktop may be personal and should be viewed privately by the instructor and not to be shared with the audience. The manipulations with the presentation program and files on the computer are under the observation of the whole class. This is a distraction for the learners, and may cause stress for some lecturers.

Most of the recording tools require the user to install and control extra software. But the Intellichalk user does not need to spend any extra effort. The system automatically records the lecture and creates the online learning material. Many institutes spend huge human and financial resources to create distance learning courses while the Intellichalk users create online courses as byproducts. The lecturer may even not notice she is also creating a distance learning lecture.

Compared to normal video records, it has much better graphic quality and smaller file size, which is well suited for long-distance transmission and online playback. The replay technique we use has the following advantages:

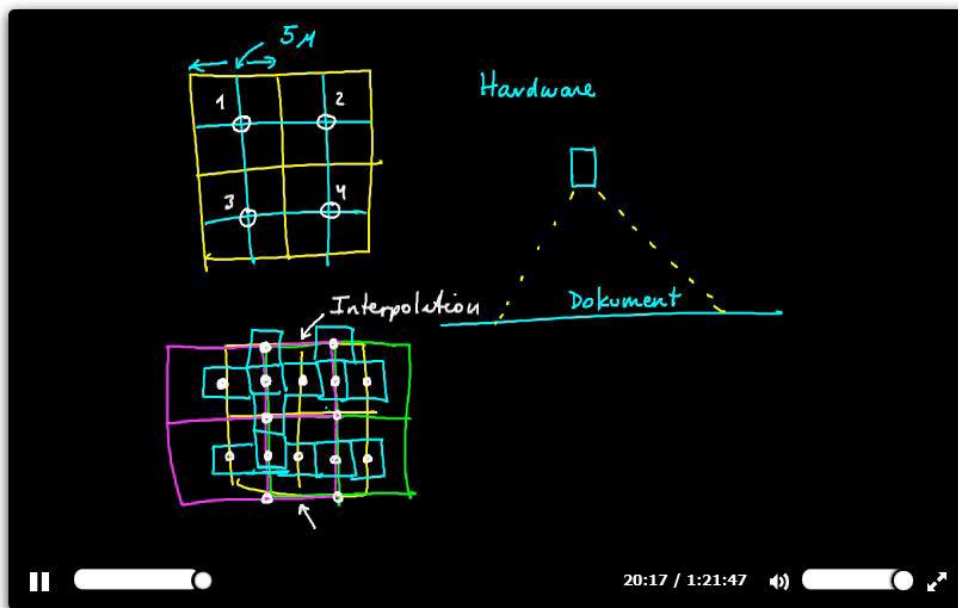


Figure 3.16. The Intellichalk player.

- No need to install software, the lecture can be played remotely on the browser (with the support of Java Runtime Environment).
- Can be used for distance learning.
- The lecture is recorded from the students' perspective; distractions from the instructor's manipulation will not appear.
- The lecture is replayed in very high graphic quality.
- The file size is very small. A typical 1.5-hour lecture generates a file of about 10 Megabytes, so it does not take up much bandwidth.

3.8 Summary

Based on the Design-based Research methodology and user-centered approach, we designed and implemented Intellichalk, a classroom presentation system with the blackboard metaphor. The aim of Intellichalk is to enhance the traditional blackboard with the benefits of a digital system, making it a more suitable tool for teaching. The first prototype of Intellichalk was implemented in 2013 and has been deployed for real classroom use ever since. Through continuous iteration of design, implementation and deployment, the functionality and the user interface has become increasingly mature.

We have introduced the functionalities and features of the system. It provides a familiar blackboard-like user interface to instructors. One design goal of Intellichalk is to support dynamic teaching techniques that were supported by traditional blackboards but are not available with common slide presentations.

It supports multi-display media systems. As the display technology develops rapidly, large high-resolution displays are becoming increasingly affordable and available. Many institutes have equipped multiple projectors in lecture halls. Existing software such as PowerPoint is designed for a single display. We aim to take the advantages of the growing display area in classrooms to enhance both teaching and learning.

The information technology and artificial intelligence has the potential to bring great changes to classroom learning. We try to implement different kinds of "intelligent assistants" to enhance classroom experience. The handwriting recognition and sketch recognition technology supports a more natural form of human computer interaction. We have demonstrated two possibilities in this direction.

The presenting of the writing process gives the students an opportunity to observe the teacher's thoughts and keep the lecture at a pace which is not too fast for students to follow. The advantage of digital slides is that they can be easily reused. The two benefits conflict with each other. Therefore, we implemented the partial reuse of lecture content, in order to improve the efficiency of teaching while keep the benefits of the blackboard. The lecture preparation system is designed to achieve this goal. Units of descriptive and repeatedly used content are called "Macros" in our system. Lecturers can prepare the

content they want to present on a paper and extract it as ink blocks. These can be added to the lecture canvas anytime, anywhere.

We also implemented a player. Students can review the lecture after class for better understanding. The archived lectures can be put online for distance learning.

4 A Study of a Wall-Sized Electronic Blackboard Used in University Classroom Lectures

4.1 Introduction

Nowadays digital projection of slides is the most common form of teaching in university classrooms. However, the screen real estate has dramatically decreased compared to traditional blackboards. We believe that large visual aids such as traditional blackboards offer many advantages for teaching compared to single-display slide presentations [80]. One study [10] compared the use of traditional blackboards (or whiteboards) and slide presentations, concluding that blackboards supported many more presentation techniques than slide software. Researchers tried to solve this problem by introducing more projectors. Dual-projector systems were developed and tested by numerous researchers [55-57]. Two of the most frequently reported benefits of increasing the visual area are an improvement in the learning effectiveness of students [56, 57] and a reduction in the cognitive loads [55]. However, the information that can be presented on dual projection screens is still less than a typical traditional blackboard.

The Classroom 2000 project [59] used three projection screens to create a public display area comparable to a traditional blackboard. It focused on the capture of in-class activity for later review and also tried to enhance group interactions in the classroom. The Virtual MultiBoard [60] can show previous slides, or other applications, using one or multiple projectors. ModSlideShow [61] proposes a presentation system on which users can use a gestural interface to manipulate the flow of slides on multi-displays. These infrastructures shared some common ideas: they all organized the displays separately, and used slides to present information. The extra projection screens were used to display history information or other environments such as a browser window.

Our approach is to use four 60-inch LCD screens placed side by side to provide a very large visual area that is comparable to a traditional blackboard. The Intellichalk system, we introduced in the preceding chapter, is used to transform the display wall into an electronic blackboard.

We have deployed the system in the classroom for real teaching practice. This study focuses on the following questions: which benefits can a wall-sized electronic blackboard bring to instructors; compared to slide presentations, can the electronic blackboard help students better understand the lecture?



Figure 4.1. The Intellichalk system running on a multi-display hardware system.

In order to address this problem, the Intellichalk system was also deployed in a large lecture room. There is only one projection screen in the lecture room. It has larger visual area but has the same resolution as one of the digital screens installed in the multimedia room. We studied the use of Intellichalk in both settings, trying to understand the benefits of the electronic blackboard, as an innovative visual aid, for classroom teaching.

4.2 Study

4.2.1 Experiment Settings

Multi-display setting

As can be seen in Figure 4.1, the public display wall consists of four 60-inch LCD screens. The total length of the display wall is 5.5 meters wide and one meter high, with resolution of 7680 by 1080 pixels. A graphical tablet with a 22-inch screen is the input device. It offers the instructor an additional view from the public screen. All five screens are connected to a computer with the Intellichalk software running on it.

Figure 4.2 shows how we arranged the four screens. The writing area extends vertically to fit the user's writing habits. The content is mapped to the four horizontally positioned screens. The instructor can get unlimited writing space by pushing up the old contents.

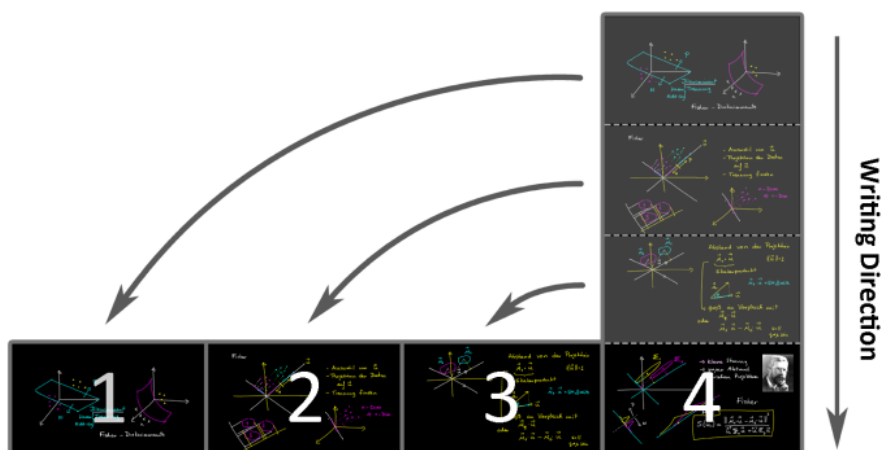


Figure 4.2. The arrangement of the displays.



Figure 4.3. The Intellichalk system running on a single-projector setting.

Single display setting

From late 2015, the Intellichalk software was also installed in a large lecture room with around 200 seats. It has a projector with the same resolution of one of the four digital displays in the multimedia room. The input devices are the same model as used in the multi-display setting.

4.2.2 Study Methods

The Intellichalk system was developed in 2013 and has been in use ever since. In order to investigate how the instructors use the electronic blackboard in the context of classroom teaching and how students evaluate the system, we employed a variety of quantitative and qualitative methods to gain multiple perspectives on the usage of Intellichalk.

Activity Log: We developed an activity recorder as a plug-in for the electronic blackboard teaching system. All the operations on the system were logged for further analysis, including writing, color switching, adding images and so on. These data will be used to objectively and quantitatively analyze how teachers use the electronic blackboard features during their lectures.

Student Questionnaire: In order to understand the students' opinions about the electronic blackboard lectures, and to understand the benefits of the system for their learning, we sent out paper-based questionnaires at the end of each course. Students were asked to evaluate the electronic blackboard system. In total, 82 students filled out the questionnaire.

Observation: Researchers were in the classroom during each electronic blackboard lecture to observe how teachers use the system. During the lectures, we observed how they manage the screens, how they interact with students, and the type of visual content the instructors used. Also, we were there to offer technical support.

Instructor Interview: At the end of each course, a brief interview was conducted with the instructor, asking her opinion about the system, the problems they encountered, and their suggestions for improvement.

These methods are complementary to each other. Interviews and questionnaires provided data from teachers' and students' experiences of teaching and learning. The activity log provides objective data on the teacher's behavior. The observations during class can identify classroom activities, which cannot be recorded, or which users fail to report.

Table 4.1 shows the courses taught with Intellichalk and type of data gathered from each course. The number of students in each course is approximate.

Screens	Instructor	Course	Semester	Duration	Students	Log	Interview	Questionnaire	Observation	PDF
4	I1	C1 : Artificial Intelligence	2013 Summer	10*1.5 h	50				✓	✓
	I2	C2 : Image Processing	2014 Summer	8*1.5 h	60	✓	✓	✓	✓	✓
	I1	C3 : Pattern Recognition	2015 Winter	8*1.5 h	40	✓	✓	✓	✓	✓
	I3	C4 : Functional Programming	2015 Winter	1*1.5 h	30	✓	✓	✓	✓	✓
1	I4	C5 : Seminar	2015 Winter	1*1.0 h	9	✓	✓	✓	✓	✓
	I3	C6 : Non-sequential Programming	2016 Summer	3*1.5 h	80	✓		✓	✓	✓
	I1	C7 : Pattern Recognition	2016 Summer	12*2.0 h	15	✓	✓	✓	✓	✓
	I1	C8 : Artificial Intelligence	2016 Summer	5*3.0 h	60	✓			✓	✓

Table 4.1. List of courses taught using Intellichalk and type of data gathered from each course.

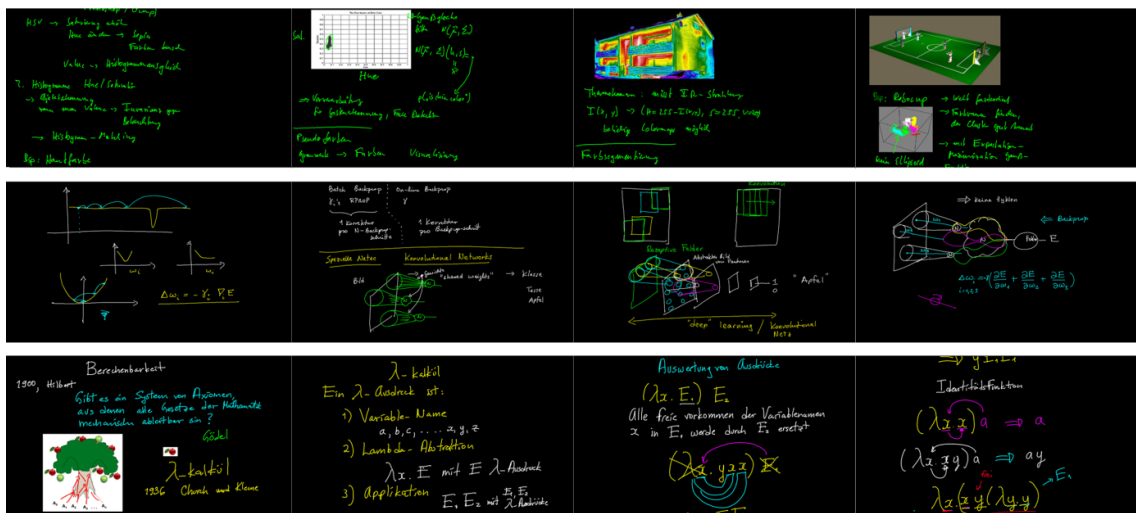


Figure 4.4. Screenshots of C2 – C4 (top to down)

4.3 Results

We chose C2 – C4 as the study objects in the multi-display setting since C1 and C3 were taught by the same teacher and C1 is excluded from the study since it was an early deployment with incomplete information.

4.3.1 Overall Results

The software system for the electronic blackboard was used by 4 lecturers in 7 courses and one seminar. C1 – C4 took place with the display wall system while C5 – C8 were taught with the single display system. Our study focuses on the consequences of multi-display based electronic blackboards used for classroom learning. Therefore, we study C2 – C4, which were taught by three different teachers and the use of the system were fully logged. Figure 4.4 shows the screenshots from three lectures. All three instructors complete their teaching with the functionality provided by the electronic blackboard.

The log system recorded all the operations with timestamps and duration on the electronic blackboard. We list the frequency of the most used functions in Table 4.2.

Operation	Frequency	Frequency per Lecture
Writing	38406	2259.2
Switch Color	1429	84.1
Move Canvas	638	37.5
Undo	269	15.8
Delete	323	19.0
Add Image	61	3.6
Move element	26	1.5

Table 4.2. Frequency of the most used functions of Intellichalk.

Writing and adding images are operations to create lecture content while other operations are used to interact with the system. Comparing these two types of operations, the vast majority (93.5%) of user manipulations are creating new teaching contents, while only 6.5% of the operations are used to interact with the system.

Screen	Writing (s)	Move Canvas (s)
4 screens (C2 – C4)	656.9 / 446.7	62.0 / 42.1
1 screen (C5 – C8)	923.8 / 482.0	155.2 / 81.0

Table 4.3. Average writing time and moving canvas time per lecture / per hour.

Considered from the perspective of time, moving canvas, writing and moving visual elements are continuing operations. Other actions require only a single click. We did not record the duration of these actions. We use the total time of writing and moving the lecturing canvas to represent the time used for creating lecture content and time spent interacting with the electronic blackboard, since these two operations are the most time-consuming actions. Table 4.3 shows the average time spent writing and moving canvas for each lecture and each hour. Data on single display use are added for comparison.

We can find that instructors spent similar lengths of time writing on the multi-display and the single-display systems each hour (446.7s and 482.0 s). However, time spent moving canvas on the single-display system is almost twice as long as the time used on the multi-display system (81.0 s and 42.1 s).

4.3.2 Refer Back

Our electronic blackboard has four screens. Each of them can present a similar amount of information to a projection screen. In our study, all users used one screen as the focus area to display the newest content. When it was full of information, they scrolled the teaching canvas to get more space to continue writing. That means each stroke went through all four screens before it left the visual area. Therefore, relevant information stays on the display wall for a long time for reference.

Screen	Times / lecture	Times / hour
4	0.55	0.37
1	4.72	2.46

Table 4.4. Refer back actions on the multi-display system and the single-display system.

Screen	Times / lecture	Times / hour
4	0.00	0.00
1	4.67	2.33

Table 4.5. Refer back actions of I1 on both multi-display and single-display systems, teaching the same courses.

We calculated the number of times the lecturer referred back on both systems to analyze the influence of the multi-display system on this common teaching practice. One refer back action is defined as: a sequence of moving back the lecturing canvas to bring back the history information that has disappeared, then changes are made to the history information or it stays on the display for a short period of time (10 seconds for example). Table 4.4 shows the average refer back actions detected on both the multi-display and the single-display systems. On the single-display system, the instructors went back 4.72

times per lecture, 2.46 times per hour on average. The actions are significantly reduced on the multi-display system, with 0.55 times per lecture and 0.37 times per hour. Table 4.5 compares the referring back actions with the same instructor and the same course (C3 and C7) on both systems. No refer back action were found when I1 used the multi-display system, while he referred back 4.67 times per lecture on the single-display system, 2.33 time per hour on average.

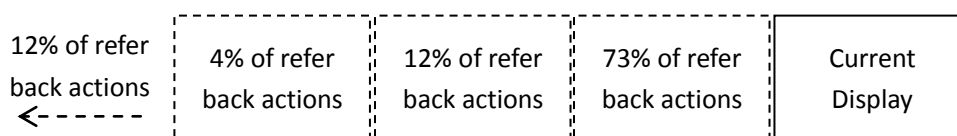


Figure 4.5. Refer back distance distribution on the single-display system.

85 refer back actions were recorded on the 19 lectures logged with the single-display system. We calculated the distance of each action and presented the distribution of all actions in Figure 4.5. We can see that more than two thirds (62 times, 73%) of the referring back actions happened within one screen distance. 10 times (12%) referred to information two screens from the current display. The lecturers only referred to information which was three screens before the current display 3 times (4%). However, 12% of all refer back actions targeted older information.

4.3.3 Use of Colors

An immediate advantage of the electronic blackboard, compared with the traditional one, is that teachers can easily use a variety of colors. The system provides users with 28 color. However, according to the logged data, instructors used only 4 to 8 colors per lecture. From Table 4.2 we find that switching color was the most frequently used function except for writing. The average number of color changes per lecture was 84.1 times, which is far more than a typical lecture on traditional blackboards.

Four colors which contrast strongly with the black background were most frequently used: they were white, yellow, green and cyan. In this study, we found that the use of colors presented several patterns.

Course	1 color	2 colors	3 colors
C2	55.8%	77.8%	92.7%
C3	46.7%	75.4%	89.1%
C4	49.2%	68.5%	84.1%

Table 4.6. The percentage of ink strokes with the most frequently used colors.

	C2	C3	C4
Color changes	67.6	100.9	72
Color used	6.5	5.4	8

Table 4.7. Average color changes and colors used per lecture.

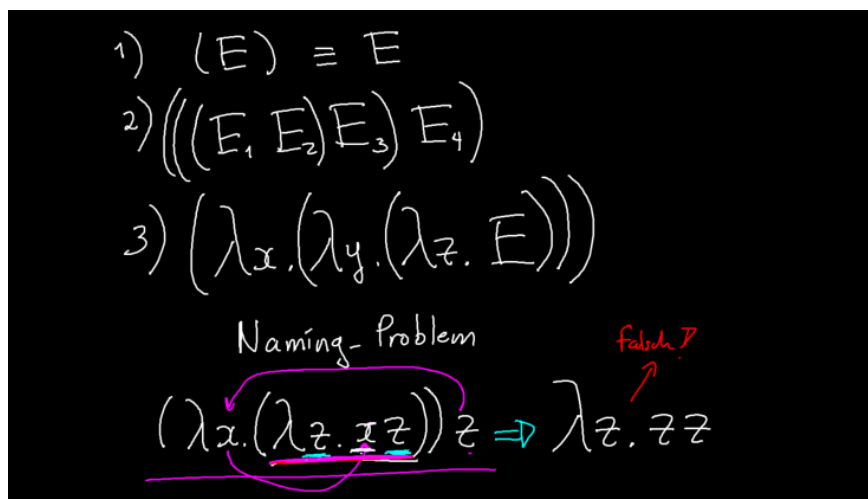


Figure 4.6. The instructor of C4 drew lots of attention marks with red ink.

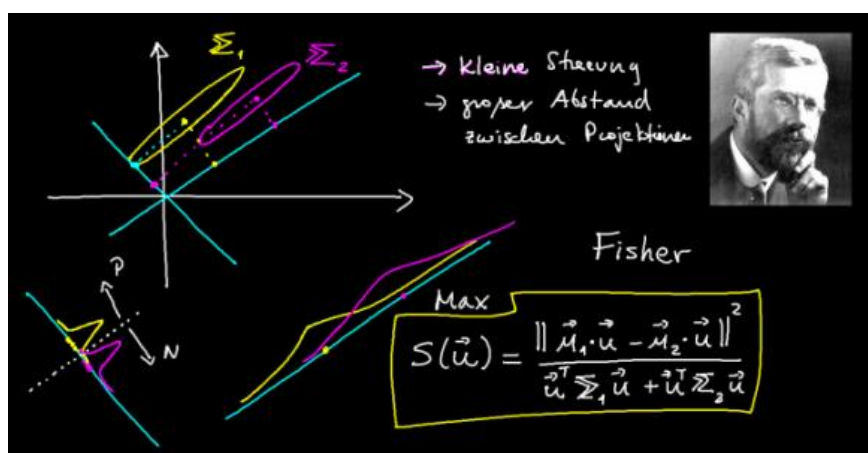


Figure 4.7. The instructor of C6 used colors to express different or related concepts.

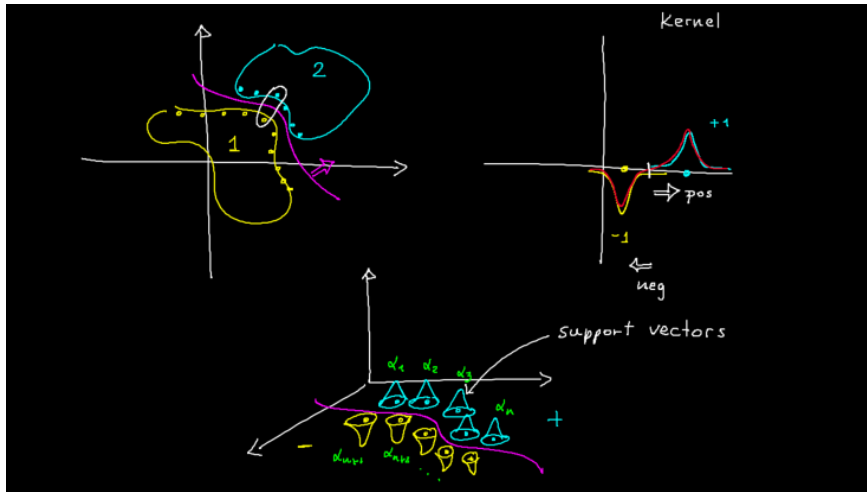


Figure 4.8. Colors were used to express different or related concepts.

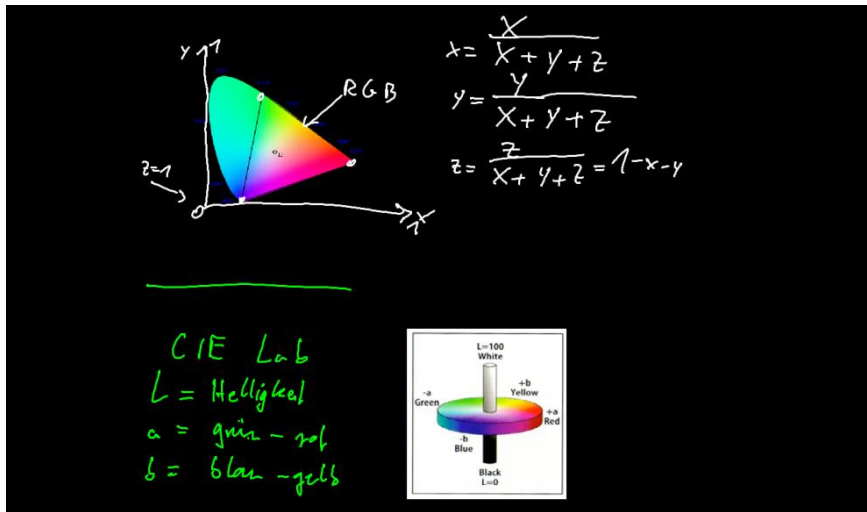


Figure 4.9. The instructor added annotations to images.

1. Using one or two colors as the basic color. The instructors chose one or two colors for the greater part of their teaching content, and other colors were used in addition. In all the three lectures, the most frequently used color occupied around half of all ink strokes. And strokes with the two most popular colors accounted for around 70 percent of the total number of strokes (see Table 4.6). Using colors in this way can create well structured content (see Figure 4.6 and 4.7 for examples).

2. Using colors to distinguish and associate concepts. In Figure 4.7, the instructor used a diagram to introduce an algorithm (Fisher's linear discriminant). Different colors (yellow and purple) were used to illustrate different concepts (two classes). The same color (yellow or purple) was used to represent related concepts (a class and its projection). This usage can also be found in figure 4.8.

3. Using colors to emphasize the existing content or to attract attention. In figure 4.6, the instructor used red and magenta, which provide a sharp contrast with the base color (white), to draw attention marks. In figure 4.7, the instructor surrounded a white formula with a yellow frame to attract the students' attention.

4. Using colors to separate content. The instructors usually picked a color to contrast with the existing color when starting a new section of their lectures. We can find examples in Figure 4.9, and the screenshots in Figure 4.4.

4.3.4 Questionnaire Results

82 valid questionnaires were collected from C2 – C4. The questionnaire results indicate that students thought the visual quality of the digital multi-display system was better than projection displays (Mean = 4.21, SD = 0.90), they enjoyed having the system in classroom (Mean = 4.01, SD = 0.91), and they expressed willingness to use the system in the future (Mean = 4.16, SD = 0.76). Moreover, students reported that the frequent use of different colors could help their learning (Mean = 4.15, SD = 0.97). When asked if the display of older information helped their understanding of the lecture contents, the majority of them (87.8%) gave positive answers. This item received the most positive reaction of the questionnaire (Mean = 4.34, SD = 0.78). Two thirds of the students (55 of 82, 67%) thought it was easier to follow the teacher's thoughts when learning with the electronic blackboard system compared to learning with slides.

Question	Mean	SD
The visual quality of the system is better than projection screens.	4.21	0.90
Overall, I enjoy having the multi-display system.	4.01	0.91
I want to use the system again in another course.	4.16	0.76
Compared to slides, learning with Intellichalk is easier to follow the teacher's thoughts.	3.79	1.01
I feel the use of different colors helped my understanding of the lecture content.	4.15	0.97
I think the display of old information helped my understanding of the lecture.	4.34	0.78

Table 4.8. Questionnaire results from students.

4.3.5 Reports from the Instructors

We did not carry out unified user training. If a lecturer wanted to use the electronic blackboard system, we introduced the functionalities of the system to her and let her practice by herself. Teachers can get familiar with the system quickly because there is not much to remember regarding the system's operations.

We asked teachers' opinions about their experience with the system in each course. Usually they were asked about the advantages of the system in their views and advice

for improving the system. I2 said the advantage of the system was “higher contrast than a normal blackboard, free use of colors and images”. I1 mentioned that when working on a graphical tablet, he could face to the class and keep eye contact with students, rather than turning his back to them. I3 also reported a benefit of working on the tablet, she said compared to normal blackboards, the whole writing area was in her view; it was easier to organize the lecture contents. I4 found the flexibility of using another environment on one of the four displays helpful for his speech.

From the logged data, we find that instructors created 18.7 screens of content for each lecture on average. Considering each screen contains approximately the same information as a slide, 18.7 screens may have less information than a slide based lecture. However, the lecture notes written on the system do not need to be as detailed as on the slides, as long as they can get through their teaching content. Teachers can also present the descriptive content in the form of images, and write only the complex derivation and explanation parts. But it takes time to prepare the lecture.

4.4 Discussions

We have implemented and deployed the electronic blackboard for long-term classroom use. Our research indicates that the digital display based electronic blackboard system has the key benefits listed below.

Reduce the effort of referring back

The display wall system displays much more information than a single projection screen. Previous content remains available for reference and comparison. From the study results, we find that instructors teaching with the single-display system conducted 6 times (2.46 to 0.37) as many refer back actions as other instructors did with the multi-display system. And the most (88%) refer back operations targeted information within 3-screen distances from the current working screen. This means that instructors can accomplish most refer back actions without interacting with the multi-display-based teaching system. The wall-sized display significantly eases the instructor’s effort of referring back. And this convenience may encourage instructors to use earlier information to support their lecturing more frequently. Although there is no statistical data, in the multi-screen classroom we observed that the teacher frequently used physical gestures to refer to the information on the previous screens.

More lecturing / less system interaction

Teaching with the Intellichalk system, 6.5 % of all operations were used to interact with the system while 93.5% of them were used to create teaching content. From the perspective of time spent, we have summed up the duration of canvas moving actions which are the most time-consuming system interaction operations. 42.1 seconds per hour, which is only half of the time as when using the single-screen setting (81.0 s), were spent moving the lecture canvas, mainly used to get more writing space. These

actions are similar to blackboard cleaning when teaching on a traditional blackboard. Users are freed from the blackboard cleaning and saved time on the electronic blackboard.

Benefits of colors

Being able to use color easily is a great advantage of digital systems over traditional blackboards. Take the slides as an example, the content on the slides are usually has various of colors while it is common to see a teacher using only white chalk writing on traditional blackboard throughout a lecture. In our deployment, we found that teachers tried to use color to help express their thoughts. They used colors for hierarchy, emphasizing and distinction. Research found that “arousing messages” such as color and images can augment the audience’s information processing, so that they can recall such messages better [81]. One study [82] shows that students recall more when the information is present with color compared to the black / white condition

During our study, students reported that the use of colors could help their understanding of the lecture content. Although the exact impact of using color on students’ learning needs further study, only from the perspective of user experience and use habits, we should provide teachers with convenience on using colors. According to our study results, we recommend that colors should be readily available when providing teaching technologies for teachers. And make sure they can pick desired color with minimum effort (no more than one click), so as to encourage them to use colors. The most commonly used colors, which are white, green, yellow and cyan in our study, placed in the most easily accessible location.

Students’ perceived usefulness

In addition to colors, students also found the display of previous information helped their learning. And overall, they believed learning with the electronic blackboard made it easier to follow the instructor’s thoughts compared to slide presentations. The inking process on the electronic blackboard exhibits the built up of information. It gives students a chance to observe the instructor’s mind, rather than showing the final results. Also, the increased display area keeps the old information available for a longer time, giving students opportunities to catch up with the lecture after a short absence of mind or note-taking.

Better visual quality / Using physical gestures

The questionnaire results show that the students were satisfied with the visual quality of the system. Actually, digital displays have many advantages over projection displays. For example, they offer higher luminance and contrast, are easier to calibrate, and do not require dimming the classroom lights. Compared with slide projection, teachers can naturally use physical gestures like when using a traditional blackboard, without the problem of casting shadows on the screen. As the display technology develops rapidly, large high-resolution displays are becoming increasingly affordable. It is highly likely

that in the near future, large digital displays will be used in more classrooms. We presented a vision of the digital future of the classroom.

Lessons learned

We have learned many lessons during the development and deployment of the electronic blackboard system. Screen mapping is a problem worth mentioning. The input tablet screen is mapped to one of the four screens (the fourth by default). The different physical dimensions of public display and private display presents problems for teachers and students. Students reported it was difficult to recognize content on C3 (see Figure 4.8) from the last row of the classroom, while I3 quickly used up the writing space with large letters (see Figure 4.6). To solve this problem we need to ensure that each letter that appears on the public display is an appropriate size: larger than 3 centimeter so that it is still recognizable from the last row of the classroom but not too large. Instructors were encouraged to use the pencil tool with 3 to 4 pixels in width for writing, and write 9 to 12 lines per screen. In fact, this is a common problem that all teachers will encounter no matter which kind of visual aids they are using. Teachers often need to adjust the font size on the slide or blackboard according to the size of the classrooms. But experienced lecturers will know whether the students in the last row can recognize the content with a glance at the public display. However, the instructors did not use the screens according to our suggestion but according to the lecture content. The role of the suggestions was only to remind the teacher this problem exists when they are using the electronic blackboard and they should not just focus on the private screen. What is really useful is that we set the default stroke size as 3 pixels. Instructors rarely change the size of the stroke, and letters cannot be too small at this size. It works in most of the time, and we remind the instructors when they have this kind of problems

As the writing space extends vertically and the content is mapped to the horizontally positioned screens, it caused lecture content to be discontinued (see Figure 4.4). This does not bother the lecturer since the tablet screen is mapped exactly to one of these screens. The writing will not cross two displays. It causes a slight readability problem to students. However, the discontinued part usually stays for a very short period of time because the instructors frequently move the canvas with short steps. They can also control the moving step to avoid lecture content appearing between two displays, but we think this is distracting and unnecessary.

Another concern maybe less visual content compared to slide-based lectures. Research shows that students prefer teaching methods that inadvertently made them learn less [83]. However, we believe in our study this is not the case. Less visual content does not necessarily mean less learning. In our study, instructors completed their teaching plan with the electronic blackboard.

4.5 Conclusion

The use of slides in the classroom has been frequently criticized. Researchers try to adopt a variety of technologies to enhance classroom learning. However, the benefits of wall-sized electronic blackboards have not been explored. We have designed and developed an electronic blackboard with a digital display wall, aiming to combine the advantages of both traditional blackboards and digital systems to create a more suitable tool for classroom teaching. The electronic blackboard has been used for long-term real classroom practice and gathered a rich set of data. From the analysis of the data we find that such a wall-sized, non-slide based presentation system has clear benefits for both instructors and students. It can reduce the effort required for the instructor when referring back. Teachers can effectively use the system for lecturing, while very few system interactions are needed. Students find that the system helps their learning and they are satisfied with the visual quality of the digital displays.

5 Classroom Interacter: A Classroom Interaction System

In the preceding chapters we introduced the Intellichalk system, an innovative classroom presentation system inspired by the idea of the traditional blackboard. In this chapter, we describe the Classroom Interacter system which is extended from Intellichalk. It enables students to participate in the classroom learning using their mobile devices. The distributed system supports wireless learning environments, remote teaching and other deployment methods. The system is designed to facilitate teacher student interaction via wireless network. It has browser based student clients to achieve easy access, supports spontaneous classroom interactions and helps the instructor understand students' learning status. Students can use their mobile devices to participate in classroom interaction, involving in their learning process.

5.1 Design Goals

Classroom interaction and collaboration

As universities recruit more and more students, lectures with large audiences are becoming increasingly common. In such classrooms, the lecturer does not have time to interact with every student. Only a few students actively participate in the lecture. We aim to provide students with an easy to access tool to encourage them to participate in classroom interaction. Students can use their own mobile devices to participate in voting, to tell the instructor their understanding status, and to ask questions without interrupting the lecture.

In another scenario, if the instructor wants to encourage group collaboration and peer learning in a class, she can divide the students into small groups to use shared mobile devices. Study [84] indicates that shared tablets can help verbal interaction in the classroom.

Give students time to follow the lecturer

Taking notes is a common behavior in university classrooms. One study indicated that students who take notes or make annotations study better [85]. However, note-taking is a race against time as the rate of speech is much faster than handwriting speed [86]. Students are typically under some time pressure when taking notes, leaving them not much time for thinking and understanding. We aim to reduce students' burden of note-taking. Students can receive the lecture content with their mobile devices, so that they have time to think, to interact with the teacher, and to add annotations to supplement the notes.

Moreover, with slide presentations, lecturers tend to deliver lectures too fast for students,

since they are familiar with the content on the slides and the omission of writing saves time. Lecturing with Classroom Interacter, the lecturer can explain the complex part step by step, giving students time to follow her thoughts.

Flexible set up

One of our design goals is to support flexible hardware configurations. Using a tablet and a projector is a lightweight deployment. An instructor can deliver lectures with a tablet PC running the Classroom Interacter teacher client. Since modern classrooms are usually equipped with computers and projectors, the instructor only needs to use a browser to connect to the Classroom Interacter server and project it to the public display.

We have built a display wall system with four liquid crystal displays to maximize its pedagogic benefits. It provides a large visual area to support data persistency and dynamic teaching.

Tablet classroom is another set up. Students can receive the lecture content via tablets, add comments on it, and interact with the teacher. Our system also supports group learning with shared devices. Students can be divided into groups to complete assigned tasks on shared tabletops. This set-up aims at promoting communication and cooperation between students.

Distance presentation and distance interaction are other possibilities. We have conducted an experiment with remote teaching. The Classroom Interacter can work with Skype to give presentations to remote classrooms. Skype is used to transmit audio and video while a browser receives the lecture content and projects it to the public display in the remote classroom.

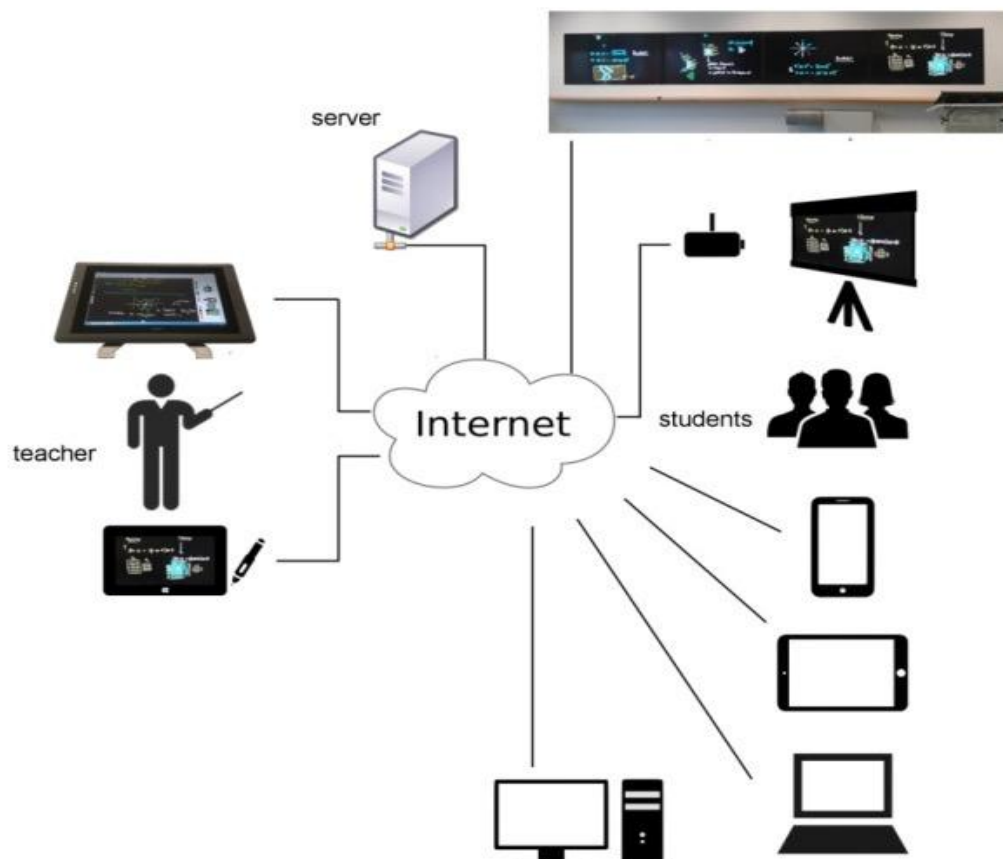


Figure 5.1. Intellichalk can be used in different configurations.

5.2 System Structure

The Classroom Interacter system is implemented based on the Intellichalk system. It consists of three parts, a teacher client, a server and one or more student clients (see Figure 5.1). The teacher client is the Intellichalk system enhanced with a network communication module and plug-ins to collaborate with the server and student clients. Teachers can use all the rich features provided by the Intellichalk system to deliver lectures. The student client is a browser-based display and interaction system. It can be displayed on large screens or projectors as public displays. Running on a personal device, it becomes a personal note-taking and interaction system. The teacher client and student clients connect to the same server over the Internet. A message exchange mechanism was implemented on the server to coordinate interactions and exchange information between the teacher client and student clients.

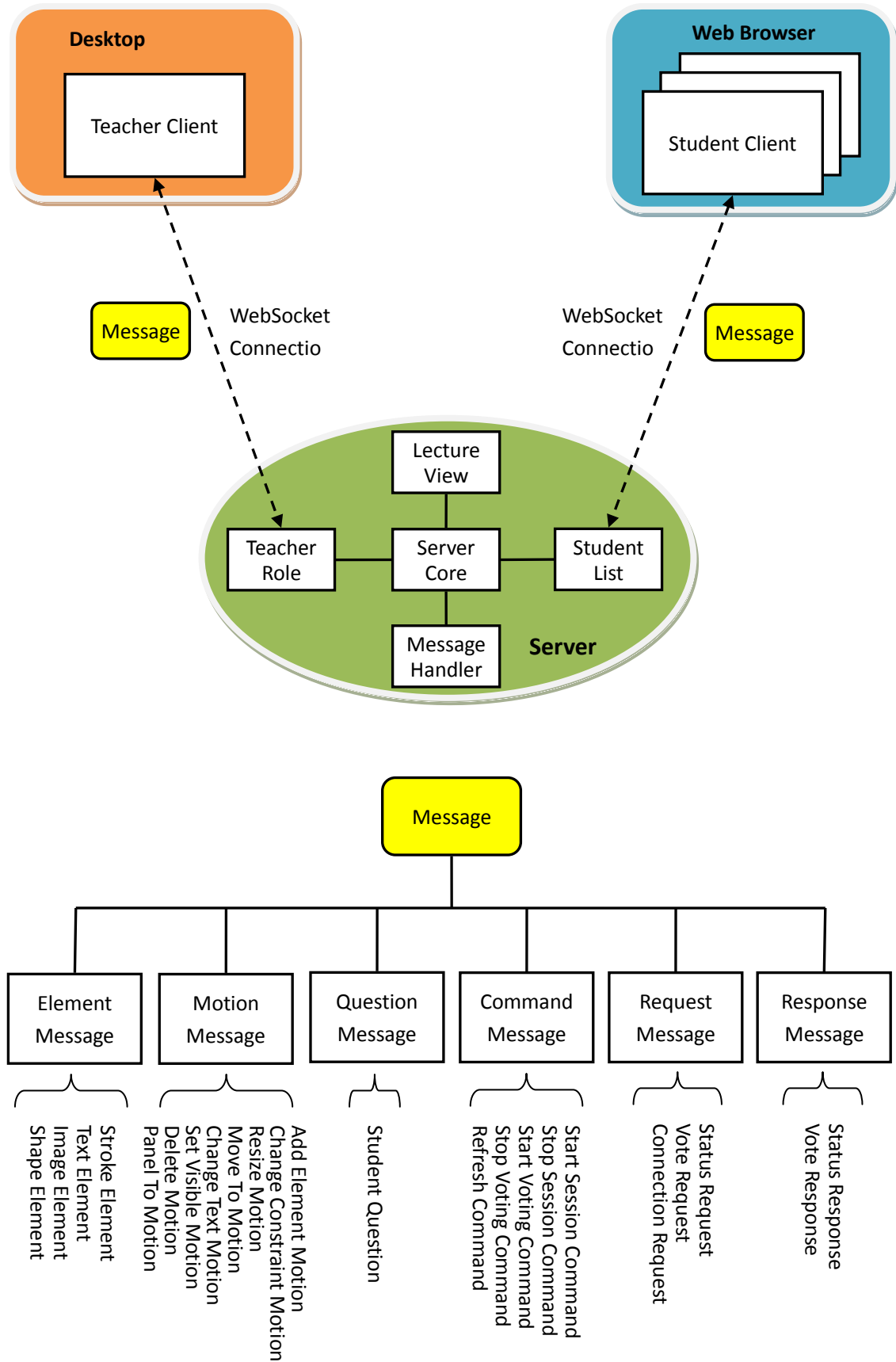


Figure 5.2. System structure of Classroom Interacter and the messages.

Figure 5.2 shows the system structure of Classroom Interacter and the messages running between different components. We use WebSocket protocol for network connections to achieve frequent, persistent and timely two-way communication between the server and the clients.

The server maintains a teacher connection for the current session and a real-time list of connected student clients. Different message processing mechanisms are implemented for different roles. The server side also maintains a current view of the lecture which is synchronized with the teacher client. The newly connected or reconnected students will receive information from the current lecture to draw a local view on their browsers.

As can be seen from Figure 5.2, the system is based on the network structure. The student client is browser-based while the teacher client is a desktop application. This design has several useful characteristics.

The browser-based student client facilitates student access to the system

While in the era of mobile Internet, the high penetration rate of mobile devices among students has promoted the development of BYOD teaching method and wireless learning environments. These teaching methods greatly reduced the cost of implementing collaborative learning and interactive learning in the classroom. And the development of network technology gradually reduced the barrier for students to participate in such teaching methods. The browser based applications have the advantage of zero download, zero installation, helping educators to achieve a high participation rate in the beginning of classroom implementation and providing great advantages for its promotion [87].

Requiring all students to download and install specific software to participate in classroom teaching can cause lots of inconvenience. Such as device compatibility issues, whether students have the skill to install the software, the time consumed, and other unexpected problems. It would be more difficult to use such software for a one-time public speaking event, since the audience may be reluctant to spend the effort to install software they are unfamiliar with and probably will not use again.

Our browser based student client allows students to participate in classroom activities by simply entering a domain name on their browser. The student client is implemented with pure html5 technique which is currently supported by all mainstream browsers. In our survey, almost all students reported that it was easy to open and use the Classroom Interacter system on their devices.

For students who use older mobile devices or do not have one, we recommend sharing devices with their neighbors. Studies have found that group-sharing of devices can facilitate collaboration and communication among students, thereby promoting learning [88-90]. This is also a deployment approach we considered when designing the system.

Desktop-based teacher client to ensure functionality and experience

In chapter 4 we can see from the user study that the teachers write an average of one to three thousand strokes in a 1.5-hour class. To ensure a fluent and consistent experience for teachers is an important consideration when designing the system. We use the mature and stable Java libraries to implement the teacher client, to ensure highly efficient system response and to avoid the impact of network status. It also has high scalability, and supports feature extension with local libraries.

For practical use considerations, the student client is browser-based while the teacher client is based on a desktop application. Encouraging students to use the system and participate in classroom interaction is the most important consideration. For the teacher, ensuring the functionality and experience to achieve our design philosophy is most important. Moreover, the zero installation feature is not essential for the teacher since researchers and technicians can install the system for the teacher, although they cannot help all students to install a system in their devices.

The network-based architecture that supports flexible deployment.

The distributed nature of the system and cross-platform characteristics of clients enables Classroom Interacter to support a variety of deployment methods. The basic function of the student client is to receive and recreate the lecture content from the teacher client in real time and animate the writing process of the teacher. So its basic role is a display system which can be used to present the lecture on a public display or personal devices. The separation of authoring and display devices makes the teacher client portable. We discuss several possible deployment scenarios and features later in this chapter.

Supports remote teaching

As universities enroll more and more students, in some universities, teachers need to deliver lectures to multiple classes at the same time, even to classes in different campuses, especially introductory courses for college freshmen. Video conferencing is still commonly used for distance teaching and distributed classes. But it cannot deliver the visual aids on blackboards or projectors in high visual quality. Other distance learning technologies [91] can deliver the slides but the audience needs to install specific software or browser plug-ins. Our solution has significant advantages compared to these systems, including lightweight deployment, no software installation for the students, interaction and collaboration support.

5.3 Teacher Client

The teacher client is the core part of the whole Classroom Interacter system. The user interface of the teacher client is shown in Figure 5.3. It shows the Intellichalk system with the network communication module and the interaction features.

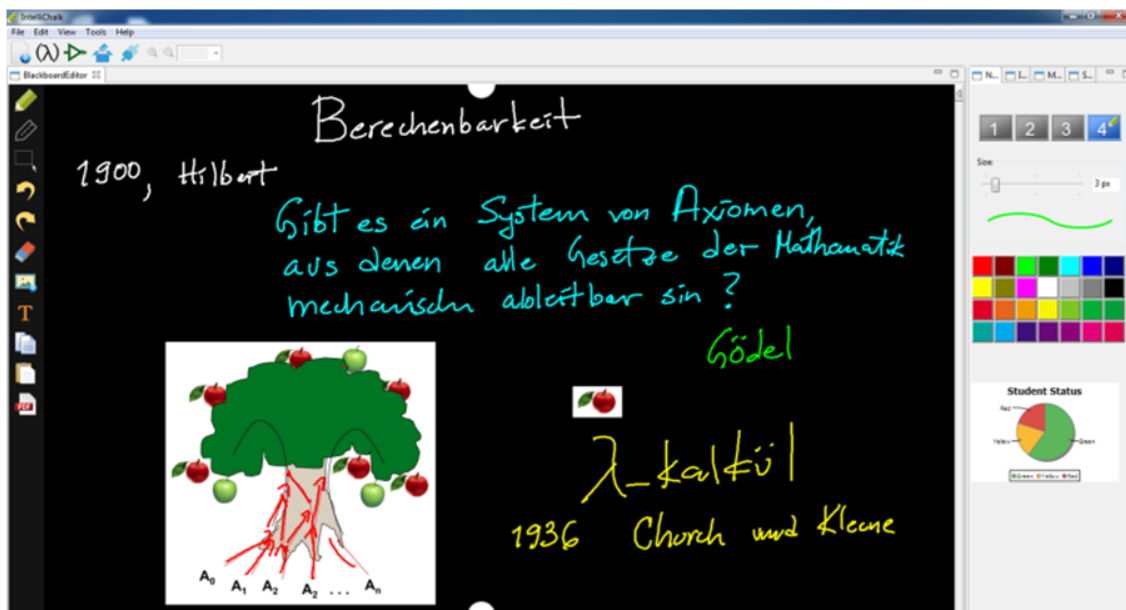


Figure 5.3. User interface of Classroom Interactor teacher client.

The interaction functions include three parts as shown in Figure 5.4. The user first needs to click the *Server Connection* button and connect to the preset server, enabling all the interaction functions of the system. The voting function triggers a live vote, the same function as traditional clickers. The voting system is designed to encourage students to participate in classroom learning and to help teachers create an active learning environment in the classroom.

Student status view displays the statistical results from the self-reported learning statuses of students who are currently connected to the server. This view is updated in real-time as the students' settings change, therefore it provides the teacher with an overview of the learning status of the whole class, which can help teachers adjust their teaching.

The *Question View* is one of the system's functional views. It can be activated and displayed on the right side of the instructor's view, showing questions sent by students from their mobile devices. The teacher can choose and display questions in the lecturing area and explain to the whole class.

Participation is completely anonymous, which has been said to be able to help students to express their real thoughts and encourage them to ask questions [92, 93]. Teachers have reported that sometimes they receive unexpected questions which are closely related to the lecture but have never been asked verbally.

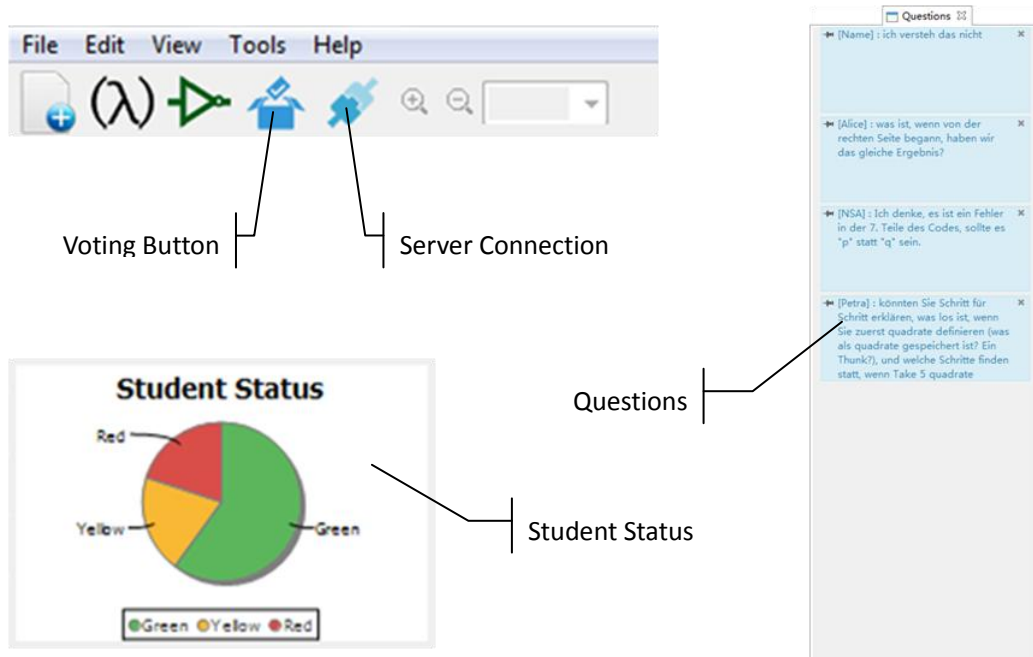


Figure 5.4. Collaboration functions on the teacher client.

5.4 Student Client

The student client of Classroom Interacter is implemented based-on the browser. Figure 5.5 shows the two-layer structure and all functions of the student client. The system reproduces the lecture content and the instructor’s manipulations on the lecture layer from received messages. An annotation layer is superimposed on the lecture layer. The content of these two layers are overlaid together on the user’s screen. Figure 5.6 shows the student client of Classroom Interacter running on a tablet.

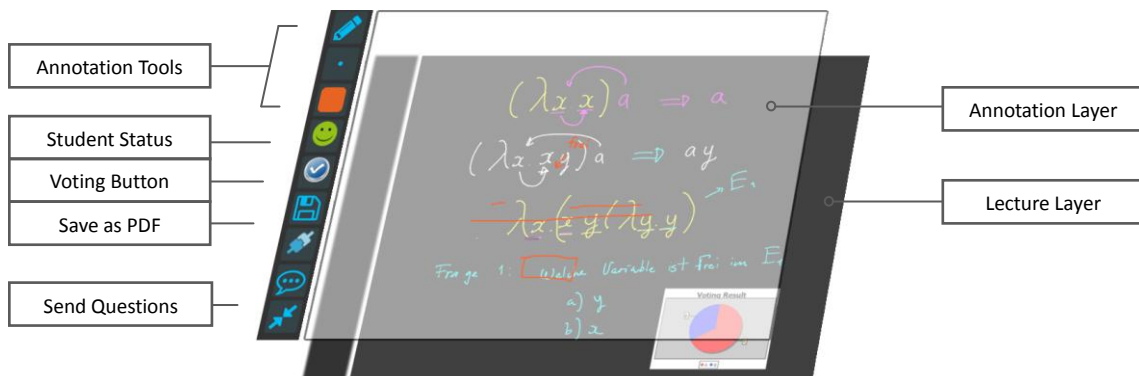


Figure 5.5. Layer structure and functionalities of Intellichalk student client.

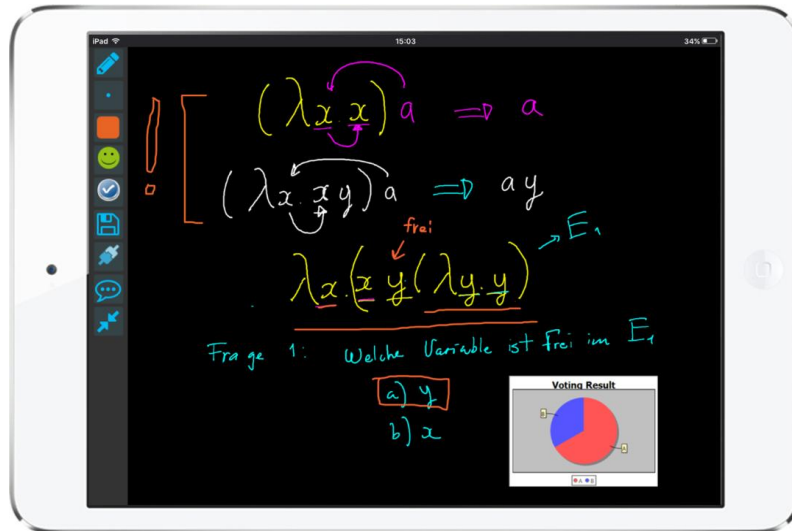


Figure 5.6. User interface of Intellichalk student client.

To start using the student client system, users only need to enter the server address in their browsers. When the web page is loaded, users can use all the functions to make annotations and interact with the teacher. The toolbar appears on the top or on the left side of the webpage, as shown in Figure 5.6. The student client has the following features:

Lecture receiving / Annotation:

The system receives the lecture content and animates the writing process of each stroke. Students can use the editing tools to add textual or hand written annotations on top of the lecture content. All of the student's operations are restricted to the annotation layer, the content of the lecture layer is non-editable in the student client. Figure 5.5 demonstrates that the user annotated with orange ink on the annotation layer, and Figure 5.6 shows the students' view with two layers added together.

Voting:

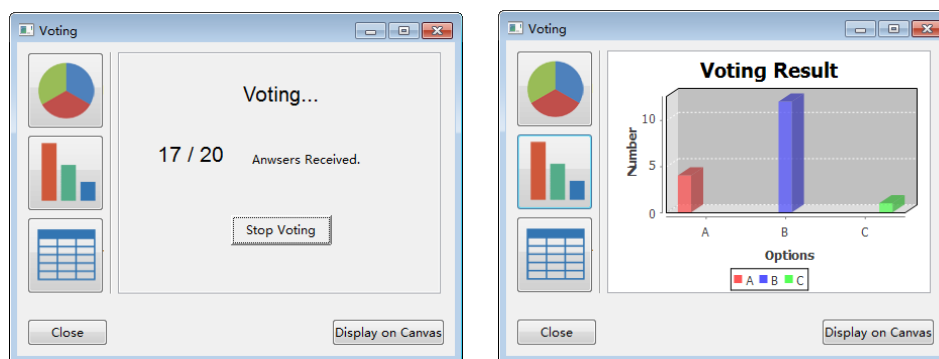


Figure 5.7. The teacher can initiate a vote anytime during the lecture and show the results to the class.

Live voting is a simple but effective tool to support classroom interaction. The instructor can start a poll at any point during her lecture. According to the type of question and the number of options set by the teacher, students can choose one of the options and send it to the server. Answers can be changed until voting stops. After voting, the lecturer will get a statistical result of all responses. It can be displayed on the screen in the form of bar chart, pie chart or table. Figure 5.7 demonstrates the instructor initiated a vote and shows the results as a bar chart.

Student Status:

Students can choose one of three different symbols to indicate their current understanding of the lecture (see Figure 5.8). A green smiling face means “I can follow the lecture without difficulty”. A yellow neutral face means “I can follow the lecture in general, although I have questions sometimes”. And a red sad face means “I cannot follow the lecture”. The teacher can see the statistical result of the whole class. Student status can be changed at any time to express users’ real experience. According to this real-time classroom status (in Figure 5.8 the pie chart indicates the student status in real time), the lecturer may adjust her lecture speed or the form of teaching. For example, if half of the students set their status as yellow or red, which means a lot of students find it difficult to keep up with the lecture, the teacher can choose to slow down lecture speed or start a poll to clarify students’ problem.

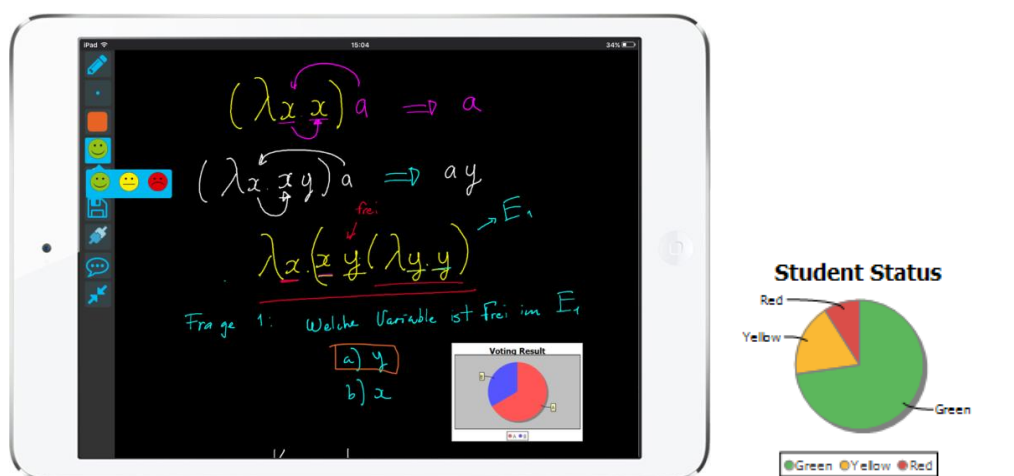


Figure 5.8. Students reported their understanding status to the teacher.

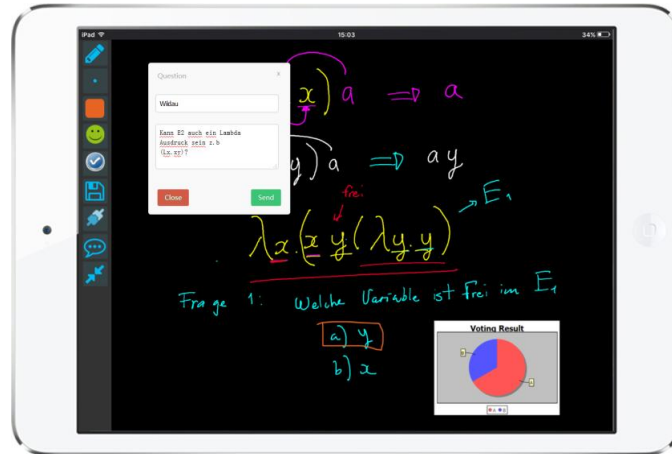


Figure 5.9. Students can send questions to the teacher from their mobile devices.

Question sending:

Students can anonymously send questions to the teacher during the lecture (Figure 5.9). In the teacher’s view, received questions are listed in an independent view. The teacher does not need to answer questions in real time because it may interrupt her lecture frequently. She can choose one of the three situations to answer questions: when a section of the lecture is finished, when a certain percentage of students find it difficult to follow her, or when the same or similar questions are asked repeatedly.

Save the lecture as a PDF file:

Users can save the lecture with their own annotations as a PDF file (see Figure 5.10). Since students do not need to copy the notes of the lecture, they get more time to think about the lecture content, to interact with the lecturer, or to write down their thoughts for later review.

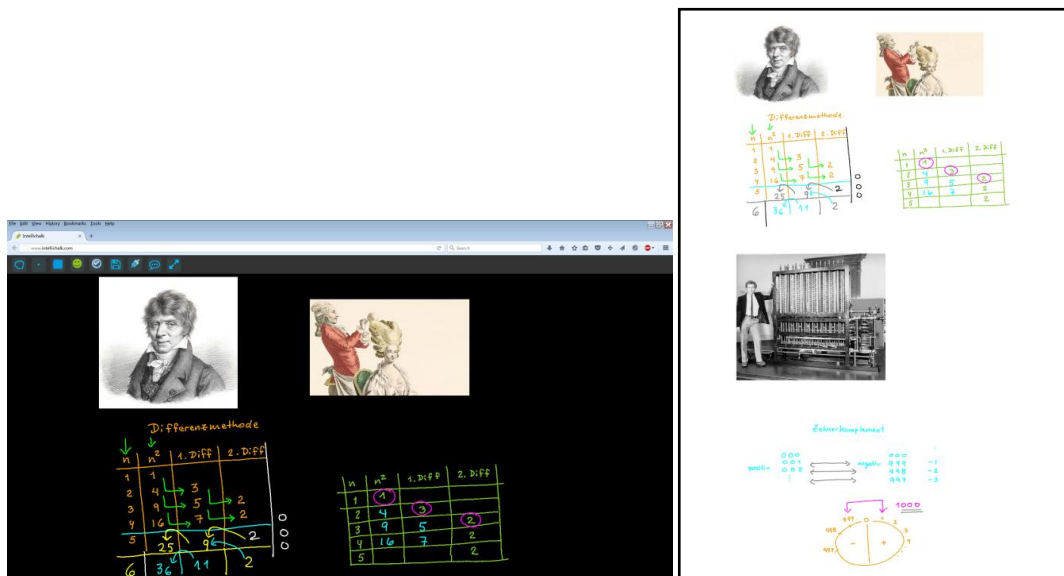


Figure 5.10. Students can save the lecture to a PDF file from the browser.

5.5 Hardware Setups

From our review of the literature, we found that most of the previous classroom interaction systems needed special hardware facilities or required the user to install specific software to participate in classroom interaction. This introduces a psychological barrier for first time users [94]. Moreover, remote learners often do not have the skills to install such client software.

There are also browser based voting systems which allow students to access specific question pages by logging on to the online learning system or scanning a QR code (Quick Response Code). These systems usually have very limited function, and the teacher must spend considerable time preparing and setting questions before class, it is not convenient to adjust these questions or edit new voting during class [95-97].

We extended the Intellichalk system and implemented the Classroom Interacter. Its network based structure and the different design focus for different roles ensures the functionality and experience for teachers and allows students to access lecture notes, interact with the teacher, and make annotations without having to download and install software.

Flexible and convenient hardware setup is an important design goal for Classroom Interacter. We will introduce several ways that we have used or tested to deploy the system in the classroom.

5.5.1. Lightweight Mobile Deployment

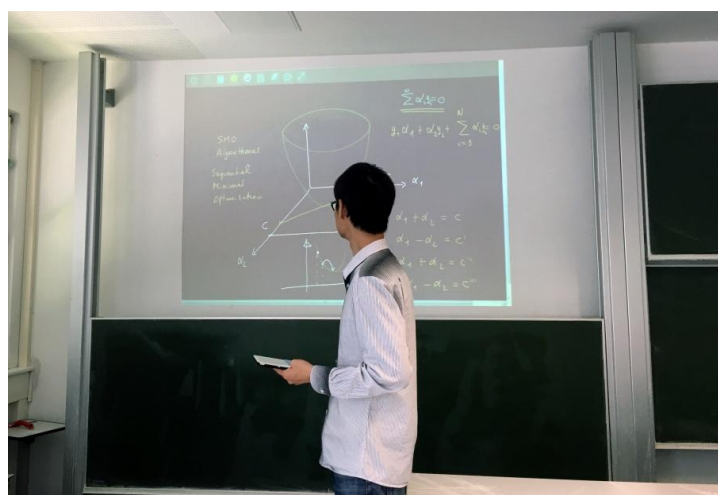


Figure 5.11. The instructor can use a tablet PC to deliver the lecture, the lecture content can be received through a browser and projected to the public display.

Imagine a teacher going into a classroom with a tablet PC running Classroom Interacter. He uses the browser on the classroom computer to connect to the server and project it on the public screen, and then he can start lecturing. He can lecture in any classroom with a computer and Internet access, which is very common in modern classrooms, without pre-installing any specific software. Moreover, he is no longer trapped behind the podium, but can walk among the audience with the handheld tablet PC to interact with them, helping them solve their problems. He can edit and adjust the content on the public display according the students' feedback at any time without going back to the podium, and continue the lecture anywhere in the classroom. All the rich features of the Classroom Interacter are supported by the handheld tablet PC. This portable setup brings great flexibility to the lecturers for classroom teaching.

5.5.2. BYOD Classroom

With the popularity of mobile devices among students, researchers and educators try to explore the advantages of these mobile devices and campus wireless networks for classroom learning. Researchers have conducted BYOD teaching at different stages of education and have found many benefits for learning [98-101]. The most frequently reported benefits include increased levels of classroom interaction, lower costs of technology integration and unlimited access. The overhead cost of device distribution and recycling is also eliminated. The challenges of BYOD classrooms are also widely reported, among them, one of the main challenges is the technical problems cause by the different platforms students are using [98]. The Classroom Interacter is designed to provide rich functionality to support BYOD classroom learning, while lowering the technical barriers for students. The system can support various types of interaction between teachers and students, assists personal note taking, and can be used on many platforms without software downloading and installation. It addresses the technical issues one may encounter when first deploying classroom interaction systems.

5.5.3. Collaborative Learning Using Shared Devices

The system can be configured to support group collaborative learning based on shared devices. Studies have found that learning based on group shared devices can encourage group collaboration and peer learning in a class [88-90]. Study [84] also indicates that shared tablets can promote verbal interaction in the classroom, since students are no longer making decisions alone, each group needs to reach a consensus through discussion. This allows team members to understand each other's ideas, learn from their peers to solve their own problems, express their views and contribute to group decisions.

Take the voting function in our system for example, team members need to discuss and come to an agreement before participating in voting. Before setting the understanding status symbol for the group, students who learn better would help the students who have

problems. Also, a group member may have the answer to one student's question before she sends it to the teacher. The questions sent to the teacher will be points of confusion shared by the whole group, and are more deserving of detailed explanation by the teacher. Further, the group members can work together to complete the study notes, containing annotations that represent the collective wisdom of the group.

5.5.4. Remote Classroom

The web-based architecture of the Classroom Interacter system means it naturally supports remote teaching. The lecture content created on the teacher client program can be received and synchronously displayed on the remote user's browser. The technology we use has the advantages of high definition visual quality and low bandwidth consumption compared with the video conferencing approach. According to our statistics, only an average of about 2 megabytes of data are sent via the Internet for a two-hour lecture. We did not implement the video communication function in Classroom Interacter, in order to reduce the complexity of the student client and ensure its ease of use. Besides, there are now many instant messaging software clients with mature video communication technology available, which we can use directly. We combine Skype [102] and Classroom Interacter for remote teaching. Our study shows that the video or audio on Skype and the lecture content on the browser are well synchronized, and the students in the remote classroom believe that it is a good means for remote teaching.

5.5.5 Distributed Classrooms

Classroom Interacter has no limit to the number of receivers. Combined with group video conferencing technology, it can be used in multiple classrooms simultaneously without location restrictions. We do not have the opportunity to deploy Classroom Interacter for real teaching in distributed classrooms, and have only tested the feasibility of this setting. In such a setting, the video of the teacher and the lecture content on the Classroom Interacter in the local classroom are transmitted to all remote classrooms, and the videos of remote classrooms are also transmitted back. The teacher does not need to control the systems in remote classrooms, but only needs to concentrate on lecturing. Content in all classrooms is synchronized. Students in the distributed classrooms can experience the non-slide based lecture that we advocate and benefit from the various interaction features of our system.

5.6 Summary

We have introduced the Classroom Interacter, a system for promoting classroom interaction and collaboration with the audience's own mobile devices. It has a distributed system structure to support both local classroom and remote classroom

teaching. It has a teacher client, a server and web based student clients. The teacher client is the Intellichalk system we described in preceding chapters, enabled with network communication and interaction capabilities. The student client is a browser based system with functions to support lecture displaying, instructor-student interaction, and personal note-taking.

This system is designed to support teacher-student interaction in the classroom. It can help teachers to better understand the students' learning status. Live voting and question sending via mobile devices can be initiated whenever needed, and the browser-based student client significantly increases the accessibility of the system. Students can use their mobile devices to participate in classroom interaction and be involved in their own learning process.

This system is designed to help students better follow the lecture. Like lecturing on a blackboard, the Classroom Interacter presents the information creation process, giving students the opportunity to observe the teacher's thoughts, and also give students more time to understand complex derivation or explanation. Students can receive the lecture notes and synchronously display them on their mobile devices, and personal annotations can also be added on the lecture notes. This feature helps students to better understand the lecture. Time spent taking notes can be saved for thinking and understanding the lecture content and adding summarized personal notes which can help students' learning both during and after class.

The system is designed to extend Intellichalk for more flexible and wider use scenarios. Our study has shown that the Intellichalk system has many educational benefits for classroom learning, and the Classroom Interacter designed based on Intellichalk, expands these benefits to remote classrooms, tablet classrooms and distributed classrooms.

6 Using Classroom Interacter in Physical and Remote Classrooms

In the last chapter, we introduced in detail the design goals, functionalities, system structure and the hardware configurations of Classroom Interacter. After several iterations of user tests and improvements, we believe the system is ready for deployment in actual classroom environments. In this chapter, we study the use of Classroom Interacter in real teaching practice. The system was first used in a BYOD classroom where students can use the system on their mobile devices to participate in classroom learning. We studied the students' evaluation of Classroom Interacter and the benefits of the system for teachers and students in the learning process. We then used the Classroom Interacter system to deliver lecture to a remote classroom, aiming to study whether the system is capable of facilitating remote teaching. Further, we study the variety of teacher-student interactions and the teacher's teaching efficiency in the remote setting compared to teaching in the physical classroom.

6.1 In the Physical Classroom

We deployed the new version of Classroom Interacter in a multimedia classroom and invited an instructor to use the system. We conducted a study to learn how the instructor and students interacted through this system, and to investigate students' opinions of the system. We focus on the following questions:

1. Students' acceptance of the system, including students' evaluation of the system's perceived usability, perceived usefulness and their willingness of future use of the system.
2. Whether the system is conducive to classroom interaction, and whether it helps to remove obstacles to asking questions in the classroom.

6.1.1 Study Participants

Students of the course “Non-sequential and distributed programming” were asked to participate in the study. Around 70 students registered for the course. They were all undergraduate students majoring in computer science and had similar background knowledge. They were asked to bring their own mobile devices to participate in the study, which could be notebooks, tablets or smart phones.

6.1.2 Study Apparatus

Classroom presentation devices: The lecture hall was equipped with a computer and a

projector with full high definition resolution, and the projected display area was large enough for students in the last row to read. A pen input device was connected to the computer. The teacher client of the Classroom Interacter was installed on the computer and the instructor could accomplish almost all manipulations with a stylus. The server ran on a computer in our institute, supporting interactions between the teacher and students.

Mobile devices: Although many mobile devices with internet connection can be used to participate in the classroom interaction, we suggested students use tablets or laptops, better with touch sensitive screens, since they offer a larger visual area to display the lecture content than smart phones and more convenient to draw annotations.

6.1.3 Study Methods

Message log: All the messages going through the server were logged for further analysis, including student's status changes, their responses to the voting and the questions they sent to the instructor. These objective data will be used to learn how students use the system and to analyze the interactions in the classroom.

Questionnaire: A 5-point Likert scale (5 = strongly agree and 1 = strongly disagree) was used in the questionnaire to collect quantitative data of users' attitude and satisfaction towards the system. This evaluation focused on the annotation and interaction functions supported by the student client. The questionnaire was designed based on the TAM (Technology Acceptance Model) [76, 77], and reviewed by two experienced professors before it was conducted. The questionnaires also included open questions, asking students about the obstacles for them to ask questions in the classroom, and the main advantages and disadvantages of Classroom Interacter in their opinion.

6.1.4 Study Process

We did not use Classroom Interacter throughout the course. Students were asked to bring their mobile devices to the classroom and used the Classroom Interacter system for three lectures. A short introduction of the system was carried out to explain the functions of the system and how they can use the system to interact with the instructor, and student were able to test the system before it was formally used in the course. The system was used in three lectures and each lecture lasted 1.5 hours. The lecturer initiated 2-4 live voting polls per lecture. Students could freely use the student status and question sending functions. After the test, they were asked to fill in a questionnaire about their experience of using the interaction system. To complement the questionnaire and message log, a researcher was in the classroom to observe how students used the system and other activities which cannot be recorded by the server or participants fail to report. After these three lectures, the lecturer used Keynote slides for the remaining lectures in the course. We continued the observation in the classroom, recording the oral questions asked by students.

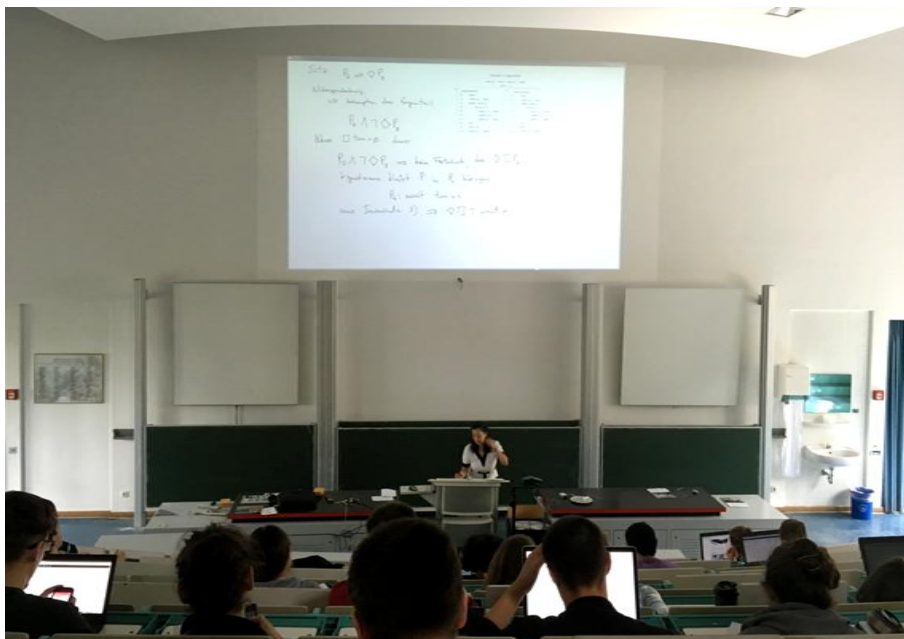


Figure 6.1. The instructor delivering a lecture with Classroom Interacter.

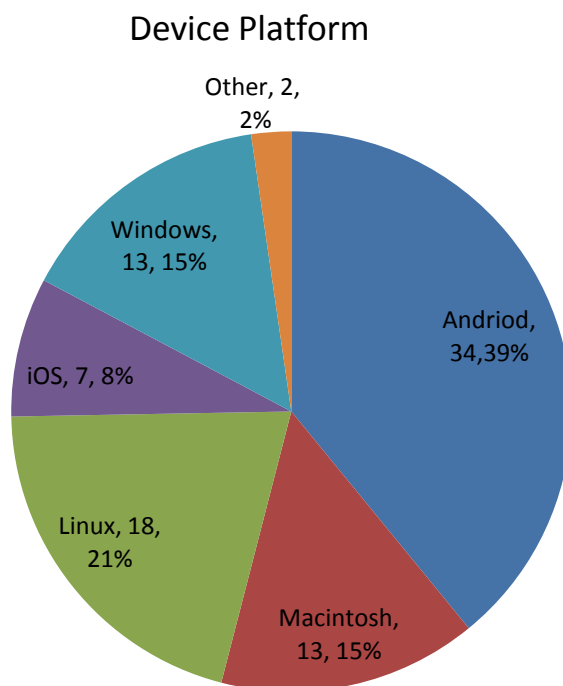


Figure 6.2. Platform distribution of connected devices.

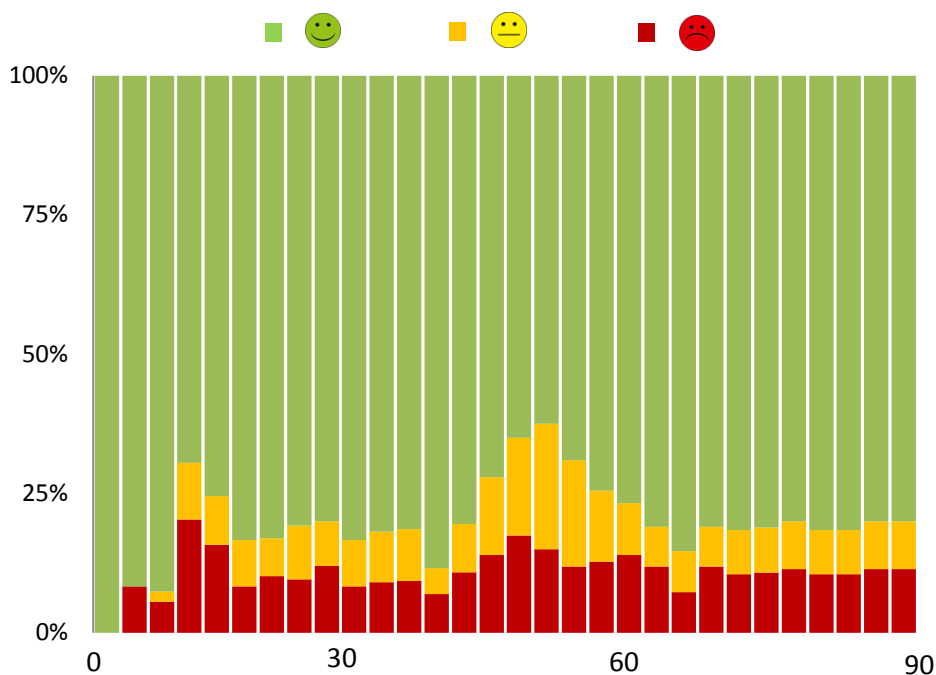


Figure 6.3. Student status change over time.

6.1.5 Results

From the logged data, we found that students used a variety of mobile devices to participate in the study. Figure 6.2 shows the connected mobile devices of the first lecture. 68 students used 87 mobile devices to connect to the system. The character of cross-platform and easy to access features provided users with great convenience when using the system. The teacher initiated two to three polls per lecture. All polls during the lecture gained high participation rates, an average of 68% of the students participated in voting.

The student status function is a novel idea. We believe it may enhance the classroom experience. From the logged data, we calculated the overall status changes over time (see Figure 6.3). 190 status changes were detected during the 1.5-hour lecture, 2.8 times per person on average. We can see that students were highly engaged. From Figure 6.3 we find that on average about 20% students set their status to yellow or red, which means they did not fully understand the lecture. The highest point happened at minute 50, with 40% users marking themselves non-green. But this ratio started to decline after that. We think it is because the teacher stopped delivering new content and started to clarify students' questions.

67 valid questionnaires were collected after the test. As shown in Table 6.1, students gave positive feedback about the system (overall mean = 3.94, SD = 0.928). The overall cronbach's alpha of the questionnaire is 0.867, indicating high internal consistency.

We employed *exploratory factor analysis* to systematically analyze the questionnaire results. Bartlett's test of sphericity is significant and the Kaiser-Meyer-Olkin result was 0.757, which means the factors exist and the data is suitable for factor analysis. From Table 6.2, we can see that four factors were found from the analysis with an eigenvalue greater than 1. They are usability, usefulness, continued use, and interactivity. A total 64.8% variance was explained by these factors, 8.2% for usability, 13.0% for usefulness, 8.6% for continued use, and 34.9% for interactivity (see Table 6.3). We explain the factors as follows: the usability refers to the degree of perceived ease-of-use of the system UI. The usefulness means the students' perception of how the system can help them learn. The continued use stands for the students' willingness to use the system again. The interactivity is the perceived ability of the system to promote classroom interaction. Each factor showed good internal consistency.

	Mean	SD
1. It is easy to start Classroom Interacter.	4.52	0.704
2. The functionalities are easy to recognize from the toolbar.	3.88	0.879
3. After some practice, I can easily work on every function.	4.30	0.779
4. Annotations on the lecture content help me understand the lecture.	3.90	0.873
5. Using interaction functions during the lecture helps me know if I understand the course concepts.	3.99	0.992
6. Saving lecture content with my annotations helps me study after class.	4.31	0.874
7. It's easier to follow the teacher's thoughts compared to slide presentations.	3.73	1.024
8. I would like to use the voting function to interact with the teacher.	4.16	0.828
9. I would like to use the annotation function during the class.	3.78	0.951
10. I would like to use the student status function to give feedback to the teacher.	3.97	1.044
11. I would like to send questions to the teacher during the lecture.	3.75	1.078
12. Participation with the voting system increases interaction with the instructor.	4.06	1.043
13. Using student status to give feedback increases classroom interaction.	3.69	1.090
14. Sending questions to the teacher increases the interaction with the instructor.	3.81	1.118
15. Using the system made me feel more involved in the class.	3.67	1.079
16. The classroom atmosphere is more active than before.	3.46	0.974
overall	3.94	0.928

Table 6.1 Students' evaluation results.

	1	2	3	4
1. It is easy to start Classroom Interacter.	.826	-.100	.180	-.146
2. The functionalities are easy to recognize from the toolbar.	.694	.055	-.160	.435
3. After some practice, I can easily work on every function.	.862	.154	-.028	.137
4. Annotations on the lecture content help me understand the lecture.	.290	.755	.066	.063
5. Using interaction functions during the lecture helps me know if I understand the course concepts.	.145	.521	.287	.484
6. Saving lecture content with my annotations helps me study after class.	.047	.744	.176	.165
7. It's easier to follow the teacher's thoughts compared to slide presentations.	-.159	.744	.185	.249
8. I would like to use the voting function to interact with the teacher.	.013	.478	.529	.235
9. I would like to use the annotation function during the class.	-.039	.366	.545	-.016
10. I would like to use the student status function to give feedback to the teacher.	.108	.149	.748	.208
11. I would like to send questions to the teacher during the lecture.	-.029	-.040	.847	.118
12. Participation with the voting system increases interaction with the instructor.	.147	.329	.072	.734
13. Using student status to give feedback increases classroom interaction.	.104	.263	.387	.545
14. Sending questions to the teacher increases the interaction with the instructor.	.051	-.083	.239	.813
15. Using the system made me feel more involved in the class.	.024	.439	.248	.575
16. The classroom atmosphere is more active than before.	.153	.288	.071	.783
Eigen value	1.316	2.078	1.380	5.589

Kaiser-Meyer-Olkin = 0.757

P < 0.001

Table 6.2. Exploratory factor analysis result of the questionnaire.

Factor	Mean	SD	Variance explained	Cronbach's alpha
Usability (item 1 - 3)	4.23	0.625	8.2%	0.745
Usefulness (item 4 - 7)	3.98	0.874	13.0%	0.776
Continued use (item 8 - 11)	3.91	0.960	8.6%	0.713
Interactivity (item 12 - 16)	3.74	1.128	34.9%	0.830
Overall	3.94	0.928	64.8%	0.867

Table 6.3. Factors generated from the exploratory factor analysis.

As can be seen from Table 6.3, students gave a high rating for the *perceived usability* of the system (factor overall mean = 4.23, SD = 0.625). And the item with the highest score was *easy to start* (item 1, mean = 4.52, SD = 0.704), 86.1% of the students agreed or strongly agreed that the system is easy to start. 80.6% of the users also agreed they can easily work on every function after some practice. These advantages come from the browser-based design which enables the cross-platform and zero installation features and they bring great convenience to the students. This convenience eliminates the technical barriers to the initial use of the system and shows the potential for its wide application in the classroom.

The *perceived usefulness* of the system also received a high rating (factor overall mean = 3.98, SD = 0.874). 74.6% students thought the interaction functions helped them understand the lecture. 80.6% of them found the annotated lecture notes useful for their study after class. According to the Technology Acceptance Model [76, 77], users' perceptions of usability and usefulness directly affect their willingness to continue using a system. Indeed, students also showed their willingness to continue to use the system's interaction features to participate in classroom interactions, and want to continue using the annotation functions in the class (factor overall mean = 3.91, SD = 0.960). The voting function, among others, was considered the most helpful feature by students (item 8, mean = 4.16, SD = 0.828). Students can see the results immediately after voting and feel involved in the interaction process while the other forms of interaction (student status and question sending) usually do not receive immediate feedback from the teacher. This may be the reason why students prefer to participate in classroom interaction through voting.

Whether it can promote interaction and enliven the class is essential for a classroom interaction system. This is also demonstrated in the student's evaluation results. As can be seen from Table 6.3, students are most concerned about the interaction capability of the system. Whether they had a good interaction experience greatly affected their evaluations of the Classroom Interacter, the interactivity alone explained 34.9% of the total variance. Students felt that using the voting, student status and question sending functions could increase their interaction with the instructor. 40 of the 67 students (59.7%) felt they were more involved in the class with Classroom Interacter.

Our study also showed potential for the Classroom Interacter to encourage students to ask question in the classroom. We continued observation after the three lectures using Classroom Interacter, 17 questions were asked by students orally in the next 5 lectures using computer-generated slides. While in the three lectures using Classroom Interacter, students sent 22, 16 and 15 questions through the system. A few of them were irrelevant to the lecture, but the total number of questions was significantly more than when teaching without the system.

The open question asks the factors which kept the students from asking or answering questions in lectures. We categorize students' answers as follows:

Obstructions from the instructor

The most frequently reported reasons that hinder students from asking questions come from the instructor. Students reported that they found it difficult to find intervals in the instructor's speech to ask questions, or the teacher usually concentrated on her talk and did not notice them raising their hands. During the observation of this study, we often saw that the teacher continued talking without noticing that one or more students were raising their hands. After a few minutes, the context of the questions passed, they had to put down their hands and continue listening to the lecture. This situation is more common for students sitting in the back or on either side of the classroom. We also observed that some students interrupted the instructor's speech and asked questions when they could not attract the teacher's attention by raising their hands. Although the teacher was not angry about the interruption of her lecture and she always said she was open for questions any time during her lecture, students only rarely did so. Only two occasions were observed in the five lectures.

Obstructions from the student themselves

Another type of obstacle to students' asking questions comes from the students themselves. Shyness, fear of speaking in public and worrying about asking "dull" questions are the typical answers. The reasons for not answering questions include shyness, afraid of being wrong, and not wanting to break the silence.

We find that Classroom Interacter is capable of solving these obstacles. Students do not need to find intervals in the speech to ask questions, they can always send questions without interrupting the teacher using Classroom Interacter. This feature gives student great freedom to ask questions. The anonymity of interaction through the Classroom Interacter can solve the problem of shyness, fear of asking "dull" questions and fear of speaking in public. Related studies [92, 93] show that anonymity of learning systems encourages student participation. The significantly increased number of questions asked via the system illustrated that the Classroom Interacter could be used to address the reported problems that hinder students from asking questions in the classroom. We also find from the students' feedback that most students thought the question sending feature improved classroom interaction (item 14, $n = 43$, 64.1%), and 45 of the 67 students (item 11, 67.2%) would like to continue using the question sending function. The teacher also believed that Classroom Interacter encouraged students to ask questions, and reported that she received some questions that had never been asked orally before but were very important to the topic.

Overall, this user study indicated students' evaluation and acceptance of Classroom Interacter. The evaluations show that users agreed that the system was easy to use, helpful for their learning, and promotes classroom interaction. They also showed their willingness to continue using the system. Although it is not a rigorous comparative study which can prove the superiority of Classroom Interacter in terms of encouraging students to ask questions, but the significantly increased number of questions and the features that address students' concerns about asking questions in the classroom have shown this potential.

6.1.6 Discussions

Designed for interaction

One contribution of Classroom Interactor to classroom learning is that both teacher and students can start an interaction dialog. The lecturer can start a live vote to interact with students, while students can also send questions to the lecturer. The information flow in the classroom is not only from teacher to students, the reverse channel is also built in. All interactions are anonymous. Studies have indicated that this can motivate students to participate [92, 93]. During the study, we found that students participated in the classroom interaction with a variety of devices. They actively participated in classroom voting and sent questions to the teacher via the system for interacting with the teacher.

Awareness of students' learning

The system gives a real-time view of students' understanding status. The instructor can adjust the lecture according to it. From Figure 6.3 we find that at the end of the lecture, about 20% students left with their status marked non-green. It is common that some students leave their lectures with questions. But we had no idea how many of them have problems in each lecture. The student status function gives a general idea about the percentages. Admittedly, students might forget to report their status changes during lectures, but the lecturer can remind them to set their status whenever necessary.

The anonymity of information encourages student participation. Students in the classroom may not publicly admit that they do not understand the lecture. The anonymous participation through mobile devices encourages students to express their real experience. The high participation rate in our study supports this statement. Therefore, we believe that the result of student status is more reliable than verbal feedback from a limited number of students.

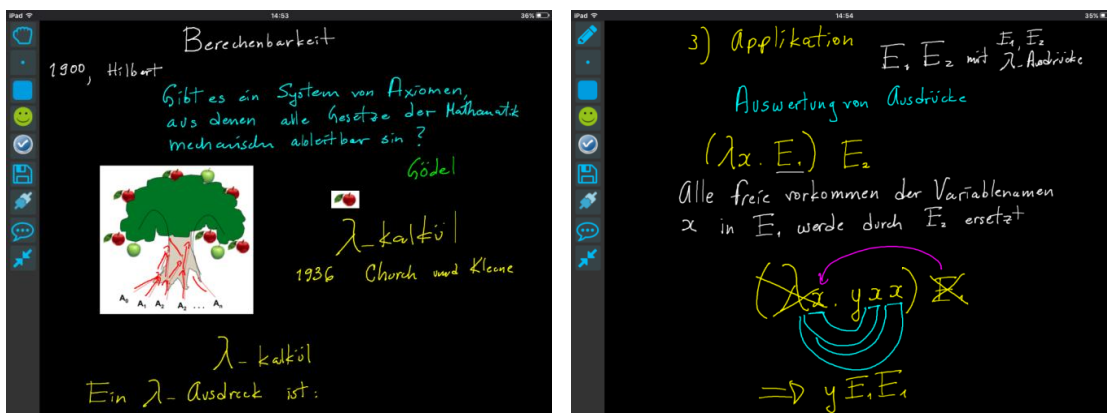


Figure 6.4. Screenshots of the lecture, taken from the student client.

For more interesting lectures

The traditional blackboard supports many more presentation techniques than slides [10]. The Intellichalk system inherits these advantages with a blackboard-metaphor interface. Compared to the slide-by-slide linear teaching style with computer-generated slides, our system supports a more dynamic teaching style. It shows the accumulation of information, allows the instructor to work on examples and adjust the lecture according to students' reaction. When provided with a large public display or multiple displays, our system can achieve more pedagogical benefits such as information persistency, referring back to previous material, and displaying two items in parallel for comparison, etc.

Our system provides a convenient use of colors and images. From Figure 6.4 we can see that the instructor used various colors and several pictures to create a vivid lecture. To be specific, she used 7 colors and switched the ink color for 72 times during the first lecture. The contrast of different colors was used to express the hierarchy of information, to represent different concepts, and to attract students' attention. The Classroom Interacter system has combined the advantages of both traditional blackboards and the digital systems, producing new possibilities for classroom teaching.

We have developed an intelligent assistant for this study. It recognizes hand written lambda calculus and returns the interpreted results. The instructor used this tool to explain the calculation step by step. It is a useful tool to assist the instructor with her explanations and makes the lecture more attractive. Our system has a highly modular structure. Developers can add teaching tools for a variety of disciplines based on the features we provided or collaborate with third-party programs.

We have developed, deployed and evaluated Classroom Interacter, a non-slide based presentation system that supports classroom interaction with students' own mobile devices. The aim of this system is to promote classroom interaction. It benefits both teachers and students. In order to make it easier for teachers to adopt, we provided a blackboard-like interface to give them a familiar environment. It supports non-linear, dynamic teaching styles that are difficult to achieve with slide presentations. The combination of both a traditional blackboard and digital systems makes it possible to give more interesting, easier to follow lectures that promote students' learning. It features a distributed system structure to support a variety of hardware configurations. We have deployed the system in a large lecture room for a computer science course and conducted a study on this system with students' own mobile devices. The user study indicates that the Classroom Interacter system encourages classroom interaction. The instructor is able to observe the understanding status of the students from their anonymous feedback. Students have given positive evaluations of the system in terms of usability, usefulness, and facilitating interactions, and shown their willingness to use the system again.

6.2 In the Remote Classroom

We also deployed the Classroom Interacter for remote teaching. A professor at the Department of Computer Science used the system in an office located in Berlin to deliver lectures to a remote class in Mexico. The course contains 15 lectures and each lecture lasts for about two hours. We have recorded in detail how the teacher and the students used the system, conducted a questionnaire survey for students and interviewed the teacher. We also compared the logged data with another course delivered by the same teacher with the same topics, but delivered in the physical classroom using Intellichalk, without the network enabled interaction functions.

The research questions of this section are:

1. Whether the system is feasible for distance learning, considering the complexity of deployment and stability of communication.
2. Compared with teaching in a physical classroom, whether the teaching efficiency of the teacher changed, considering whether he can create the same amount of content when using Classroom Interacter for remote teaching.
3. Does the system facilitate teacher-student interaction, which is a common problem in distance learning? Whether students feel unimpeded to communicate with the teacher and whether they feel encouraged to ask questions.

6.2.1 System Deployment

The teacher sat in an office at the Freie Universität Berlin and taught a group of students at a university in Mexico. Two screens were used on both sides. The teacher displayed the video of the remote classroom on one screen and created the lecture content on the other screen which was a graphical tablet. In the remote classroom, the two screens were used to display the video of the teacher and the received lecture content, as can be seen in Figure 6.5 and Figure 6.6. Students in the remote classroom were allowed to use their laptops, tablets and other mobile devices to connect to the server and participate in the teacher-student interactions. The Classroom Interacter server is located in the United States, allowing users to connect from around the world.

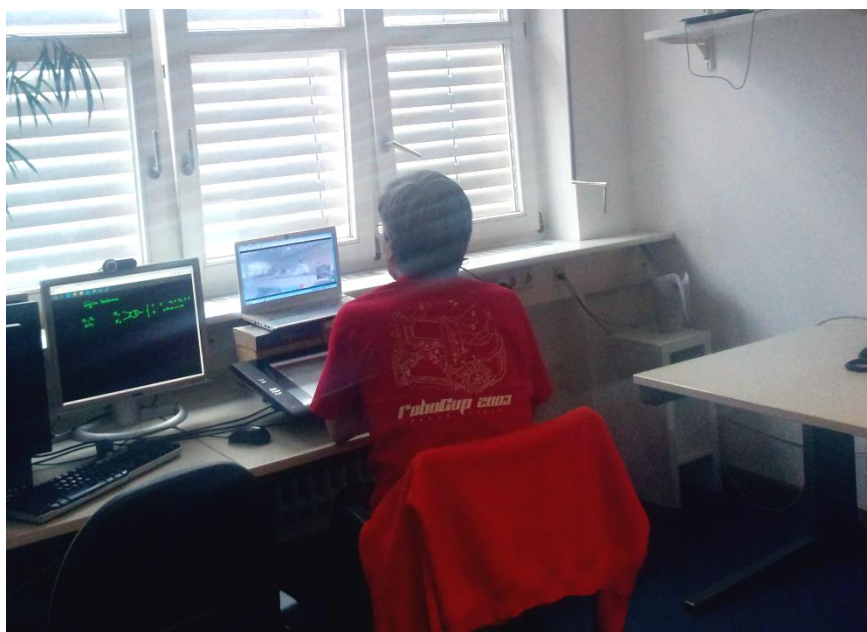


Figure 6.5. A professor is delivering a lecture to a remote class.

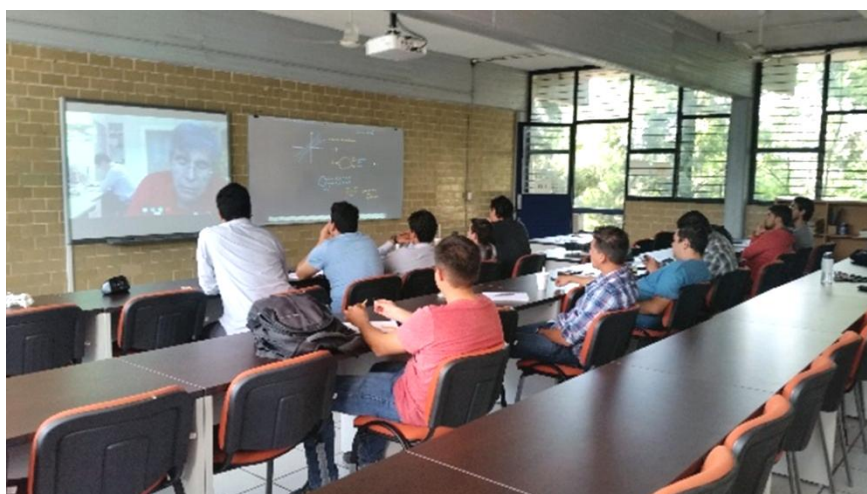


Figure 6.6. The remote class uses two projectors to display the video of the lecturer and the lecture content.

We used Skype for video communication. Video and audio communication is not implemented in the Classroom Interactor for several reasons: First, there are many widely used commercial instant messaging tools available which are free, easy to get and have mature solutions to support high-quality communications. Second, it is not necessary for each student to have a video or audio channel in the class since they can watch and hear the lecturer from the public media stream, and this can ensure the ease of use and browser-friendly features of the student client so they can use a variety of mobile devices in the classroom to receive the lecture notes and interact with the teacher.

6.2.2 Study

The professor from the Department of Computer Science uses Classroom Interactor to teach Pattern Recognition course to 13 students in a remote classroom. The course includes 15 lectures, and each lecture lasts for around two hours. In the previous semester, the professor used Intellichalk, the same function as the Classroom Interactor but without the network communication and interaction capabilities, to teach the same course in a physical classroom. We compare how the teacher used the system in these two courses and attempt to find out whether the instructor's teaching efficiency was affected by the remote teaching setup. Several research methods have been adopted in this study.

Observation: The author was in the office every lecture to observe and record important information, including the video and Classroom Interactor connection status, the communication between the teacher and students, and other unexpected situations encountered during the lecture.

Questionnaire: An on-line questionnaire was sent to the students, asking their opinion about this teaching method and the technology we use as well as their experience and suggestions.

Activity log: The teacher's operations on the system are recorded for further analysis and comparison with the logged data in local classroom. The communication between the teacher and students via the system is also recorded.

6.2.3 Results

Network connection status



Figure 6.7. An Illustration of the network transmission for the remote teaching.

Lecture	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Classroom Interacter	X	2	1	0	0	0	0	1	0	2	0	0	0	1	0
Skype	0	0	0	0	0	0	0	2	0	0	0	2	1	0	0

Table 6.4. The number of disconnections for Classroom Interacter and Skype during the 15 lectures.

Figure 6.7 shows the locations of the instructor and the remote classroom. The average RTT (Round Trip Time) between the instructor's computer and the server in the USA is approximately 170 milliseconds. And the average RTT between the remote class in Mexico and the server is about 30 milliseconds. This means every stroke drawn by the teacher takes about 100 milliseconds plus the processing time on the server to reach the remote classroom. Table 6.4 presents the number of disconnections of both Classroom Interacter and Skype in the 15 lectures. In the first lecture, due to the proxy server settings issues, we did not use Classroom Interacter. A total of seven disconnections were recorded in the next 14 courses, averaging 0.5 times per lesson. Skype disconnected 5 times in total, and 0.33 times per lecture on average.

Teaching activity

	Physical Classroom	Remote Classroom
strokes / lecture	2419	3732
strokes / hour	1683	2021
color changes / lecture	101.9	149.0
color changes / hour	70.9	80.7
color used / lecture	5.4	10.2
time for creating content (seconds per hour)	477.3	586.0
time for system interaction (seconds per hour)	40.9	122.8

Table 6.5. The comparison of teaching activities in physical and remote classes.

From Table 6.5 we can see that the teacher writes more content per hour in remote lectures, about 20% more than in physical classroom lectures (2021 in remote classes and 1683 in physical classes). He uses a significantly greater variety of colors in distance learning (10.2 colors used per lecture in remote classes and 5.4 colors in physical classes), and shows a higher color switching frequency in distance teaching. The system also records the time the teacher uses to create lecture content and interact with the system. The operation of creating teaching content mainly includes writing, adding images, text and digitized handwritten notes. The time for system interaction is the time used to move, modify and delete visual elements, and drag the lecturing canvas. As shown in Table 6.5, the teacher spends an average of 586.0 seconds per hour on creating

lecture content and 122.8 seconds interacting with the system when delivering lectures to the remote class. The time for system interaction takes up 17.3% of the total operation time. While in the local classroom, the teacher uses an average of 477.3 seconds per hour on creating lecture content, and 40.9 seconds for system interaction. The time used for system interaction is 7.9% of total operation time. As can be seen, compared with teaching in a physical classroom, the teacher spends a greater proportion of time on system interaction.

Questionnaire results

Table 6.6 shows the evaluations of Classroom Interacter from students in the remote classroom. We used a 5 point Likert scale (5 = strongly agree, 1 = strongly disagree) to investigate students' experiences with the remote teaching and received feedback from 11 students. Overall, they fully agreed that using Classroom Interacter with Skype was a good solution for remote teaching (item 1, mean = 5.00, SD = 0). When asked about the technology we used, 10 of the 11 students thought the visual quality of Classroom Interacter and the quality of video was good (item 2, 3). 9 of them thought the sound and video of Skype and the content on the Classroom Interacter were synchronized well (item 4, Mean = 4.09, SD = 0.20).

Question	Mean	SD
1. Overall, I think the Classroom Interacter + Skype is a good solution for distance learning.	5.00	0.00
2. The quality of the video communication is good.	4.09	0.16
3. The visual quality of the Classroom Interacter board is good.	4.45	0.20
4. The video and the Classroom Interacter board are synchronized well.	4.09	0.20
5. The instructor uses the remote teaching technology appropriately.	5.00	0.00
6. The instructor encourages me to ask questions.	5.00	0.00
7. I am comfortable asking questions using the videoconferencing format.	4.36	0.19
8. I would have felt more engaged in a normal class setting.	3.82	0.34
9. After some practice, I can easily work on every function.	4.36	0.19
10. Voting during lectures helps me know if I understand the course concepts.	4.72	0.13
11. I think the student status function can help the teacher make better lectures.	4.91	0.09
12. Sending questions to the teacher helps me solve my problems.	4.64	0.15
13. Saving lectures with my annotations can help my study.	4.91	0.09
14. The Classroom Interacter system increased my interaction with the teacher.	4.91	0.09
15. Using this system made me feel more involved in the class.	4.45	0.15
16. I would like to use the Classroom Interacter system in the future.	4.91	0.09
17. I will suggest that other instructors use this solution for remote teaching.	4.73	0.19
18. I was distracted by my mobile device during the lecture.	2.36	0.39

Table 6.6. The questionnaire results from the remote students.

All students thought the remote teaching technology was appropriately used and they were encouraged to ask questions during the lecture (item 5, 6). 10 students felt they were comfortable asking questions through the video conference format, and only one student gave a neutral opinion (item 7). When asked their opinion about using their personal devices to interact with the instructor, they gave very positive evaluations on both usability and usefulness (item 9 - 13). We can see that all students felt the system increased their interaction with the instructor (item 14, Mean = 4.91, SD = 0.09) and felt more involved in the class (item 15, Mean = 4.45, SD = 0.15). Students also expressed their willingness to use the Classroom Interacter system again (item 16, Mean = 4.91, SD = 0.09) and would suggest that other teachers use it for remote teaching (item 17, Mean = 4.73, SD = 0.19). However, 7 of the 11 students believed that they would feel more engaged in a normal classroom (item 9). 2 students also reported that they were distracted by their mobile devices during the lecture (item 18).

6.2.4 Discussions

Technical feasibility

The trial shows that using Classroom Interacter and Skype for distance learning is technically feasible. First of all, it provides a lightweight approach to implement distance learning, especially suitable for remote classrooms learning. The remote class only needs to use the video communication tool to receive teacher's video and sound, and use a browser to receive the lecture content written by the teacher. Compared with other remote teaching tools, our method is more convenient to setup. The remote classroom does not need to install any special software other than the video communication tool. Students can use their browsers to receive the lecture content, add annotations, and interact with the teacher.

We have found that the average network RTT from the teacher to the remote classroom was about 170 ms plus 30 ms. The network condition was not good, and it caused about one disconnection in every two lectures, which is slightly more than Skype (about one disconnection in every three lectures). When Classroom Interacter disconnected, the remote class only needed to refresh the browser to re-synchronize with the teacher, and it did not disturb the lecture too much. When the network condition is better or the remote classroom is not physically too far from the teacher, the network connection will be much better.

As can be seen from the students' feedback, they felt Classroom Interacter plus Skype is a good solution for distance learning. They gave very positive evaluations of the video communication, the visual quality of the lecture content, and they reported that the video of the teacher and the lecture notes on the browser were well synchronized.

For all 14 remote lectures, the teacher used Classroom Interacter and the video communication tool Skype to successfully complete his teaching tasks. Students in the remote class were able to setup the computers and projectors to receive the information

from the teacher without difficulty. And they gave a high appraisal of the technology we used. The practice shows that Classroom Interacter has a practical feasibility for remote teaching.

Compared with physical classroom

In our study, teachers use Intellichalk for teaching in the physical classroom, and Classroom Interacter is used for the remote classroom. Intellichalk can be seen as a stand-alone version of Classroom Interacter, without the network communication features. For teachers, there is no difference except whether they are facing a video of the remote class or real students in the classroom. Intellichalk has been used in long-term real teaching practice, and is a mature tool to assist teachers in their teaching.

We recorded the teacher's activity data when using Classroom Interacter for remote teaching, and compared it with the data collected in the physical classroom using Intellichalk, aiming to study whether the remote teaching technology we use can ensure the teacher's teaching efficiency.

As can be seen from Table 6.5, in contrast to our expectation, the teacher was in a more active state when teaching remotely. He writes about 20% more strokes per hour than he does in the physical classroom. And the frequency of color switching is 14% higher than when teaching in the physical classroom. The average number of colors used in each lesson is also significantly increased.

According to the teacher's feedback, the reasons for the improved efficiency in remote teaching may be related to the following reasons. First, the teacher was sitting in the office when teaching the remote class, it is more comfortable and relaxing than standing in the classroom. Second, he faced a small class of 13 students when teaching remotely, while the physical classroom, which has about 60 students. And lastly, he used his native language at a higher speaking speed for remote teaching but used his second language in the physical classroom, which may have caused a slightly efficiency variance.

We cannot tell the exact reasons why the teacher is more efficient in remote teaching, but we can conclude that his teaching efficiency has not lowered by the indirect form of teaching. The distance learning technology we offer does not create obstacles to his teaching.

Teacher-student communication

The questionnaire results show that students felt the distance learning technology we used did not hinder their communication with the teacher. They felt comfortable asking questions using the video conferencing format. In addition to asking questions directly to the teacher using the microphone, students can also send questions to the teacher via their mobile devices. As shown in Figure 6.8, the teacher displays the questions sent by the students on the lecturing canvas and explains them to the class. The vast majority of students have expressed their willingness to use the voting, question sending and

student status setting functions to interact with the teacher. They felt that the Classroom Interacter system was able to increase teacher-student interaction and made them more involved in the classroom.

Even though students highly appraised the distance learning technology we used and believed it increased their interaction with the teacher, most students thought they would be more engaged in a real classroom setting. This is the disadvantage of distance learning technology, we can use a variety of ways to reduce the barriers to teacher-student interactions, and even provide more possibilities than in the physical classrooms to facilitate communication. But these communications are always indirect. For most students, face-to-face interactions with the teacher in physical classrooms will make them more involved. In addition, it cannot be ignored that two students reported that they were distracted by their mobile devices during the lecture. There is no effective way to solve this problem now, but fortunately, in the small-scale and fast-paced classroom, only a small part of the students have such problem. Even with these problems, the remote teaching technology is widely needed since it addresses the problem of location restrictions. And the development of technology has brought more possibilities that benefit remote classroom learning.

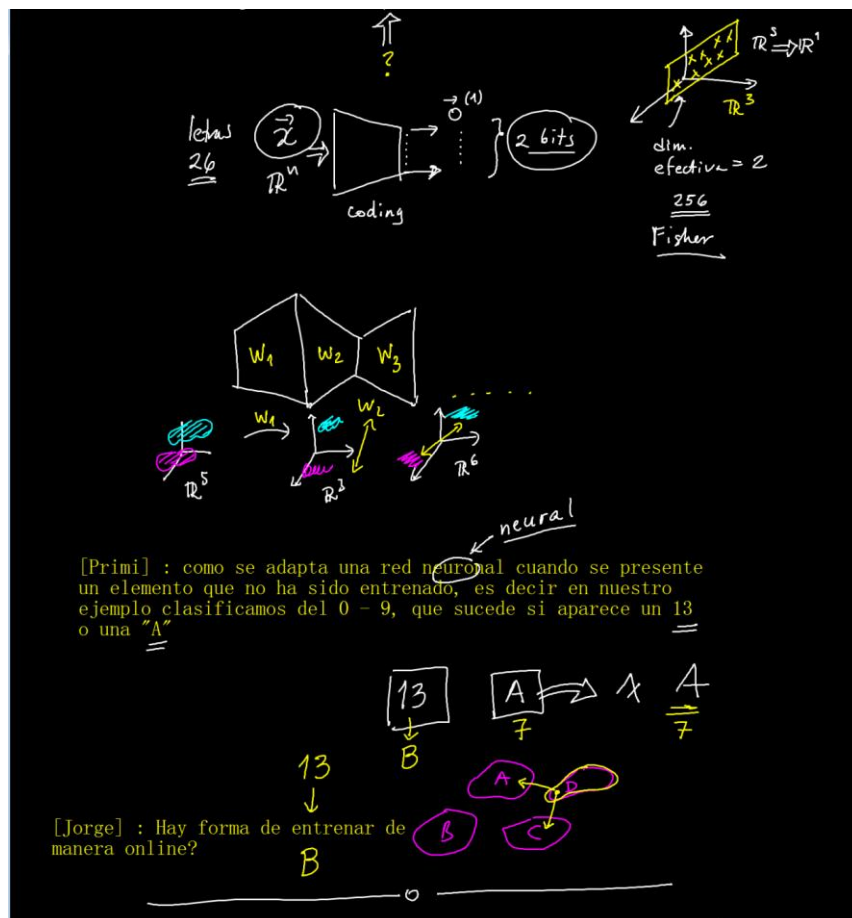


Figure 6.8. The lecturer put the questions from students onto the public display and explained them to the class.

6.3 Summary

In this chapter, we first introduced the use of Classroom Interacter in the physical classroom. We have deployed the system in a large lecture room for teaching and conducted a study on this system with students' own mobile devices. The user study indicates that the Classroom Interacter system can encourage classroom interaction. The instructor is able to observe the understanding status of the students from their anonymous feedback. Students have given positive evaluations of the system in terms of usability, usefulness, being able to promote classroom interaction, and shown their willingness to use it again.

We then investigate the use of Classroom Interacter for remote teaching. The study shows that the use of Classroom Interacter combined with video conferencing technology for remote teaching is technically feasible, stable and well synchronized. Compared to physical classroom teaching, using Classroom Interacter for remote teaching does not reduce the teaching efficiency of the teacher, the lecture content created per hour did not decrease. Students reported that there was no obstacle to communicating with the teacher, they were comfortable asking questions via the technology we used and they felt encouraged to ask questions.

7 Summary and Future Work

This dissertation introduces Intellichalk, a novel classroom presentation system which supports multiple public displays. It inherits the advantages of traditional blackboards, but also combines the superiorities of digital systems, forging new capabilities for classroom teaching. This system has been implemented in the classroom as a long-term teaching practice that aims to understand the benefits of the multi-display-based electronic blackboard as an enhanced teaching aid.

To explore the potential of students' personal digital mobile device for learning, we have incorporated network communication capabilities into the presentation system with the objective of providing a convenient tool to encourage students to engage in classroom interaction using their own mobile devices. This system has been deployed in both physical and remote classrooms to study its technical feasibility and users' acceptance, as well as the impact of its implementation on the interaction between teachers and students.

7.1 The Contributions of This Work

1. Develop Intellichalk, an electronic blackboard

In the Intellichalk project, we used design-based research to continuously develop and improve the teaching system based on feedback from both teachers and students, aiming to provide them with a practical tool to enhance classroom teaching and learning.

It supports multiple public displays.

The move from traditional blackboards to now widely used computer-generated slides has dramatically decreased the screen real estate in classrooms. Many teaching techniques such as presenting previous information for later reference and discussing and comparing two concepts and contents in parallel cannot be easily achieved with a single display. Moreover, more and more university classrooms are equipped with more than one projector but lack of suitable software to make good use of them. Related studies [55, 56, 58] show that the increased visual area can improve students' learning effectiveness and reduce their cognitive loads. The Intellichalk system supports a different number of public displays (restricted by the hardware). It provides teachers with a familiar and convenient way to organize and make full use of multiple public displays for classroom learning.

It combines the advantages of traditional blackboards and digital systems to create new capabilities for teaching.

Traditional blackboards have been used in the classroom to present and explain the lecture content of various disciplines for over two centuries. One study [10] shows that

traditional blackboards support many more teaching techniques than slides, while the digital systems have clear advantages in data storage, multimedia capabilities and material reuse. We design the Intellichalk system based on the idea of traditional blackboard, but also absorb the advantages of digital systems, forging a more suitable system for classroom teaching.

It has a user-friendly user interface formed through years of practical use.

As important as the functionality, the user interface directly affects the user's experience and their perception of the system. We have gradually improved the user interface through the iterative design process. The blackboard-like user interface provides teachers with a familiar working environment. It offers fluent writing experience and a convenient way to use multimedia resources. Various colors are readily available with a single click, and different functions can be flexibly configured. The user interface is continually improved and developed through actual classroom application, reflecting the user-centric philosophy.

It has intelligent assistants to enhance the classroom experience.

We have designed a kind of program that runs in the background to provide services to the user. For example, the handwritten lambda calculus interpreter recognizes handwritten input and outputs the interpreted results step by step. The logic circuit simulator can recognize hand-drawn logic circuits and shows the results after running in the background. We plan to work with third-party software to develop more intelligent assistants. Algebra software can be used to calculate or plot the mathematical formulas and functions. Speech recognition can help teachers to convert voice input to text. Developers can add a variety of intelligent assistants to help the instructor and enliven the classroom.

It has a highly modular software structure, which allows extension at different levels.

Feature changes, extensions and upgrades are issues that we have taken into consideration when designing the system. Therefore, we have adopted the OSGi framework to design a highly modular architecture. Overall, the system modules can be divided into three categories, the basic modules, the intelligent modules and the plug-in modules. More types of modules can be defined and added to the system. Specifically, each type of module can also be extended. The service-based collaboration between components enables lazy loading, hot plugging and dynamic functional switching. The loosely coupled system architecture makes the extension of intelligent assistants convenient, and reduces the difficulty of changing and extending system functions during the iterative implementing process.

2. Concludes design suggestions for classroom presentation systems

We continuously improve the system according to feedback from teachers and students during the design-based research process, to ultimately give the classroom presentation

system a mature functionality which results in high satisfaction. We summarized the features a useful classroom presentation systems should have based on the design and deployment process of the Intellichalk electronic blackboard system. These suggestions are summed up based on our classroom practice, hopefully this will offer useful references to presentation system designers.

The blackboard metaphor

We find that traditional blackboards have many advantages compared to the widely used computer-generated slides, especially in STEM disciplines where complex reasoning and explaining are needed. They offer a large visual area to show the history information and to present the relevant information together for comparison. They present the buildup of information, which allows students to watch the thoughts of the instructor. We believe that by combining these advantages of traditional blackboards and the superiorities of digital systems, a more suitable presentation system for classroom teaching can be created. Intellichalk provides an example of such a system.

Separation of views

The separation of the public and the instructor's views ensures the public display contains only the information relevant to the lecture, preventing the waste of the screen real estate, while keeping the instructor's manipulations out of the public screen, preventing distraction for the students. Moreover, as one professor mentioned, he could face the class and keep eye contact with the students, rather than turning his back to them. A separate view for the instructor brings many advantages for classroom learning.

Supports dynamic teaching styles

One of the most frequently criticized limitations of slides is the linear, slide-by-slide style of presenting information, which is said to be unsuitable for classroom teaching. While the traditional blackboard supports many dynamic teaching techniques, which we should inherit. A classroom presentation system should support non-linear, dynamic teaching skills such as comparison of relevant information, convenient reference to previous content, adjusting the lecture content according to student's feedback, work on examples, and so on.

Tradeoff of reuse

We advocate the partial reuse of lecture content, which is different from the completely reusable slides and non-reusable writing content on the traditional blackboard. For descriptive content, such as definitions and descriptions that do not contain reasoning or an explanation process, we suggest reusing them as images or digital ink blocks. These fragments can be prepared before class and added to the lecture view when needed. We believe this approach will help teachers save time spent on trivial writing and allow them to spend more effort on complex reasoning and explaining.

Enhances classroom experience

New technologies such as Information and Communication Technology and Artificial Intelligence make it possible to create interesting tools to help teaching and enhance classroom experience. Great teaching tools should be capable of improving teaching efficiency or learning effectiveness while improving the learning experience at the same time. We have designed and developed a series of programs called intelligent assistants in order to achieve this goal. We attempt to work with a variety of third-party software to develop intelligent assistants for various disciplines.

Reduces students' cognitive load

In order to reduce the students' cognitive load in the classroom and increase their learning effectiveness, we have adopted a variety of methods. The multi-display system increases the visual area and enables persistency of preceding information, which can ease the cognitive load of the students since they do not need to remember all previous details [58, 63]. Teaching with an electronic blackboard, the teacher is slowed down by her handwriting, thereby reducing the risk of cognitive overload. It gives the students time to understand the lecture. The presenting of information development process give students a chance to follow the lecturer's thought. Reducing the cognitive load is also an important issue to consider when designing a classroom instruction system.

3. Develop a lecture preparation system, which can digitize the handwritten notes on the paper

Compared with office software, some professors prefer to use pen and paper to record and express ideas. In mathematics, physics, chemistry and other disciplines, the existing office software requires a lot of work to complete the formula editing, diagrams, sketches and so on. We have developed a tool that can extract the hand-written contents from the paper. It runs independently and allows teachers to prepare their lectures using pen and paper, contents written on the paper will be extracted digitally and segmented into digital ink blocks with a single click. These digital ink contents can be added to the Intellichalk system whenever needed or used in other teaching software as images. The system provides teachers with the option of preparing the lecture with pen and paper and then using the prepared content on electronic systems, while enabling easy storage and reuse.

4. Study the benefits of multi-display based electronic blackboard for teaching

As the screen technology develops rapidly, large digital displays and high-resolution projectors are increasingly affordable and available. It is highly likely that in the near future, these kinds of displays and projectors, especially large digital displays will be used in more classrooms. We have deployed the Intellichalk system on a digital display wall for long-term classroom teaching and gathered a rich set of data. We have compared it with a single-display setting. From the analysis of the data we find that such wall-sized, non-slide based presentation system has clear benefits for both

instructors and students. It can reduce the effort required by the instructor when referring back. Teachers can effectively use the system for lecturing, while less system interaction is needed compared to the single-display setting. Students find that the system helps their learning and they are satisfied with the visual quality of digital displays.

5. Implement Classroom Interacter to promote teacher-student interaction via mobile devices

Typical lectures in university classrooms are attended by large audiences, lecturer-centered and have very little interaction. Most students are passive learners in the classroom. The popularity of mobile devices among students and widespread wireless networks shows an opportunity to change this situation and create an active environment in the classroom. We have extended the Intellichalk classroom presentation system to enable students to participate in classroom learning using their own mobile devices. The Classroom Interacter we developed has a distributed system structure to support flexible setup. The browser-based student client supports easy access without any downloading or installation. It is designed to promote classroom interaction and collaboration, to help students to better follow the lecture and to support more flexible settings and a wider range of use scenarios.

6. Deploy Classroom Interacter in both physical and remote classrooms

We have deployed the Classroom Interacter system in the physical classroom and asked students to use the system with their own mobile devices. The user study indicates that the Classroom Interacter system can encourage classroom interaction. The instructor can better understand the students understanding of the lecture from their anonymous feedback. Students have given positive evaluations of the system in terms of the usability, usefulness and facilitating classroom interactions, and shown their willingness to use it again.

We also combined the system with video conferencing technology for remote teaching. Study indicated that this solution is technically feasible, stable and well synchronized. It did not reduce the teaching efficiency of the teacher, and students reported that they felt the technology did not hinder their communication with the teacher, they were comfortable asking questions via the remote teaching system, and they felt encouraged to ask questions.

7.2 Suggestions for Future Work

For researchers and developers who are interested in continuing to do research based on Intellichalk and Classroom Interacter, we offer a few suggestions on the directions of future work.

1. Develop more intelligent assistants for various disciplines

The intelligent assistants can extend the functionality of Intellichalk and enhance the classroom experience. We have designed the plug-in system to support the extension of intelligent assistants. The hand written lambda calculus interpreter and the hand-drawn logic circuit simulator have shown how the intelligent assistants help instructors with their teaching and enhance the classroom experience. When a great number of intelligent assistants have been developed for various disciplines, such as tools for chemical symbol recognition, physical law simulation and mathematical function plotting, the usefulness and applicability of the system will be greatly enhanced. Developers can also work with different kinds of third-party software to expand the application scope of Intellichalk with reliable services.

2. Archive the course and create online teaching platform

When the system has large-scale users, educators and researchers can create an online teaching platform to make these educational resources available. The course storage and playback methods we designed make these course materials available for online teaching with several advantages compared to video or flash format. The file size is extremely small while the quality of visual contents is exactly the same as on the local computer. The current play requires the support of Java runtime environment on the client computer, but with a small extension to the browser-based student client of Classroom Interacter, it can be used to play the lecture without any additional requirement.

3. Study the pedagogical benefits of the system

Rigorous comparative studies can be conducted to explore the influences of the system or the impact of its specific features on learning outcomes or the cognitive load of students.

4. Further exploration of the collected usage data

Since all the operations of the teacher on the system are recorded by default, we can further explore the value of these data, for example, to establish a course evaluation mechanism. Researchers can work together with the participants in the classroom to design the evaluation indicators, such as activities and operations that should be encouraged or avoided. If the evaluation mechanism is implemented, the teacher can get feedback from the system immediately after each lecture. It may not be as accurate as student surveys or expert analysis, but teachers can get feedback quickly and easily so they can improve their teaching skills one lecture at a time. The usage data can also be used to study the user's habits in order to provide teachers with personalized features and improve the usability of the system. In addition, it can be used to study how experienced teachers use the system, and to provide reference for new teachers to achieve efficient teaching.

7.3 Concluding Remarks

This study explores the feasibility and benefits of digital multi-displays and students' mobile devices for university classroom teaching through the development of teaching systems and their deployment in classrooms. The results reported here rely on, and are limited by the current development of display technology and personal mobile devices. Technology will continue to change the classroom. The exploration of educational technology is as gradually and endless as the development of technology. Soon, digital displays will be larger, less expensive, and have more features, while personal mobile devices will have new capabilities, new sizes, and new connections and interactions. Educational researchers need to constantly apply technology in practice, reflect on and improve educational theories, and improve educational technology. Our work provides a new starting point for research on digital multi-displays and personal mobile devices for classroom practice.

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Appendix I

Zusammenfassung

Neue Technik führt immer neue Möglichkeiten in das Klassenzimmer ein. Im aktuellen Stadium der technologischen Entwicklung haben große Digitalanzeigen und persönliche mobile Geräte das Potenzial, weit in Universitätsklassenräume integriert zu werden. Diese Studie untersucht die Machbarkeit und Vorteile der Verwendung von Multi-Digital-Displays und persönlichen mobilen Geräten von Studierenden in der universitären Lehre.

Im Vergleich zu weit verbreiteten computergenerierten Folien bietet die traditionelle Tafel Vorteile in Bezug auf die Größe des Betrachtungsbereichs, der Sichtbarkeit der Information und der Benutzerflexibilität usw. Die traditionelle Tafel wird daher immer noch von Instruktor:innen aus den Fachbereichen Wissenschaften, Technik, Ingenieurwesen und Mathematik bevorzugt. Große Digitalanzeigen bieten einen visuellen Raum vergleichbar mit der traditionellen Tafel, mit großer visueller Qualität. Damit ist es möglich, die Vorteile der traditionellen Tafel und der digitalen Systeme zu kombinieren, um innovative Lehrmittel zu schaffen. Allerdings fehlt es an praktischer Bildungssoftware, um das Potenzial zu nutzen, diese neuen Werkzeuge für Bildungszwecke einzusetzen.

Das erste Ziel dieser Arbeit ist es, ein neuartiges Klassenraum-Präsentationssystem zu entwerfen und zu entwickeln, das nicht nur die Vorteile der traditionellen Tafel hat, sondern auch die Eigenschaften von digitalen Systemen aufnimmt und ein geeignetes Werkzeug für den Unterricht darstellt. Dieses System wurde im Klassenzimmer als eine langfristige Lehrpraxis implementiert, die die Vorteile der Multi-Display-basierten elektronischen Tafel als verbesserte Lehrhilfe zu verstehen sucht.

Gleichzeitig hat der weit verbreitete Besitz von mobilen elektronischen Geräten unter den Schülern zur Möglichkeit geführt, die Interaktion des Lehrer-Studenten zu fördern und den passiven Lernstil der Hochschulvorträge zu verändern. Ich habe Netzwerkkommunikationsfähigkeiten in das Präsentationssystem integriert, mit dem Ziel, ein bequemes Werkzeug zu schaffen, um die Schüler dazu zu ermutigen, sich in der Unterrichtsinteraktion mit ihren eigenen mobilen Geräten zu engagieren. Dieses System wurde sowohl in physischen als auch in entfernten Klassenzimmern eingesetzt, um seine technische Machbarkeit und die Akzeptanz der Nutzer sowie die Auswirkungen ihrer Umsetzung auf die Interaktion zwischen Lehrern und Schülern zu untersuchen.

Basierend auf der iterativen Entwicklung und dem langfristigen Einsatz in den Lehrmethoden habe ich praktische Klassenzimmertechnologien entwickelt, ihre Auswirkungen auf das Klassenraumlernen und die Vorteile, die diese neuen Technologien für Lehrer und Schüler bieten, untersucht. Darüber hinaus habe ich das Feedback von den Schülern ausgewertet und einige Vorschläge gemacht, die sich auf die Gestaltung neuer Klassenzimmer-Präsentationssysteme beziehen. Meine Arbeit bietet einen neuen Ausgangspunkt für die Erforschung von digitalen Multidisplays und persönlichen mobilen Geräten für die Klassenraumanwendung.