Remote Physics Experiments in 3D Virtual Environment

Bettina Scheucher

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3D Virtual Environment for Remote Physics Laboratories
in Learning Settings

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Bettina Scheucher

Graz University of Technology
A-8010 Graz, Austria

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Advisor: Univ.-Ass. Dr. Gütl Christian
Co-adivsor: Associate Director Judson V. Harward

Ferngesteuerte Physik Experimente in einer 3D virtuellen Umgebung

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Bettina Scheucher

Technische Universität Graz
A-8010 Graz

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Begutachter/Betreuer: Univ.-Ass. Dr. Gütl Christian
Betreuer: Associate Director Judson V. Harward

Abstract

In the context of science education the interrelation of physical theory, model and experimentation is hard to comprehend, and therefore laboratory work plays a major role in order to understand abstract concepts. From a constructivist view, research in this direction indicates that besides direct and active experience of the world's phenomena also discussions and collaboration with educators and peer learners are significant for the learning process. Regarding distance education of complex science concepts, electronic laboratories have become increasingly popular. However, most of those distant laboratories lack in providing collaboration and communication. Consequently, this fact combined with the opportunity to work on practical experiences in a collaboratively way over distance has motivated the thesis goal to create a 3D collaborative virtual learning environment using desktop-immersive technology. Unlike traditional computer-based learning technologies, these kinds of 3D environments provide multiple communication channels between users and improve presence and awareness in the learning process in addition to laboratory experimentation within an immersive 3D space.

To achieve this prototypical environment the practical part of this thesis focuses on the integration of internet-accessible physics experiments with Project Wonderland, Sun's toolkit for creating collaborative 3D virtual worlds. Internet-accessible laboratories (iLabs) provide access and control of actual labs available 24/7 and when combined with the TEALsim 3D simulation toolkit, they enable the student to visualize physical phenomenon synchronously generated by the experiment. Integrating these tools within a collaborative immersive environment provides the opportunity for teachers and students to work together as avatars as they control, visualize, explore and discuss the results of an experiment.

In order to assess the desired collaborative value of the developed learning environment, an initial study was performed. One of the major findings of this evaluation indicates that immersive qualities of the prototype will enhance the collaborative experience of laboratory environments along with reconsiderations of the environment's arrangements. Consequently, further suggestions for improvements form the basis for future development in the short term as well as long term perspective to improve the learning process.

Kurzfassung

In der Lehre der Ingenieur- und Naturwissenschaften tragen praktische Laborversuche wesentlich zum Fortschritt des Lernerfolges bei, da erworbene theoretische und methodische Kenntnisse durch vielfaches Experimentieren erprobt werden können, um in weiterer Folge das Verständnis von abstrakten Konzepten zu verbessern. Bezugnehmend auf die Fernlehre, gewinnen virtuelle Labore in diesem Zusammenhang zunehmend an Bedeutung. Durch die computergestützte Zugriffssteuerung von realen Laborinstrumenten über das Internet, können zeitliche und räumliche Begrenzungen bei Laborübungen weitgehend aufgehoben werden. Im Laufe der Jahre haben Forschungsarbeiten jedoch gezeigt, dass neben aktivem und explorativem Lernen auch die Zusammenarbeit bzw. Kommunikation mit anderen Studenten für den Lernprozess von Bedeutung ist. Der Untersuchungsteil dieser Arbeit macht deutlich, das der Großteil virtueller Labore diese soziale Komponente vernachlässigt oder nur unzureichend bedient. Auf dieser Tatsache basierend, wurde die Idee einer 3D kollaborativen, virtuellen Lernumgebung für interaktive Laborexperimente entwickelt.

Der praktische Teil dieser Arbeit umfasst die Integration eines ferngesteuerten Physik Experimentes (iLab) in Project Wonderland, ein Werkzeug von Sun Microsystems zur Erstellung von 3D kollaborativen, virtuellen Umgebungen. Zusammen mit dem Einsatz eines 3D Simulationswerkzeuges (TEALsim), werden gleichzeitig physikalische Phänomene, erzeugt durch das reale Experiment, dreidimensional visualisiert. Im Unterschied zu herkömmlichen computerbasierten Laborräumen, bietet diese immersive 3D Umgebung mehrfache Kommunikationskanäle und vermittelt zudem das Gefühl physisch präsent zu sein, da der Lernende in Form eines Avatares virtuell repräsentiert wird. Über geographische und technologische Grenzen hinweg, können Experimente durchgeführt, visualisiert sowie Ergebnisse in der Gruppe besprochen werden.

Abschließend wurde im Rahmen dieser Arbeit eine Studie durchgeführt, um den gewünschten kollaborativen Mehrwert der entwickelten Lernumgebung zu evaluieren. Ergebnisse zeigen, dass kooperatives Lernen von räumlich, getrennten Lerngruppen in immersiven Umgebungen, das nötige Potential aufweist um die Qualität der Fernlehre deutlich zu verbessern. Neben dem Impuls, die Elemente des virtuellen Lernraumes neu anzuordnen, schaffen konstruktive Verbesserungsvorschläge eine solide Basis für zukünftige Weiterentwicklungen, um über kurz oder lang den Lernprozess fortwährend zu verbessern.

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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Eidesstattliche Erklärung

Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst, andere als die angegebenen Quellen/Hilfsmittel nicht benutzt, und die den benutzten Quellen wörtlich und inhaltlich entnommene Stellen als solche kenntlich gemacht habe.

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Chapter 1

Introduction

In the past few years due to the evolution of information and communication technologies a number of highly interactive, multimedia three-dimensional Virtual Environments (VEs) have been developed. In other words, a 3D space is provided that consists of interactive components allowing users to explore and manipulate objects in real-time (Sherman & Craig, 2003). Furthermore, such environments provide the illusion of being immersive and increase the participant's sense of reality by enabling the user to perform actions and behaviors which are analogous to those she or he can initiate in the real world. Based on desktop-immersive technology providing interaction with traditional input devices, like keyboard and desktop mouse, the use of these kinds of VEs has become increasingly common in many educational application domains (Dalgarno, 2002). Especially in science education, the use of a third dimension has captured the attention and interest of educators worldwide. This interest originally arose from educators' demands for more flexible and expressive technologies to support understanding of complex systems in scientific disciplines (chemistry, physics, mathematics, medicine, etc)(Louis, 2004).

In this context, hands-on experimentation has been considered to be a vital activity when trying to deeply understand ideas about abstract concepts (Leleve, Arnous, & Prevot, 2009). This approach follows the constructivist learning theory assuming that knowledge is based on direct and active experience of the world (Huang, 2002), in other words, students construct their own understanding through experiencing things. However, research in distance education has found also constructivist approaches (Bates, 2005). Due to the fact that attending hands-on laboratory sessions is not always possible because of time and space, hands-on training is nowadays also required in the distance learning context (Leleve et al., 2009). Consequently, different kinds of laboratory environments have been developed to provide laboratory activities also in virtual spaces. Among them, there are virtual environments providing both interaction with simulated phenomena and remote experimentation with real laboratory equipment. Since students need

opportunities to experience complex systems phenomena in order to reveal mistaken assumptions (Jacobson & Wilensky, 2006; Dori & Belcher, 2003), such computer-generated simulations can enable the students to compare theoretical with experimental results at a distance. Furthermore, remote laboratories offer the possibility to students to access real experiments remotely either by campus-wide WLAN access, or from outside the university (Hardison, De-Long, Bailey, & Harward, 2008). Nevertheless, while several VLE's are designed as single-user environments, wherein learners accomplish experiments by themselves, recent approaches indicate that sharing experiences in a group, discussing results together, and interacting with other participants can bring learners to a higher achievement level (Laister & Kober, 2002).

In this context, the 3D desktop-immersive technology might overcome this issue (Dalgarno, 2002) providing multi-user support in order to enable interaction not only with objects but also with other users, represented as avatars. Multi-user VLEs, also known as collaborative virtual learning environments (CVLEs) are richly immersive due to the 3D environment and provided multiple communication channels learners get the feeling of collaborating with real people and being a part of a group (Chee & Hooi, 2002). Since the theory of constructivism also focuses on learning as a social process through proactive interaction with peers (Gül, Gu, & Williams, 2008), therefore 3D CVLEs provide students an opportunity to gain experience in the same way as they would do it in a real laboratory. Consequently, CVLEs constitute a meaningful constructivist tool to complement and expand laboratory activities in order to enrich student's learning experiences.

1.1 Motivation and Objectives

In the light of these facts stated in the previous section, a CVLE for internet-accessible physics experiments has been developed in cooperation between the Center for Educational Computing Initiatives(CECI) at Massachusetts Institute of Technology (MIT) and the Institute for Information Systems and Computer Media at Graz University of Technology (TUG).

Given that 3D virtual environments provide features to address issues such as presence, social interaction, and engagement, a decision was made to study Project Wonderland to discover if it could provide a shared sense of space for physics education where students and educators are able to work and learn together in a collaboratively way. Through the integration of specific technologies and projects, the prototype should allow participants of this immersive environment the use of a 3D simulation to visualize the real behavior of an actual remote physics experiment. The fact that educators indicated an interest in using CVLE with their students was a motivation as well as the promising communication and collaboration tools in such a multi-user environment.

Additionally, an initial study to assess the collaborative and communication values as well as usability and learning issues of the prototype was motivation. Therefore evaluation results of the applicability in learning settings of the prototyped 3D CVLE were objectives as well, motivated by the outcome whether the objectives of supporting learning and teaching by means of better collaboration in the CVLE were achieved.

1.2 Thesis Structure

This thesis is structured in two main parts. The first part deals with the basics and backgrounds and introduces a number of frequently used terms, such as 3D virtual environments or laboratory environments for web-based learning at a distance in a collaboratively way. Consequently to clarify their meaning in the context of the thesis. Additionally, related work that motivates the prototypical implementation of a CVLE is outlined. The second part then describes the outcome of the thesis. Based upon the theoretical foundations of the first part, the implementation details of a CVLE prototype and a processed evaluation is shown.

Chapter 2 gives a basic introduction into 3D virtual environments as well as different types and application domains are described. In addition a web-based learning approach is outlined, contrast full-immersive with desktop-immersive environment for distance learning purposes. As well technology and pedagogy evolution is reflected, mainly discussing the theory of activity and constructivism.

Chapter 3 discusses learning approaches of complex science in a distance learning context. Therefore, the first part of this chapter introduces laboratory environments, in particular virtual and remote laboratories and first collaborative approaches are presented. Besides benefits, limitations and general problems are outlined as well. Furthermore the second part of this chapter introduces 3D CVLE and related work. 3D CLE receives extra attention because it is the basis of the thesis.

Chapter 4 provides a conceptual approach of the planned 3D CVLE prototype. Furthermore the particular electromagnetic experiment that is related to the prototype implementation is introduced. Consequently the applied technologies as well as the delivery platform for the prototype are discussed.

The second part of the thesis (Chapters 5 to 6) describes the outcome of the thesis. Thus, chapter 5 discusses implementation steps involved in the production of a thesis. First platform configuration and components are discussed as well as the applied 3D API is explained. Afterwards selected details of the implementation are outlined and a glimpse of the prototype CVLE is presented.

Chapter 6 presents an evaluation of the prototype and its results of the applicability of the prototype CVLE. First, motivating reasons for the study are outlined and the experiment setup, pre-phase and class scenario are discussed. Afterwards findings of usability and learning experience as well as collaborative and communication values are presented. Finally, future work depending on the evaluation results and conclusions are given.

Finally, Chapter 7 outlines the lessons learned by listing encountered problems and findings. Afterwards possible tasks for future work on the prototype CVLE and its application are given, followed by an outlook on the role of 3D CVLE in the distance learning context. A summary concludes the thesis.

Chapter 2

Theoretical Analysis

2.1 Introduction

This chapter provides definitions of the key terms that are used throughout the remainder of the thesis. The major types of 3D virtual environments are then discussed. After that, the range of applications of 3D virtual environments is summarized with the particular focus on desktop non-immersive environments. References to published descriptions of 3D applications are included in this overview. Since the focus of this thesis is the use of 3D environments for educational purposes, the second part concentrates on a theoretical discussion of the web-based learning approach. Within this part the level of immersion in conjunction with learning is elaborated. The technology and pedagogy evolution in terms of distance learning is then reviewed, concluding the theoretical discussion of the activity and constructivist theory supported in three-dimensional environments.

2.2 3D Virtual Environments

2.2.1 Definition

In the late 1980s the term 'Virtual Reality' (VR) was popularized by Jaron Lanier, a modern pioneer of this field, often described as „the father of virtual reality" (Lanier, 2001). Virtual Reality (VR) is a technology that allows users to explore and manipulate a highly interactive, computer-based, multimedia three-dimensional environments in real time (Sherman & Craig, 2003). Users get the ability to interact with a VR system in the same way as their interaction

with objects and events in the real world. With the media hype of the early nineties, the term virtual reality has been used for everything from a 3D game up to video-like installations. This hype has tended to make the use of the term clichéd and it is now used in the research literature much less frequently than the term 'Virtual Environment' (VE) and 'Virtual World'. Consequently, VE's and virtual worlds still refer to the use of virtual reality technolgies, providing a display which allows the user to experience an entirely computer-rendered space as if it were real. Within educational areas the term 'Virtual Environment' is problematic because today the term 'Virtual Learning Environment'(VLE) is widely used to encompass any web-based learning resources supplemented by discussion tools allowing for synchronous or asynchronous text communication. Most of such environments only consists of text pages and 2D graphics. Wilson (1997) defines a VE as a „computer-generated model, where the participant can interact intuitively in real time with the environment or objects within it, and to some extent has a feeling of actually 'being there', or a feeling of presence'.

Dalgarno (2002) summarizes the most important features and main characteristics of a 3D VE, that distinguish them from other types of virtual environments, as follows:

- *Three-dimensionality* Objects within and the environment itself are modelled using 3D vector geometry and x,y and z coordinates are used to describe their shape and position in 3D space.

- *Smooth temporal changes:* According to the current position of the user in 3D space, the user's view of the environment is rendered dynamically, that means, the user has the ability to move freely through the environment and their view is updated as they move.

- *Interactivity:* Some of the objects within the environment respond to user action, for example, information may be displayed or a simulation may be started when an object is selected with a mouse.

Consequently, to clearly differentiate from two-dimensional text-based environments, this particular type of VEs, which is characterized with these introduced features, constitutes the subject of the practical work of this thesis.

2.2.2 Types of VEs

Today, VE uses techniques of computer graphics to present a model environment to the senses, through a variety of computer media, ranging from full-body immersive to traditional desktop

applications, that are not fully immersive. The boundaries are becoming blurred, but all variations of VEs will be important in the future. Due to the fact that VEs are used in a variety of ways, an overview of different kinds of virtual environments is given in the following.

2.2.2.1 Full-Immersive Virtual Environment

Early interest in 3D environment research focused on 'Immersive Virtual Environments' technologies. The term 'immersive' or 'sensor-immersive' referred to environments which require expensive hardware and computer generated sensory input, such as a head-mounted display (HMD), along with special interaction hardware, such as data gloves (Robertson, Card, & Mackinlay, 1993). Immersion allows the user to gain a total immersive feeling of being in an artificial simulated, three-dimensional world, which is completely generated by a computer. From the technical point of view, the requirements of an immersive VE are the isolation of the human perception from influences of the real world as well as the stimulation of the human perception to achieve the desired illusion of a non-existing environment (Kauff, Schäfer, & Schreer, 2000).

The HMD was the first device which was provided users with full visual immersion. Already in 1965 a HMD was demonstrated by Evans and Sutherland, but it tooks more then 20 years before the first commercial available HMD („EyePhone" system) was introduced. Important features of HMDs which distinguish them from other displays are, firstly, the user's view to the VE. Because the HMDs are mounted on the head the user is able to look around the real environment. Secondly, they provide stereoscopic image and lastly, because of the head-tracking feature, the effect when the user is turning the head to look around is simulated (Dalgarno, 2004). However, using a HMD together with a traditional keyboard as well as movements and object manipulation by a desktop mouse is not possible. Due to this fact new input devices were required for interaction in immersive environments like data gloves, which allow six-degree-of-freedom input for directly manipulating the environment, interaction with virtual objects and complex hand gestures. Unlike traditional two-degree-of-freedom mice, the use of such input devices allow a more intuitive navigation through an immersive environment, including information from the three most important senses of sight, hearing and touch (Ko & Cheng, 2009).

Another popular alternative concept for immersive viewing is the 'Cave Automatic Virtual Environment' (CAVE) which provides the illusion of immersion in a room-sized cube. CAVE, developed by the Electronic Visualization Laboratory (EVL)[1] at the University of Illinois in

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[1]http://www.evl.uic.edu/index2.php

the early nineties, was the first VE system which allowed participation of multiple users simultaneously. Stereo images are projected on three or four walls and the floor of the cube and through wearing special glasses everything appears as 3D images and one or several users may enter and navigate inside the CAVE. Additionally a head tracking system continuously adjust the stereo projection to the current position of the user (Beier, 2004). Depending on the different number of sides the CAVE consists, the VE system is either fully-immersive (five walls) or semi-immersive (three walls).

2.2.2.2 Semi-Immersive Virtual Environment

Semi-immersive systems include large screen projection, small cinema-like studios, where audiences can share the feeling of being in a scene, although the navigation is usually in the hands of an experienced operator (Horne & Hamza, 2006). This type of VE enables more participants to experience a simulated environment projected on a single display surface and constitute an alternative to the use of desktop non-immersive displays or HMDs. That means, the view of an environment is projected onto one ore more walls of a room. The wall size may not be relevant rather the peripheral field of view (FOV) of the user, if the VE surrounds the user. The key factor, if it is a semi or fully immersive VE is therefore the FOV, which describes how much of the user's view can be covered.

Fully-immersive VE systems can produce a virtually total FOV using tracking technology. Unlike semi-immersive VEs, if users turn their heads, tracked or not, they will exit the virtual environment abruptly because the screen in front of them cannot follow their movements. The user will end up looking at the room where the VE system is located.

2.2.2.3 Desktop-Immersive Virtual Environment

Although fully-immersive VEs captured the attention of many researchers in the nineties, research into non-immersive or rather desktop-immersive virtual environments, was forced at the same time, and became increasingly important. Since the graphics capabilities of standard computers began to improve dramatically and the lower cost for powerful PCs and graphics hardware, monitor-based exploring of 3D environments and viewing of 3D objects using desktop computers was feasible. Development of desktop-immersive VEs requires hardware that is part of traditional computer systems, most of them are comparatively inexpensive. In addition, due to the demands of the computer games industry for richly detailed 3D environments with realistic frame rates and very high response rates, the mainstream use of VEs on traditional computer systems has become possible. Consequently the desktop-immersive VR technology was made accessible to those with computers typically found in many offices (Robertson et

al., 1993) by means of traditional input devices, like keyboard and mouse. Neverthless, since the display in a desktop-immersive environment only covers a small area of the user FOV, the amount of visual immersion is limited.

2.2.2.4 Tele-Immersive Virtual Environment

A special branch of immersion is called 'Tele-immersion' or 'immersive tele-presence' and is applicable for daily use in tele-communication and other areas of networked services. Tele-immersion is defined as a union of audio and video conferencing, networked collaborative VE in the context of data-mining and significant computing. The goal of tele-immersion is not to reproduce a face-to-face meeting rather enable collaborators world-wide to work together in a shared, virtual environment as if they are in the same room (Lascara et al., 1999). This shared environment may be a three-dimensional environment that does not physically exist or cannot be physically visited, but is able to give a great sense of presence in the shared space (Park, Kapoor, Scharver, & Leigh, 2000).

For example, immersive tele-conferencing systems provide immersive tele-presence in a shared virtual environment in which the conferees will have the impression of being immersed. Tele-immersion does not mean that the conferees sitting in front of a display and showing videos of their counterparts. In fact they are sitting around a shared virtual table next to each other using large displays, covering almost the complete viewing angle of the user, providing life size pictures of the conferees. These circumstances ensure a natural reproduction of eye-contacts and body language when collaborating in an effective and natural manner (Kauff et al., 2000). The Tele-immersive technology pursues a collaborative approach, however, this kind of technology focuses on fully immersed as well as avatar-based tele-presence. Fully immersive tele-presence means simulated shared environment which are generated by using displays with wider FOVs like CAVEs or large wall-mounted displays. Since this theoretical analysis is focusing on desktop VE technology, the term collaborative VE (CVE) used in the following, refers to the desktop VE technology providing avatar-based tele-presence. Finally the following table shows the field of view of different display types used in the range of VEs explained above (Kjeldskov, 2001).

2.2.3 Application Domains of Desktop-Immersive VEs

Three-dimensional desktop-immersive virtual environments are used today in many different areas of education, entertainment, industry, business and science . The number of applications is growing rapidly as computers with sufficient graphics capabilites become affordable products. In the entertainment sector, the use of the third dimension, particularly within today's computer

Table 2.1: The field of view of different display types for VEs

Display Type	Field of View (approx.)
Standard computer monitors	20-40°
Head mounted displays (HMDs)	30-80°
Large wall-mounted displays	100-140°
CAVEs	up to 360°

games, has become a standard feature and players can hardly imagine a life without the feeling of being immersed. Popular computer games, which were developed in the beginning of the three-dimensional gaming era, for example Wolfenstein3D[2] (launched 1992), Doom[3] (launched 1993) and Quake[4] (launched 1996), both developed by *id Software*[5] are designed as first-person shooter games. This type of game immerses the player in a virtual-reality environment viewed froom the first-person perspective. Nevertheless, in past years computer game designers were focusing to increase the sense of immersion by replicating the approaches of a first-person point of view, to make desktop games feel more like virtual reality (McMahan, 2003). Using advanced features like stereo sound and multilevel environments with increased interaction for players, these three-dimensional computer games have led to a worldwide acceptance of this form of non-immersive desktop environment. Consequently, today's computer games establish a basis for further research in other domains, providing a virtual environment with a high degree of immersiveness, engagement, and presence in an affordable, manageable format (McMahan, 2003).

In this regard, applications of computer games have been increasingly linked to the field of education, most recently this domain is called *edutainment*, a form of entertainment designed to educate as well as to amuse. For instance, the AquaMOOSE 3D[6] project developed a gaming environment based on the three-dimensional desktop-immersive technology to offer an edutainment experience, where students engage with exploration of three-dimensional mathematical concepts while enjoying themselves at the same time. The AquaMOOSE project aims to facilitate learning processes in a more meaningful way than instructions in traditional classrooms. Students learn about the behavior of parametric equations by means of three-dimensional graphics to show the behaviour of mathematical functions, represented in an underwater-themed world

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[2]http://www.idsoftware.com/games/wolfenstein/wolf3d/
[3]http://www.doomworld.com/pageofdoom/doom.html
[4]http://www.idsoftware.com/games/quake/quake/
[5]http://www.idsoftware.com/
[6]http://www.cc.gatech.edu/elc/aquamoose/

(Edwards, Elliott, & Bruckman, 2001). Since AquaMOOSE is designed as a multi-user environment wherein students control an avatar and move through three-dimensional space. Hence, students are allowed for collaborative learning provided by challenging games and the ability to chat synchronously, although they may be geographically distant. This multi-user approach providing synchronously interaction with other peers become possible due to the increasingly growth of the Internet and Communication technology (Bates, 2005). Based on this fact, multi-user support in such three-dimensional desktop-immersive environments offer new prospects for distance education, when collaboration plays an important role (Dickey, 2005).

Consequently, this approach has involved that a more extended program of research has been focusing on educational multi-user virtual environments (MUVE). Recent research exploring the nature of learning with MUVE has outlined interesting educationally relevant outcomes, including motivational power and the opportunity to collaborate in groups at a distance (Jacobson, Kim, Miao, Shen, & Chavez, 2009). For instance, the *River City* (MUVE) project[7] focuses on science inquiry curriculum of health and diseases, ecology, and biology. Structured activities that progress to more complex activities, such as conducting scientific experiments, has outlined significant findings of learning content knowledge, inquiry skills and motivational efficacy (Dede, Clarke, Ketelhut, Nelson, & Bowman, 2005). Furthermore, these environments not only offer excellent space for spatial learning in a shared environment, but also great potential for three-dimensional visualization of complex concepts in simulated virtual laboratories. The Charles Stuart University (CSU)[8] has been developed a *Virtual Chemistry Laboratory*, which is based on an accurate simulated three-dimensional model of a traditional chemistry laboratory realized as a desktop-immersive virtual environment. The overall goal of this project was to enable distance education for chemistry students, allowing for navigation in a first-person view, free exploration, collecting and assembling items of apparatus and laboratory procedures (Dalgarno, 2002). Generally, three-dimensional VEs offer space for simulations in the learning process as well as training scenarios. Applications for *Simulation* and *Training Scenarios*, constitute an important learning and training tool especially when simulating a dangerous situation or the scenario of the training simulation is too cost-intensive. For instance, the project *Virtual Acadamy*[9] developed by the VEGA-group, realized an airplane training scenario within a desktkop-immersive VE to allow students to control the appearance of a three-dimensional airplane model by an application that runs externally. Remotely training and learning by representing simulations of complex scientific content in a three-dimensional environment, not only saves money, improves capability, and transforms trainings, but also an intriguing way is

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[7]http://muve.gse.harvard.edu/rivercityproject
[8]http://www.csu.edu.au/
[9]http://www.vega-group.com/newsroom/infocusnew/virtualacademy/

provided to engage students in the study of science while also fostering deeper learning.

Other points of interest are applications for product development. Many companies, which are focusing on this area, have used traditional single-user Computer-Aided Design (CAD) systems for product design and modelling. For example, AutoCAD[10], developed by AutoDesk in 1982, allows for computer aided modelling of both two-dimensional and three-dimensional objects to enable designers and customers to see how products will look before they are built. Due to the fast growth of the Internet and Communication technologies, CAD features have been increasingly developed and have led to the emergence of new collaborative CAD (COCAD) systems. Business globalization and collaboration with technological partners across the product life cycle have become increasingly important. The use of three-dimensional virtual environments and digital models as virtual tools allow for virtual product realization and collaborative design. Such multi-user CAD applications offer the possibility to work collaboratively with other geographically dispersed users. COCAD systems, an example *CyberCAD*, make use of three-dimensional virtual environments with user-interactive control and viewer centered perspectives to establish a virtual synchronous collaborative design environment to overcome geographical constraints. Consequently, reduction in product development time by reducing design rework and cost savings through the Internet are objectives as well. (Hock Tay & Roy, 2003).

2.2.4 Conclusions

This Chapter provided the definition of three-dimensional VEs as systems wherein users are allowed to interact with three-dimensional objects and action events in the same way as they are used in the real world. The most important feature of these environments is to provide the user with a feeling of presence, a feeling of actually 'being there'. By means of virtual reality technologies the environment immerses the user in different ways. Consequently, the types of VEs are overviewed in this chapter, differentiating between full-immersive, semi-immersive, desktop-immersive and tele-immersive VEs. Since this thesis is focusing on desktop-immersive applications, a particular focus of this type of VE is given and application domains are presented. However, this review emphasizes the increasingly growing trend of the educational use of desktop-immersive environments. Due to the acceptance of game-based platforms as VEs with a high degree of immersiveness, engagement, and presence in an affordable, manageable format, those platforms become increasingly popular for distance education. In addition with the fast development of Internet and Communication technologies, the multi-user support for these environments offers tremendous potentials for the education sector. Especially in

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[10]http://www.autodesk.de/adsk/servlet/home?siteID=403786&id=406067

areas where collaboration is necessary. In consideration of this fact, that the subject of the practical work of this thesis is focusing on a web-based learning approach by means of a three-dimensional environment as defined in this chapter, in the following distance education using the Internet as communication medium is discussed.

2.3 Web-based Learning Approach

Since the advent of the World Wide Web, educators worldwide have realized its potential as a medium for teaching, termed as 'Web-based learning' (Bates, 2005). Such web-based learning systems have become increasingly popular due to the provided convenience and flexibility to learn without time or location restrictions. Such systems are designed to provide users with a pool of resources, accessible by many users, wherein they are able to gain knowledge (Bates, 2005). Nevertheless, much research is now exploring new ways of online learning experiences to improve the features of the e-learning community (Monahan, McArdle, & Bertolotto, 2008). In this context, collaboration becomes a major feature in the development of new learning technologies and therefore the addition of synchronous communication methods and multimedia is being studied (Bates, 2005). Together with the use of three-dimensional graphics, the idea of creating three-dimensional environments to provide immersive online learning experiences was created (Dalgarno, 2002). In this context, the following section elaborates the level of immersion in conjunction with learning, replacing the term 'full-immersion' with 'desktop-immersion' and their impact on the users learning experience. Since this learning approach aims to engage and motivate student's through actively involving them in the learning process, the theories of activity and constructivism are discussed in the subsequent chapter.

2.3.1 Full-Immersive vs. Desktop-Immersive Learning

Recent results of a number of studies which explored the learning benefits of physically immersive environments over desktop environments have found no significant difference. The fact that learners wearing a HMD showed greater learning than learners who explored a similar environment using a desktop computer is not confirmed. As well a greater sense of presence in physically immersive environments does not automatically lead to a better spatial learning (Dalgarno, 2004). The reason for that may be the physical and psychological stress which often occures in such fully-immersive environments, which can lead to simulator sickness of the user (Wilson, 1997). This problem can not occure in desktop-immersive environments, rather these environments offer more accessibility and usability then physically immersive environments, since users of desktop computers are already familiar with controlling them. Therefore

the accessibility of desktop environments is much easier, besides the costs of 3D input devices are much more expensive than traditional input devices for controlling a desktop-immersive application.

Considered as a whole, it appears that the improvement of a learning process does not necessarily require physical immersion[11] in 3D environments. Moreover, a distinction is drawn between physical and psychological immersion[12] (Dalgarno, 2004). Because mental and emotional immersion can also take place in desktop virtual environments, in spite of the lack of visual or perceptual immersion , and anyone who has played a desktop non-immersive computer game, knows the truth of this (Robertson et al., 1993).

2.3.2 Technology and Pedagogy Evolution

Since recent research has shown interest in creating three-dimensional learning environments to improve the features of text-based e-learning systems, a new type of distance learning systems has been formed. The term *Distance learning* has been in use for many years and addresses the problem of students and educators being present at the same location at the same time. At the beginning it was a form of home study, when students received course material via postal service. Later on audio and video cassettes represented a newer form of distance education, but the interaction between students and teacher was still missing (Bates, 2005). Since the advent of the World Wide Web and significant growth in the development of e-learning communities, a modern form of distance learning was feasible worldwide providing two-way communications (Monahan et al., 2008). Such technology-supported asynchronous and synchronous communications support geographically dispersed working, learning or social environments (Gütl, Chang, Kopeinik, & Williams, 2009). Consequently, web-based tools enable interaction and facilitate communication among learners, either individually or as groups, but at a distance. Bates (2005) states that researching in distance education has found activity and constructivist approaches to teaching and learning like traditional education. For example, a learning system called Moodle[13], developed in 1999, enable educators to create online courses and allow students for constructivist learning, learning from his or her own experiences.

The previous chapter has emphasized that appropriately designed desktop virtual environments can engender a sense of presence, which is so important in the context of distance learning,

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[11]In this context the term immersion is used to refer to an objective measure based on the technologies being used.

[12]In this context the term presence is used to refer to a subjective measure of the degree to which the user experiences a sense of 'being there'.

[13]Moodle Learning System: `www.moodle.org`

since collaboration plays a major role in the learning process. Another important aspect that motivates the use of VEs is termed as constructivism. The theory of constructivism aims towards an actively approach of constructing knowledge by the student, in place of the passive approach of knowledge absorption from textbooks and lectures. This approach and the importance of collaboration in conjunction with distance learning is discussed in the following.

Activity and Constructivist Theory

The development of advanced Internet and Web technologies and the resulting availability and accessibility of various forms of media - like audio, video and virtual worlds - has led to an improvements of web-based learning and has pushed development of online learning environments (Monahan et al., 2008). Provided interaction and simulation features, realized through client-server technologies, engage the active learning process in such environments. Since interaction between educator and student and among students is a critical part of active learning approaches, such environments may offer new possibilities in this context. Especially in distance education, when providing students access to a part of reality for the purpose of exploratory learning and problem-based learning. These types of learning can also be derived from the theory of constructivism, which concentrates on the conceptualization of students' learning process that means students could learn actively and construct new knowledge based on their prior knowledge (Huang, 2002). Constructivism also characterizes how students construct their own understanding and knowledge through experiencing things. They form knowledge by themselves and act as creator of their own meaning.

Constructivism assumes that knowledge is based on direct and active experience of the world and is built around the process of discovery, when interacting within an environment. That means, constructivst learning allows for creative interaction with the educator rather than outcome-based learning (Huang, 2002). Consequently learning takes place in discussions and in collaboration with educators and peer learners. The instructor's role will no longer be the center of knowledge but rather changes into a facilitator's role, being a consultant, guide and resource provider. Another perspective in the theory of constructivism is the focus on learning as a social process wherein students acquire knowledge through proactive interaction with peers (Gül et al., 2008), called 'social constructivism' (Vygotsky, 1978). Vygotskian emphasizes the importance of learning in a socio-cultural context, interacting with peers, in the cognitive process. These group activities constitute cooperation rather than competition among students and require collaborative skills. Jonassen, Davidson, Collins, Campbell, & Haag (1995) states that conversation and collaboration are key words in the constructivist approach to learning. Therefore in this context the term *Collaborative Learning* is connected with social constructivism.

Collaborative Learning

The term *Collaborative Learning* is essential for distance learning and refers to small group-oriented learning, where the group members actively support the learning processes of one another. Social interaction like discussing technical issues and exchanging information and knowledge can impact student's understanding of abstract concepts. Communication technologies which are used in collaborative learning systems range from email to video conferencing to VoIP in shared environments (see chapter 3.3). Finally, collaborative learning and social constructivism may bring learners to a higher achievement level compared to individual and competitive learning scenarios.

2.4 Summary

Following the theory of activity and constructivism, interaction with the world is relevant for the learning process, much research is underway to enhance a user's learning experience by means of online three-dimensional VEs, providing interaction and collaboration. In this context, the next chapter outlines laboratory work as a fundamental educational tool in engineering and science education, because of the possibility to provide highly interactive experiences. From the perspective of collaboration and social constructivism in distance learning, apart from reality, the most appropriate way to generate an authentic laboratory activity compared to traditional laboratories may be through the use of three-dimensional VEs. It is the examination of the use of desktop-immersion and multimedia, combined with collaborative tools and laboratory work within science education, that forms the focus of the next chapter.

Chapter 3

Distance Education of Complex Science

3.1   Introduction and Terms

This chapter is about recent research facing initiatives to improve learning science by means of computer supported learning environments. The term science refers to a system of acquiring knowledge using observation and experimentation to describe and explain natural phenomena. Basically, understanding of those complex systems is a critical part of learning science and is necessary for solving real-world problems. Due to causal interactions and functional relations between parts of the system and with other systems, they are difficult to understand (Hmelo, Holton, & Kolodner, 2000). Complex systems are commonly found in natural and physical science, whereas natural science means the study of the physical world and social science, the systematic study of human behavior. There are many different fields existing within the natural science domain including biology, chemistry, physics, earth science, and a number of cross-discipline fields[1]. Jacobson & Wilensky (2006) states that difficulties students experience in learning concepts are relevant to understanding complex systems that are currently taught in existing science courses. Learning science means more than a set of facts or explanations in most theoretical books. Knowledge of complex systems integrates experiment and observation of the real world (Sabelli, 2006) which requires more activity on the part of the learner. Hence, hands-on experience of the science laboratory constitutes a necessary supplement to the passive

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[1]http://encyclopedia.thefreedictionary.com/Natural+sciences

experience of reading textbooks and listening to lectures (Corter, Nickerson, Im, & Ma, 2007).

Consequently, explorations of how complex science systems work, can be an excellent way to help learners achieve a deeper understanding of such complex domains (Hmelo et al., 2000). In conjunction with rapid advances in computational technologies, new ways of thinking about complex systems has opened new areas for experimentation and challenged students to learn. The use of information technologies has been explored to augment the laboratory experience and expanded the ideas of what constitutes a learning environment to help students learn scientific systems locally or at a distance. That means either local computerized laboratories providing additional simulated applications to help learners in their hands-on task (Dori & Belcher, 2005) or entirely distant electronic laboratories when learners cannot afford to travel and attend hands-on sessions in real laboratory settings (Leleve et al., 2009). In this context, hybrid versions constitutes a promising mix of simulated and real systems, from a local or distant perspective. Figure 3.1 shows an overview of different forms of Computerized Laboratories.
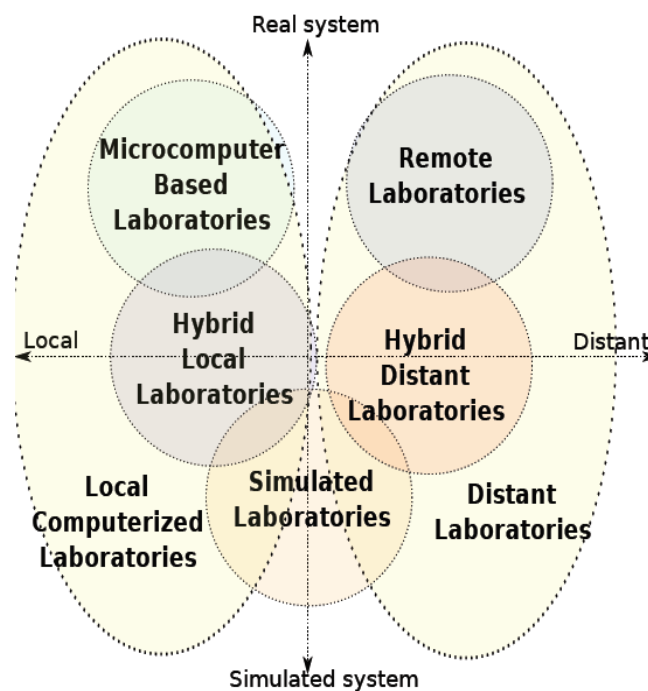
Figure 3.1: Different forms of ELabs according to distance from users and realness of handled system (Leleve et al., 2009)

In this regard, Leleve et al. (2009) distinguishes between local computerized and distant laboratories. Thus, distant laboratories are classified in remote, hybrid distant and simulated laborato-

ries. Concerning the distant learning context of this chapter, remote and simulated laboratories are introduced and defined as laboratory environments within the following section. Furthermore, limitations are pointed out and in this context the hybrid distant approach of remote and virtual laboratories is presented. Moreover, demands of collaboration within those environments are discussed and potential solution approaches are outlined. Consequently, since recent research indicates that boundaries among virtual applications simulating natural phenomena, remote accessible laboratories and real hands-on experimentation are blurred in the sense that most laboratories are mediated by computers, and that the psychology of presence may be as important as technology (Corter et al., 2007), three-dimensional VEs are linked to this matter, as an innovative constructivist learning environment and introduced in the subsequent section.

Research reveals that VLEs provide support for constructivist-based learning activities by allowing learners to interact directly with three-dimensional models from a first-person perspective (Dede, 1995) and focus on shared learning within a computer-based world. However, its critical to determine the educational potential of three-dimensional virtual environments, but research findings have shown that such VEs point out several characteristics that make it promising as a collaborative platform and a constructivist tool for learning science via students' interaction of models (Jacobson & Wilensky, 2006). In this context, Collaborative Learning Environments worlds are defined as well as discussed as an emerging medium for laboratory environments, providing multiple collaboration and communication channels. As well related research work is presented to deliver insight into the possibilities of three-dimensional VEs as collaborative platforms.

3.2 Laboratory Environments

3.2.1 Introduction and Definition

Traditionally, education in many domains of science or engineering are focusing on the study of theoretical as well as practical applications of concepts. During the last decades research has shown that the traditional approach of learning science concepts by means of practical sessions in real laboratories is changing dramatically (Del Alamo, 2004). Distance learning has been popularized in recent years because of the exponential expansion of the Internet and the fast development of new technologies. One of the major restrictions for distance learning in science and engineering education is the difficulty of laboratory activities (Kim, Park, Lee, Yuk, & Lee, 2001). However, the practical component is a very important factor of the science curriculum, to enforce learning of theoretical concepts and bridging the gap between theory and practical understanding (Machotka, Nedic, & Göl, 2008). Hands-on laboratories, allow students to

operate a real plant while they have direct physical contact with equipment to conduct experiments. Changing the character of laboratory-based courses has raised an intensive debate about the value of physical (hands-on) versus computer-simulated laboratories (Corter et al., 2007). Software packages for computer simulations of real experiments have been developed to improve student's learning experiences. An environment wherein such a simulation takes place is called virtual or simulated laboratory and enable essential functions of laboratory experiments. Moreover, the presence of shared infrastructure across universities has led to the creation of a third kind of technology platform, called 'Remote Laboratories'. Remote laboratories blend aspects of the physical and virtual, and represents an auspicious alternative to working in a real laboratory.

Fact is, that nowadays many labs in science and engineering are mediated by computers to interact with the lab equipment remotely via computer-based interfaces. However, there are still several issues related to pedagogy, whether web-based lab experiments provide the level of education and experiences comparable with traditionally conducted labs (Nedic, Machotka, & Nafalski, 2003). Over the past decade, remote laboratories were mostly designed in the way that the remote hands-on approach is just available for one student. Though there are many advantages to remote laboratories, a drawback remains in the social isolation caused by such an approach. Since modern learning theories promote collaboration among students, a new approach to remote laboratories providing communication tools is needed (Gravier, Fayolle, Bayard, Ates, & Lardon, 2008). In the following, the virtual and remote laboratories are explained in detail and applications are shown. Finally limitations are discussed and a collaborative approach of remote experimentation is given.

3.2.2 Virtual Laboratories and Active Learning

Virtual laboratories are designed for simulating real-world behaviour and phenomena to help students acquire new knowledge through learning by doing (Morozov, Tanakov, Gerasimov, Bystrov, & Cvirco, 2004). Virtual Laboratories, are non-physical tools, providing a simulated environment wherein an real-life laboratory experiment is represented by a computer model. The experiment therefore takes place in the form of a simulation, which is intended to represent laboratory experiments in a realistic fashion as closely as possible and engage students in active learning. Learning with simulations transfer conceptual and procedural knowledge (Harms, 2000), as well as an effective explanation of theoretical concepts is given. Students are allowed to conduct experiments step by step to eventually find solutions to complex problems.

A virtual laboratory constitutes as an interactive medium and low cost alternative, compared to real laboratories, because of no time and physical restrictions (Nedic et al., 2003). Virtual labs provide complex and abstract experiments, consequently, a virtual laboratory offers the oppor-

tunity to experiment and practice without being exposed to hazards and is often used as a pre-lab for dangereous assignments (Mueller & Erbe, 2007). However, several simulated environments which are used to demonstrate science experiments, are mostly displayed with two-dimensional graphics, thus, lacked realism. Especially when demonstrating physical or chemistry experiments, a more realistic solution is necessary for understanding those phenomena. Virtual laboratories which are providing three-dimensional simulations may offer a solution for realistic hands-on experimentation.

There are a number of different approaches for virtual laboratories in different subjects of science education in existence. For example in chemistry, a web-based video approach for the experiments presentation has been developed by the Oxford University, called 'Virtual Chemistry'[2]. Based on a Macromedia Flash-based virtual laboratory 'LiveChem', visual results of chemical reactions are showen by a short Flash animation that will appear in the web browser, showing how the reaction happens and the visual result. Another highly interactive virtual reality simulation of lab exercises is called 'ChemCollective'[3] developed at Carnegie Mellon University (CMU). This virtual lab focuses on scenario-based learning based on real-world chemical concepts and provides students with the opportunity to practice these abstract concepts and get a better intuition about chemistry phenomena. A similar approach has been developed at Brigham Young University (BYU) called 'ChemLab'[4]. The goal of this virtual lab is to encourage creative learning by means of laboratory simulations in an open ended environment, almost like a video game. This environment allows students to explore an experiment in multiple ways and to get a feeling about the consequences which can follow when doing experiments within a lab.

The virtual chemistry laboratory[5] developed at Multimedia System Laboratory[6] (MarSTU) allows students to carry out more than 150 chemical experiments in a three-dimensional simulated laboratory. The lab equipment and chemicals, available to learners, is changed in the environment depending on the chemical experiment. Learners are allowed to set up chemical apparatus and interact with them in a way that is similar to the real lab procedures, like changing the parameteres of the experiment and doing some measurements by virtual measuring instruments. Additionally, a 'Molecular builder' is provided as a separate tool of the laboratory. The builder allows manipulation of a three-dimensional representation of molecules and atoms to visualize phenomena which learners cannot see (Morozov et al., 2004). This laboratory constitutes

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[2]http://www.chem.ox.ac.uk/vrchemistry
[3]http://ir.chem.cmu.edu
[4]http://chemlab.byu.edu/
[5]http://mmlab.ru/projects/index_en.shtml
[6]http://mmlab.ru/index_en.shtml

an approach for an active and engaging learning environment to improve learners intuition of chemical experiments.

Finally, the *Virtual Reality Program Simulation (VRPS)* is a real-time virtual laboratory providing interactive experiments for physics education. VRPS is an educational tool using a virtual reality interface that brings a 3D model of real equipment and a visual representation of a physical situation together, in an interactive manner. Those experiments are shown as 3D animations in a 3D web browser, which is created with 3D Webmaster, a software toolkit for creating interactive 3D web pages. Within this browser, users are allowed to move around and interact with the displayed virtual world. In terms of development, the virtual world has been created by means of the Supercape Control Language (SCL). VRPS's main goal is to enhance students' understanding of abstract physics concepts by providing a degree of reality by means of creating an interactive learning environment. (Kim et al., 2001)

Without doubt simulations are a very useful, easily accessible teaching and learning tool. They provide the ability to connect the theory of the classroom with the practice of the laboratory while teaching analytical thinking skills. Although virtual laboratories are effective tools to improve student understanding of complex science concepts it may creates a misconception about the work in a real laboratory due to idealized data. Another major concern is of interest to educators, the lack of collaboration. (Nedic et al., 2003).

3.2.3 Remote Experimentation

Laboratory experience plays a crucial role in a student's learning process, the use of traditional laboratories present many difficulties and students often cannot get the necessary experience in traditional laboratories. Faced with the fact that laboratory instruments are costly, suitable space is limited and the student's use of the labs is difficult to schedule and manage, a reasonable substitute for hands-on laboratories was requested to bridge the challenges of using real laboratories.

Consequently, universities around the world have been set up so-called 'Remote Laboratories' to enable remote experimentation, a relatively new phenomenon in distance education. Such remote laboratories are software environments which allow learners access to real laboratory facilities through the Internet from anywhere at any time. Laboratories are an essential part in science education, performing practical experiments can contribute to the students' motivation for learning, foster their understanding of abstract concepts as well as work collaboratively with other students.

Although nothing can replace synchronous learning through face-to-face interaction, such remote laboratories are a helpful extension when attending a conventional class is not feasible

because of distance. Additionally the trend towards increased use of remote experimentation is also based on the fact that equipping a laboratory is a major expense and its maintenance can be difficult. In other words, laboratories are only available when equipment and educators, to set-up the hardware, are both available. Therefore the idea of providing students access to experiments from their home 24 hours a day, seven days a week, was a reason as well. Consequently, experimental facilities can be shared by learners across the world that might not otherwise have the resources to purchase and operate costly lab equipment (Del Alamo, 2004). Therefore, students are allowed to control real equipment, analyze the measured data as well as to take the opportunity to repeat the experiment on their own as often as needed, afterwards.

Several universities have commissioned remote laboratories framework projects in recent years. For instance, the electrical engineering laboratory (ECE) developed at Carnegie Mellon University(CMU)[7] empowers students to create information on the internet by remote computer access to physical laboratory instruments. Students are allowed to collect informations through conducting actual experiments on equipments, like oscilloscopes and function generators, at any time and from any location over the internet. Independent from the location of the student, a video camera observes what is happening at the apparatus in the real laboratory. Furthermore, also based on this approach the *Engineering Remote Laboratory Program*[8] at University of Technology in Sydney has been developed. Since 2001 five remotely accessible laboratories for undergraduate engineering courses have been constructed, supporting experiments across a diversity of Engineering fields[9]. The UTS Engineering Remote Laboratory is one of the first and largest remote laboratories of its' kind in the world. Another approach has been implemented by the MIT iLabs project[10] in 1998, since then multiple experiments have been implemented to support students learning process. Since the iLabs Project is part of the practical work of this thesis, a detailed explanation is given in Chapter 4.2.1.

3.2.4 Collaborative Demands in Laboratory Environments

Over the past years, development of remote laboratories has been focusing on a common infrastructure, to share access to individual laboratory equipment worldwide and provide practical lab work at a distance (Nedic et al., 2003). Nevertheless, there is also a strong interest in another pedagogical issue emerging from this new technology. Social-constructivism, known as a modern learning theory, trys to make students learn from their own observations and discuss

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[7]http://www.ece.cmu.edu/~stancil/virtual-lab/virtual-lab.html
[8]http://www.eng.uts.edu.au/
[9]http://remotelabs.eng.uts.edu.au/about.html
[10]https://wikis.mit.edu/confluence/display/ILAB2/about+iLabs

misunderstandings with the teacher but also with other students (Gravier et al., 2008). Beyond sharing access and increasing the pool of shared educational resources in remote platforms, there is definitely a need to remove distance barrieres and provide students in one country with the opportunity to collaborate with students in other countries (Machotka et al., 2008). A remote infrastructure encompassing today's learning theories, wherein students and educators from all around the world come together to conduct experiments, share experiences and discuss results with their peers afterwards. Currently there are multiple remote laboratories existing worldwide, but only a few are designed and constructed in such a way to allow participants to collaborate in real time. In the following a few approaches of collaborative remote laboratories in different levels are introduced:

3.2.4.1 Examples of Collaborative Remote Laboratories

The NetLab project

At University of South Australia (UniSA), an advanced remote laboratory termed 'NetLab'[11] has been developed and incorporated into the curriculum of engineering courses. NetLab allows lecturers and students to access real equipment and perform experiments remotely via the internet. The user can interact and control the real instruments through an client-side interactive Graphical User Interface (GUI), which is created from photographic images of the instrument's front panels and looks like a larger interactive image of an instrument, for example an oscilloscope (see Figure 3.2). Through clicking on one of the oscilloscope images, a larger interactive image of the oscilloscope appears to increase readability. The commands are immediately sent and processed through the NetLab server. Consequently, users are able to interact with these instrument images in the same way as they would interact with real equipment. For example, Machotka et al. (2008) explains interaction in the way that "*the mouse is used to click on a button or rotate a knob in the same way that a finger would be used to press the button or turn the knob*" to get a sense of realism and functionality that matches the physical instruments. Additionally, there is a web camera window available providing live video streaming of the the remote laboratory. The web camera is used to observe the real apparatus, enhance the feeling of being present, and monitor the execution of the user's commands, like the movements of the buttons. (Machotka et al., 2008).

The NetLab architecture is designed to perform experiments in groups of two or three students by means of a virtual collaborative workspace. However, working alone is also possible. During the experiment, all students in the group have full control of the equipment, to coordinate their actions when conducting the experiment an a collaboratively manner, students are allowed to

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[11]http://netlab.unisa.edu.au
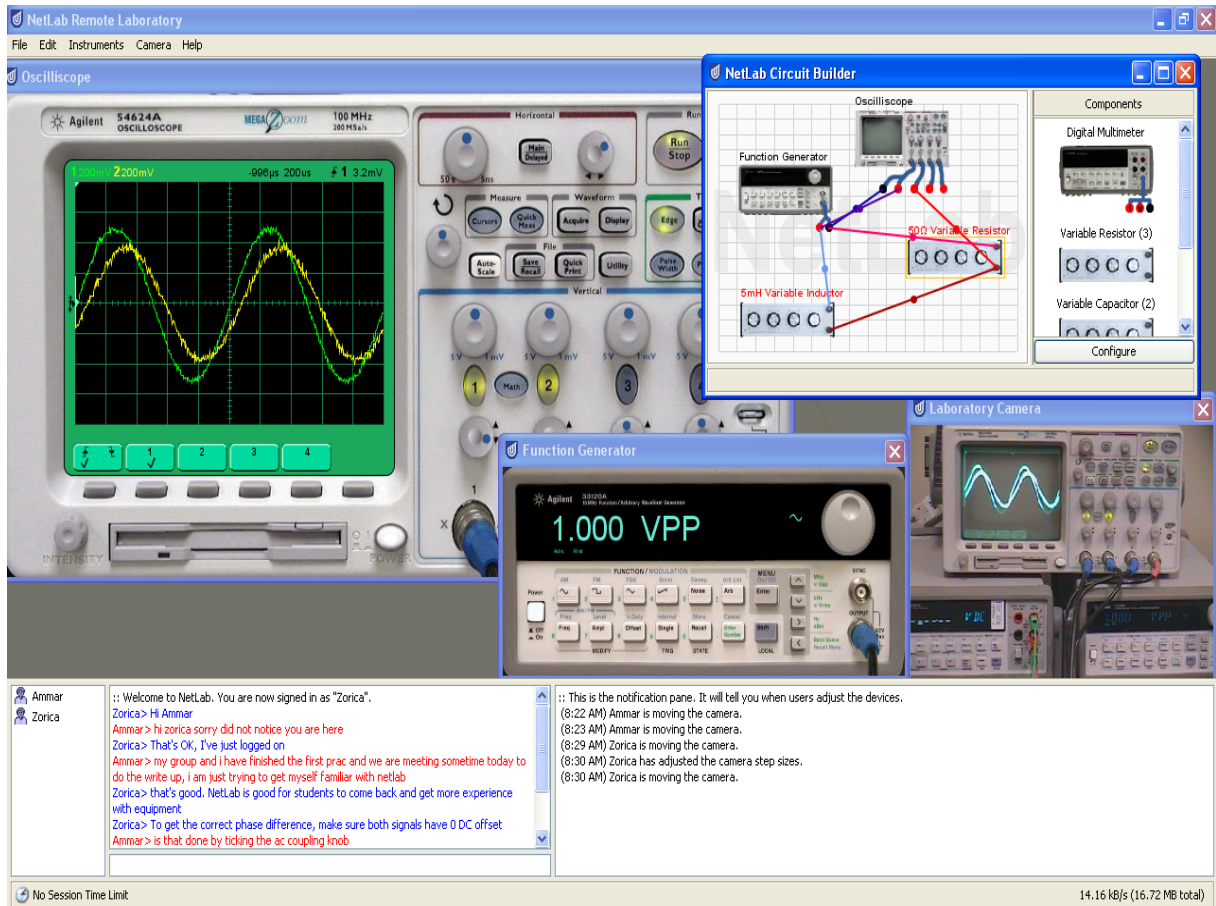
Figure 3.2: Main Graphical User Interface of NetLab with a collaborative session in progress (Machotka et al., 2008)

communicate via the chat window (see in the bottom of Figure 3.2). NetLab also considers collaboration in the form of pre-experiment and post-experiment meetings, to plan the work and perform manual simulations before the experiment is started and discuss misunderstandings, afterwards. For this purpose, Netlab is providing an integrated communication pane by using the Centra® Saba® software (see Figure 3.3). This includes the support of synchronous and asynchronous collaboration activities like whiteboards (see Figure 3.4) and document sharing (Nedic & Machotka, 2009).

The DIESEL Project

The DIESEL[12] project (Distance Internet-Based Embedded System Experimental Laboratory) is a three year distance learning project at the Intelligent Systems Engineering Laboratory on the Magee campus of the University of Ulster, Northern Ireland. The overall objective of the

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[12]http://diesel.infm.ulst.ac.uk/
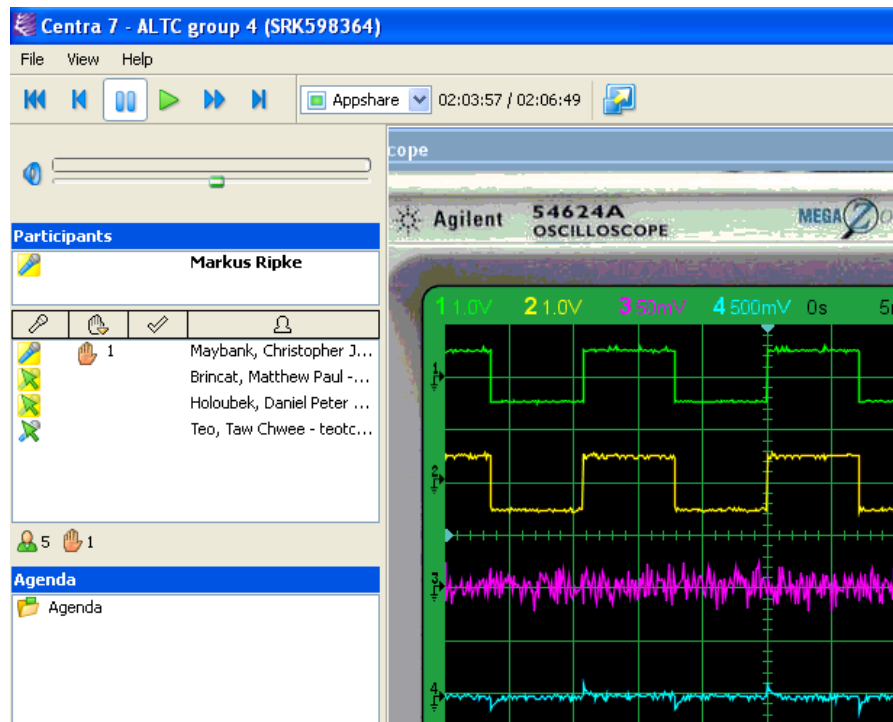
Figure 3.3: Centra® provides seamless integration of communication pane with application window (Nedic & Machotka, 2009).
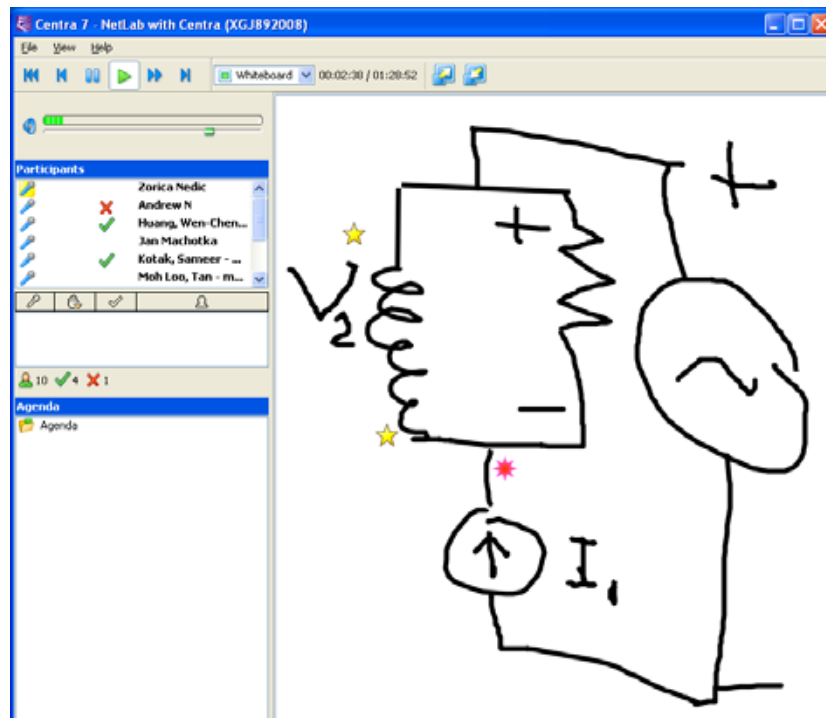
Figure 3.4: Shared Whiteboard drawing within Centra® (Nedic & Machotka, 2009).

DIESEL project was to complement and extend existing undergraduate and graduate courses for embedded system modules. Remote-access to real laboratories is provided to enable students to conduct practical experiments in this area via the Internet (Callaghan, Harkin, McGinnity, & Maguire, 2007). The first version of the DIESEL project was designed as a non-collaborative learning environment which allowed individual students to control real equipment remotely. Due to modern learning theories the DIESEL architecture was redesigned and an extension to the existing remote laboratory has been developed to facilitate remote users synchronously access and allow them to share equipment in on-campus laboratories with geographically diverse users. This approach makes use of internet-based communication tools to provide real practical exercises in a similar way as a collaborative interaction in traditional laboratories. As example, Figure 3.5 shows two students working collaboratively on the execution of a washing machine simulator program by means of a video conference as a communication tool. A remote desktop and a virtual circuit interface is displayed, wherein students are allowed to write and compile the program which has to be performed (Callaghan et al., 2007).
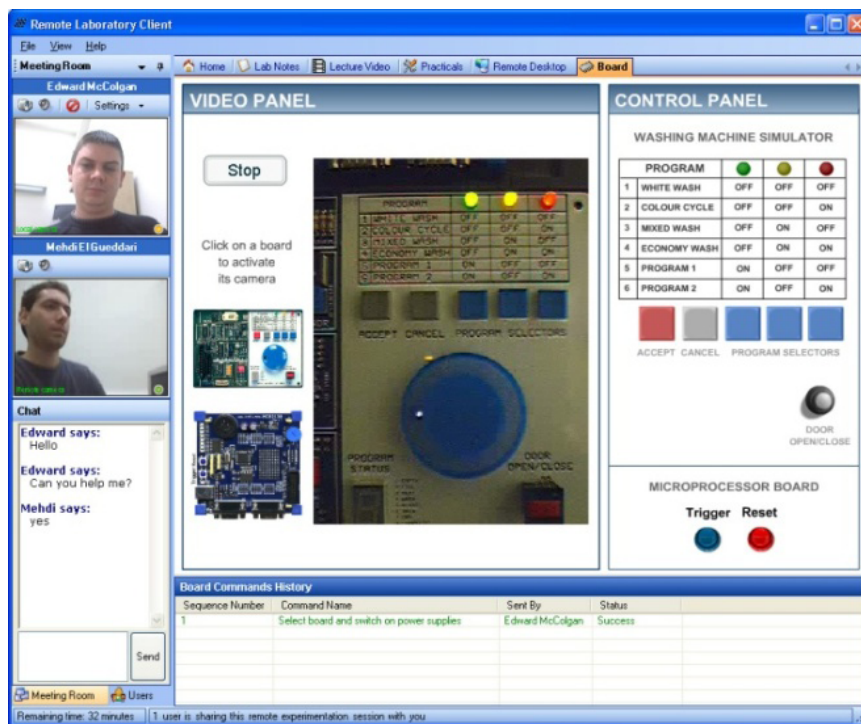
Figure 3.5: Collaborative working session in progress (Callaghan et al., 2007).

3.2.5 Limitations and Summary

Collaboration at a distance is more difficult than working together in a real laboratory next to each other and there is definitely a long way to go to reach real synchronous collaborative learning within remote laboratories. In this context the way to communicate, various tools which are available, is an important issue when considering about a synchronous collaborative learning environment for remote and virtual experimentation. Regarding to this, Gravier et al. (2008) reviewed multiple papers dealing with collaborative remote laboratories and noticed that besides whiteboards, video conferencing and instant messaging like chat, rather voice over IP is the most used media (see Figure 3.6).
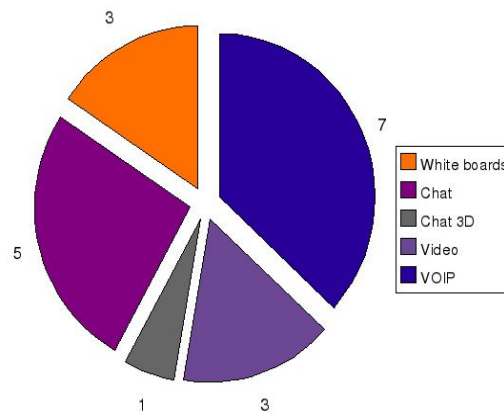
Figure 3.6: Communication tools in the review (Gravier et al., 2008).

This chapter has shown significant advantages of virtual as well as remote laboratories over real laboratories. Remote labs score with their flexible accessibility and connection to real devices, virtual labs mostly with their provided possibility for safe experimentation. Remote Experimentation is a trend that has become visible during the last years because virtual laboratories are viewed as not providing students with the impression of working in a real laboratory. In other words, remote laboratories fill a niche between simulation and traditional laboratory projects. Of course simulations can be very useful in educational settings, but the direct interaction with the real world is missing, which is so important for learning abstract physics concepts.

Consequently, research in *Hybrid forms of Laboratories* has been started, to merge virtual with remote laboratories. As example, the National University of Singapure (NUS) [13] has developed

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[13]http://vlab.ee.nus.edu.sg/intr.html

a web-based three-dimensional virtual experimentation system, to merge virtual simulations with remote experimentation, called *VLab*. The 3D Oscilloscope Experiment offers students the same experience as moving around and conducting the experiment in a real laboratory. Adjusted controls are converted into command for real instruments in the real laboratory, and the result of the experiment is sent back to the client to be displayed in real time (Lu, Ko, Chen, & Cheng, 2002). In this hybrid approach remote experimentation is extended by a simulated representation of the real equipment in a three-dimensional environment and allows for a much more realistic and natural experience than in plain virtual laboratories. However, this system shows limitations due to the lack of collaboration. Since the environment is designed just for one person, users are not provided with any communication and collaboration tools. Although the problem of direct interaction with the real world is solved with this concept, the lack of collaboration still remains.

In consideration, besides the potentials many laboratory environments offer, there are still significant limitations, mainly the collaborative interaction does in most cases either not exist or not sufficiently. A decisive factor is that many laboratory environments are mostly designed for the use of one person. Definitely, development of collaborative remote laboratories, relating to Chapter 3.2.4, has shown how students can take advantage of various communication tools. However, there is still more potential existing in terms of communication and collaboration in remote as well as virtual laboratories. In a wider research context, 3D virtual collaborative and immersive environments have become mainstream (Callaghan et al., 2007) and educators worldwide have been investigating in the use of online virtual worlds as a constructivist-based learninng environment. Anyhow the demand for an innovative learning environment providing collaboration and presence is high and the development of an environment supporting a balanced mixture of real, virtual and remote labs become increasingly popular. In the following Section 3.3, three-dimensional environments are introduced and related work in terms of avatar-based collaboration and communication for educational purposes is outlined.

3.3 3D Collaborative Learning Environments

3.3.1 Introduction and Definition

The fast development of virtual environments as well as the World Wide Web in the past decade has created an important variant of virtual environment applications, called online *Collaborative Virtual Environments (CVEs)*. This distributed environments allow users to share a three-dimensional virtual space for chatting and socialization using desktop virtual reality technology. Within these virtual worlds, students can navigate, interact with virtual objects and study the

educational material, which can be either a 3D model or even text, image, sound or video (McArdle, Monahan, & Bertolotto, 2008). Multiple users are enabled to collaborate regardless of their global positions, in a shared virtual environment concurrently, connected using the Internet. Those stimulating multimedia systems have become an important communication medium especially for distance learning, in the areas of science and engineering education, termed as *Collaborative Learning Environment (CLE)* (Thrasyvoulos, Konstantinidis, & Pomportsis, 2009).

Dede (1995) suggests that the key capabilities of an online collaborative VE are telepresence and the induction of immersion, meaning the subjective impression that a user is participating in a "world" comprehensive and realistic enough to induce the willing suspension of disbelief. Generally a CVE provides providing a shared environment to create a 'shared' sense of space wherein users can interact. Within the environment each user is represented by an 'avatar, which is a 3D representation of that person (Stephenson, 1992). As avatars users having the feeling that they are directly cooperating with real people, also called 'shared presence'. The main features of a 'Shared Networked Environment' stated by Casanueva & Blake (2000); Gütl et al. (2009) are summed up in the following:

- *Shared Sense of Space:* Illusion of being in the same place, which physically do not exist.

- *Shared Sense of Presence:* All users are represented as avatars, entering the VE enables the user to see the others as avatars and the other users can see the new user's own avatar.

- *Real Time Interaction in Learning Activities:* Interactions in learning tasks together in a group showing each other's behavior as it occurs in real time.

- *Communication Medium:* Enable communication in multiple ways like text-based, voice or by gestures.

3.3.2 Technical and User Challenges

Technical requirements as well as challenges when using technologies like virtual worlds are listed in the following (ACS, 2009):

- *IT Requirements and Firewalls:* The adoption of new technologies like these virtual worlds requires a wide range of system requirements and support on the part of the IT department. Additionally, some of these environments addresses security issues as TCP and UDP ports opened through a corporate firewall as well.

- *PCs and Audio:* Graphically rich applications like a three-dimensional VE require modern graphics cards, powerful CPUs and large memory capacity. Therefore most PCs typically are not able to run virtual worlds because they were purchased for daily computing. In mostly cases, even the workstations don't meet the necessary requirements, the right software plug-in to view the environment is missing and has to be installed.

- *Audio:* The best experience in virtual worlds requires VoIP-based audio to provide natural discussion between participants. The requirements are a headset with a microphone but modern PCs provide built-in microphones and speakers though.

- *Bandwidth:* Most virtual worlds use a client-server architecture for delivering graphically rich experiences. Therefore bandwidth is an issue for downloading the client application as well as for good resolution of graphics and video streaming.

As shown in chapter 3.2.4 , development of laboratories supporting collaborative lab work has been started and has led the way by providing various communication tools to establish collaborative interaction between peers. However, the feeling of real presence, the sense of being there physically, is still missing in many of those laboratories. (Ashby, 2008) indicates that students in many existing laboratory environments experience isolation from peers and instructors caused by the lack of immersive presence and collaboration. When working in traditional laboratories, students are used to conducting experiments in a group next to each other and actively support the learning processes of one another. However, in the majority of laboratory environments students do not recognize the presence of other peers in the lab rather they feel mostly out of touch because they are not able to see them. Consequently, the question arises: Can remote and virtual experiments develop collaborative student' skills in the same way or even better than traditional real experiments? A possible answer may be 3D Learning Environments, which provide the opportunity for collaborative and immersive interaction of participants, which are requirements to enable constructive learning in the learning process (Lucca, Romano, & Sharda, 2003). In this context, related research work in terms of avatar-based communication in three-dimensional learning environments is reviewed in the following.

3.3.3 Related Work

3.3.3.1 Example: The C-VISions project

The C-VISion project[14] has been developed at the National University of Singapore (NUS) to concentrate on supporting science education, including physics, chemistry and biology by using the desktop variant of virtual reality to create an online CLE. The C-VISions learning environment consists of four interconnected levels, a social world as a community location, a biology, a chemistry and a physics world for supporting science learning. C-VISions encourages active students to run science experiments in the virtual world and view the outcomes as they change simulation parameters. The project is mostly focused on physics education due to the difficulty of physics phenomena. The physics world provides three learning simulations, one of them is the Billiard World simulation wherein students can learn about mass, acceleration, conservation of momentum, friction, and the coefficient of restitution. Within the environment, buttons are available which allow users to change their viewpoint and to navigate within the world as avatars. Additionally mouse and keyboard interaction is provided. Objects like the billiard table, two balls and the cue stick are contained in the environment, which can be manipulated by the participants. Users can interact with these objects to carry out experiments. Figure 3.7 shows the Billiard World in C-VISions with two active users. Generally, C-VISion is a multi-user system, that means when an event happens in one user's environment, this event is propagated to all other connected participants. Figure 3.7 shows a function provided by C-VISions, called event visualization, which enables students to replay the current simulation event synchronously (Chee & Hooi, 2002). A plotting graph of the current event is displayed in a mini world browser as well.

Additionally, the Billiard World supports real-time video streaming, that means students are able to share video resources with other peers, provided that they are located in the same virtual world. Since communication and collaboration tools are vital for collaborative learning, C-VISion incorporates text-based and audio-based communication as well as a shared electronic whiteboard and a shared mind map editor, to support higher level representation of ideas. (Chee & Hooi, 2002)

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[14]http://yamsanchee.myplace.nie.edu.sg/Publications/2002/CSCL2002CheeHooi.pdf
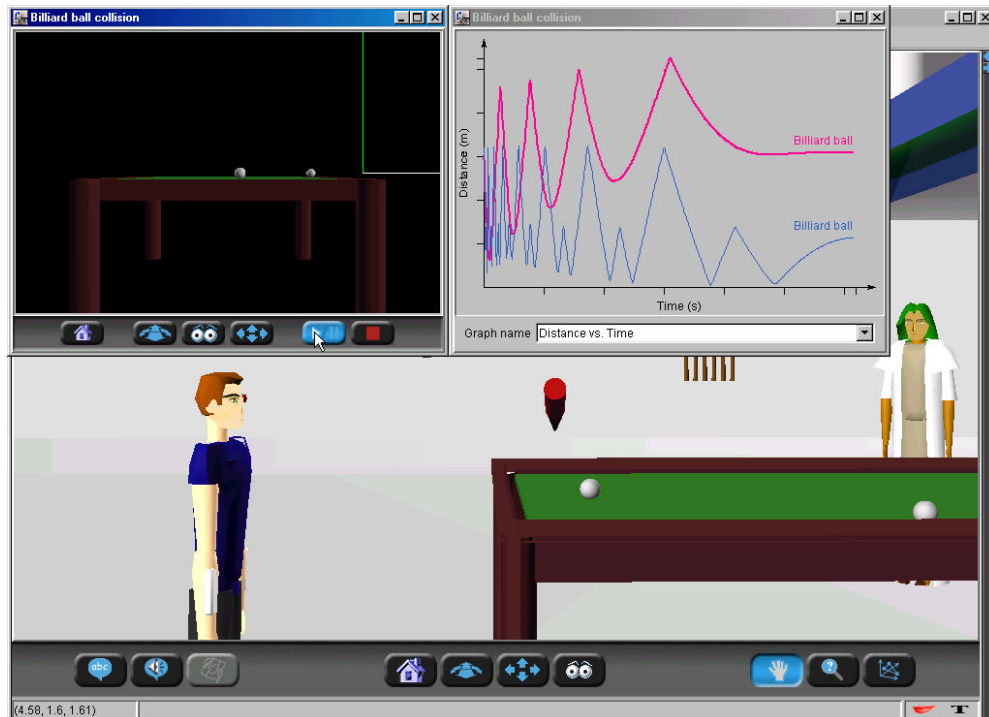
Figure 3.7: Event visualization in C–VISions (Chee & Hooi, 2002).

3.3.3.2 Virtual Campus of NTU - Collaborative Shape Modeling Laboratory

The *Virtual Campus*[15] at the Nanyang Technological University (NTU)[16] constitutes a shared virtual world for teaching computer graphics and shape modeling, built with the Virtual Reality Modeling Language (VRML)[17] under Blaxxun Contact 7 communication platform[18]. The overall goal of this project is to motivate and engage students for learning computer graphics concepts and to achieve better results when using a three-dimensional environment as a learning tool. Students are introduced to theoretical concepts of virtual reality, real time rendering, and shape modeling within the virtual space during lectures as well las after classes for consultations. Therefore the *Colllaborative Shape Modeling Laboratory*, a part of the virtual campus for hands-on experience, is used by the students for defining complex geometric shapes, appearances and transformations by simple mathematical and analythical formulas (Sourin, Sourina, & Prasolova-Forland, 2006).

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[15]Virtual Campus of NTU, `http://www.ntu.edu.sg/home/assourin/vircampus.html`

[16]NTU web-site, `http://www.ntu.edu.sg`

[17]VRML specification, `http://www.web3d.org/x3d/specifications/vrml/ISO_IEC_14772 -All`

[18]Blaxxun Contact, `http://www.blaxxun.com`

Students are able to connect to the virtual world by the use of the Internet, in-world they are represented as avatars. The virtual class-room can be entered both from the Virtual Campus or by a direct link, showed in a separate frame of the browser. The first time a student enters the classroom, a software plug-in is required to allow for defining shapes with mathematical formulas. After the plug-in installation, which is actually an extension of VRML, students are requested to type individual formulas, shape modeling commands in the chat box of the browser, and the function-defined geometry and appearance of shapes will become visible. The mathematical formulas, written in C-style syntax, allow for interactive changing of the geometric shape and its three-dimensional texture. The appearance of the individual shape can be defined by either function-commands or fixed colors. Figure 3.8 shows the interactively created shape, hovering in the middle of the room. The smaller shapes, displayed in different parts of the room, are examples of the best work of other students. Students are also allowed to discuss their experiences in the chat box.
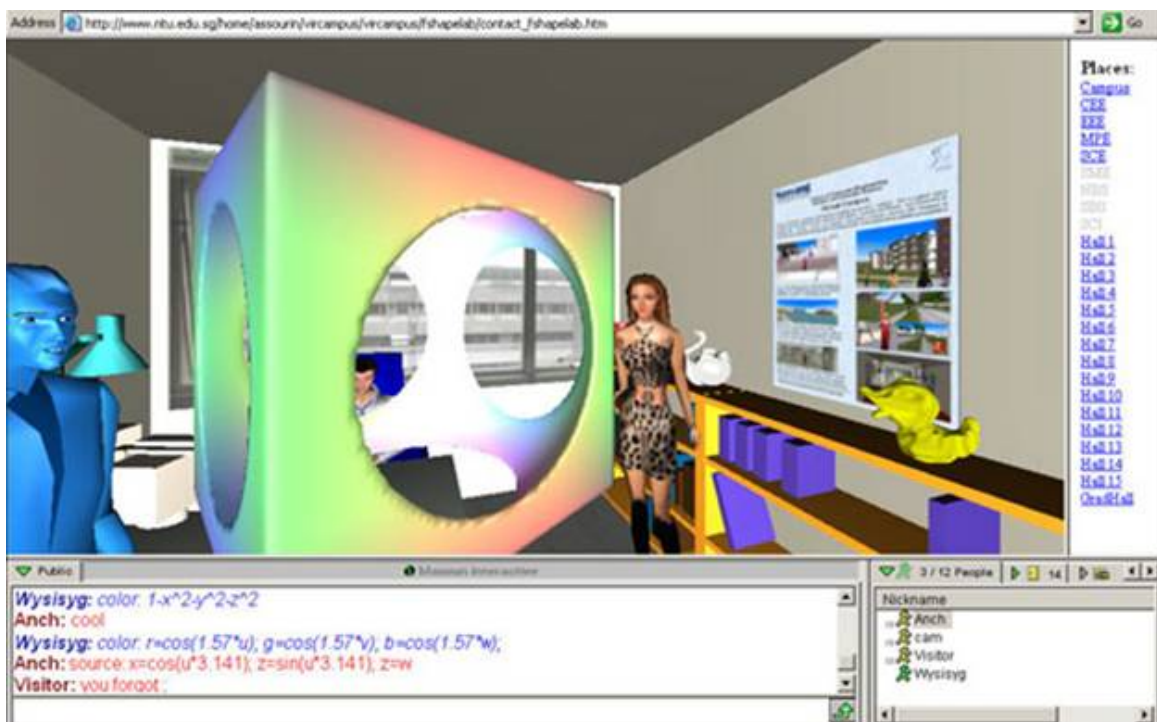
Figure 3.8: Collaborative Shape Modeling Hand-On Experience in the Virtual Campus of NTU (Sourin et al., 2006).

The Virtual Campus can help students to understand computer graphic concepts in a more motivating, engaging and simpler way than in traditional classrooms. This approach is based on the active learning theory due to the provided hands-on experience. Supported by a three-

dimensional environment students may achieve better learning results when practicing function-based shape modeling. Since the environment also provides space for text-based communication, students of the collaborative shape modeling class are able to discuss misunderstandings with other in-world students.

3.3.3.3 AWEDU - Chemeet World

The Chemeet project[19], developed at the University of Milan, is a three-dimensional virtual environment used for distance learning in the Active World Educational Universe (AWEDU)[20], using the Activeworlds' Technology. AWEDU is an educational community based on VR and Web technologies. Within this educational environment, students are allowed to communicate via text-based chat and interact with others, represented as avatars. The represented avatar is able to move around and perform gestures. AWEDU support learning of different educational subjects, for instance, art, language, science or history. Consequently, students are enabled to attend classes, perform experiments and participate in discussions. However, to visit the AWEDU environment, users are required to have the AWEDU browser installed. The Browser interface combines the 3D environment with a chat tool, an integrated web browser and a window displaying different tabs with useful information, as four main windows. (Dickey, 2005). Figure 3.9 shows the AWEDU Browser of the presented Chemeet World project.

The AWEDU Chemeet three-dimensional world focuses in particular on chemistry and biochemistry education, using Chime[21], a popular plug-in in the Chemistry field developed by Symyx. This plug-in enables the representation of three-dimensional models of molecules. Inside Chemeet's world students are allowed to explore together the spatial configuration of a molecule, its shape and orientation, in the first person view, to enhance students understanding of molecules' complex structures. As avatars they can interact with molecular objects and simulate chemical experiments. Additionally, a white board is provided and used during online tutoring, to improve in-world communication. The white board allows for active participation of both teachers and students, similar as if they were attending a traditional class, in particular for making excercises or having further explanations.

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[19]http://users.unimi.it/chemeet/chemeet_world.html
[20]http://www.activeworlds.com/edu/awedu.asp
[21]http://www.symyx.com/products/software/cheminformatics/chime-pro/
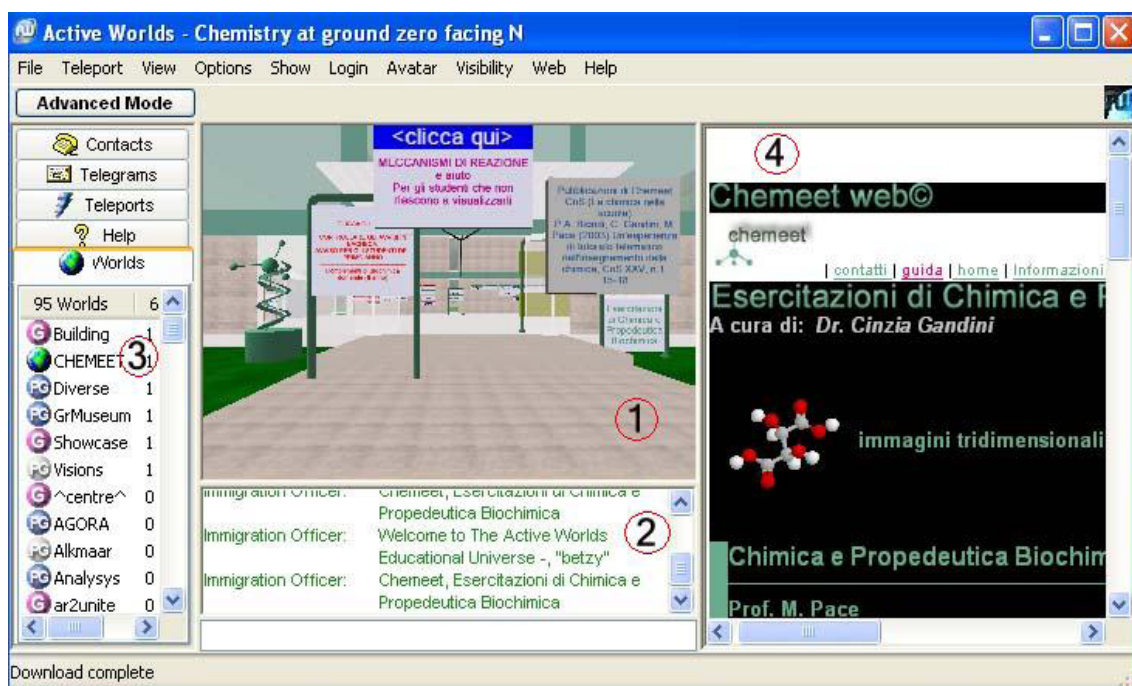
Figure 3.9: AWEDU - Chemeet World browser (Louis, 2004).

3.3.3.4 Project EduAction - Mission Queen Maud Land

The *EduAction* research group[22] is focused on the development of a virtual learning environment to study the potential for stimulating active participation and collaboration from a pedagogical point of view. For this purpose, a non-immersive desktop CVE, called *Mission Queen Maud's Land (MQML)*, has been developed, the scenario of the application represents a research laboratory, located in Antarctica. MQML system is actually designed for five simultaneous users (four students accompanied by a teacher) and consists of three modules, combining the CVE with a web site and audio narratives (Halvorsrud & Hagen, 2004). The introductory narrative sound clip is played back to convey the background story. By means of a supporting web-site which supplies the necessary background information for each task, the participants explore the educational content in the CVE and complete their tasks. Figure 3.10 outlines the three components of the MQML system.

Participants can be geographically distant and still meet each other, in a shared, virtual three-dimensional environment, connected by the Internet. Within the virtual world, each students has a role as researcher, represented by an avatar, and in collaboration they explore and solve different tasks related to the basic characteristics of the DNA molecule and gene technology.

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[22]`http://www.telenor.com/rd/pub/rep02/R_35_2002.pdf`
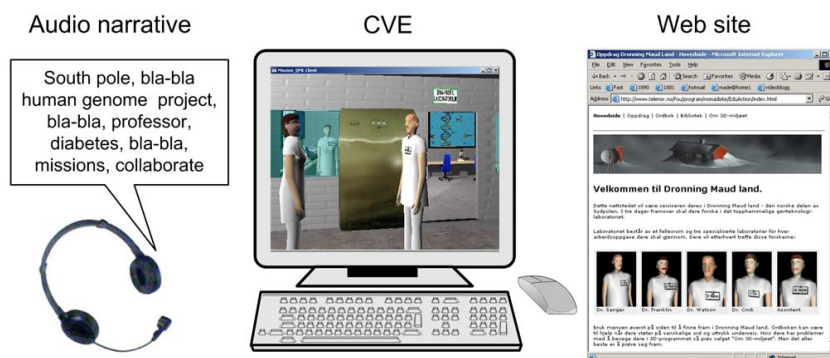
Figure 3.10: The three main components of the MQML learning environment (Berge, Furberg, Hagen, & Halvorsrud, 2002).

The point is to find the sequence of a human DNA molecule by completing three steps: 1. rebuilding DNA, 2. synthesizing insulin and 3. DNA fragmentation. Therefore, the environment provides necessary tools and molecular components to construct, rebuild, and repair both DNA molecules and proteins (Halvorsrud & Hagen, 2004). Generally, the three-dimensional environment is designed not only to enable students to enter and navigate in the research laboratory (macroscopic level), build and interact with three-dimensional objects, the students are also enabled to immerse the avatars inside human cells (microscopic level) (Berge et al., 2002). Additionally, when the participants move between the two levels, they are introduced into a context-related change of their avatars. Figure 3.11 and Figure 3.12 displays the avatars exploring in both levels of the CVE.

Halvorsrud & Hagen (2004) outlines the results of the study, showing that the MQML system was well received by the students, they found it essential to be represented by an avatar, being able to see the other students' location and their movements during their explorations in the CVE. Results in terms of learning experience, compared to the first two subtasks, the implementation approach of the third subtask, DNA fragmentation, indicates an unsuccessful exercise. Regarding to the learning outcome, a knowledge assessment test has been carried out, results of questionnaires showing very high scores related to interactions in the CVE. All things considered, the MQML system constitutes an enjoyable learning experience and the CVE in particular, as an effective tool to support experience and understanding of the basic chemistry of a DNA molecule, generally in the field of molecular biology and gene technology.

Figure 3.11: Representation of two students as human-like avatars synthesizing insulin in the macrocosm level (Berge et al., 2002).
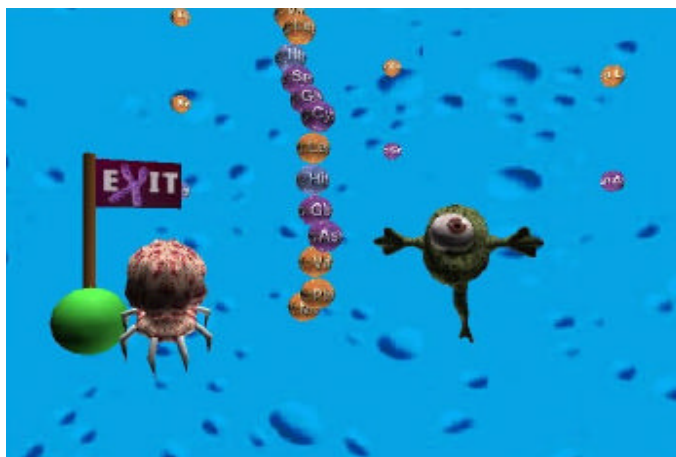
Figure 3.12: Representation of two students as organism-like avatars and the completed insulin molecule in the microcosm level, ready to return to macrocosm level (Berge et al., 2002).

3.3.3.5 The Protein Gallery - Project Wonderland

The *Protein Gallery*[23], developed at the University of Leeds[24], constitutes a collaborative, interactive, virtual environment for the visualization of protein structures for teaching Bioinformatics and Biology concepts. Within this space, students, represented as avatars, are able to work and to be immersed in the virtual world from any location over the Internet, talk and see other avatars. The Gallery is realized by using the Sun's Project Wonderland, a free, open source Java

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[23]http://code.google.com/p/wonderland-protein-gallery/
[24]http://www.leeds.ac.uk/

Project for creating collaborative three-dimensional virtual worlds.

Since proteins can not be imported into a three-dimensional application because they are just available in PDB file format from the RCSB Data Bank[25], the PDB file format of each protein had been converted into X3D[26] format, the suitable format to import models into Wonderland. Within the virtual world, the student is allowed to interact with the protein model by rotating it to specific areas of interest on the model and all avatars will view the changes to the model. Additionally, avatars are enabled to specify particular protein models and types which they wish to import into the in-world gallery. Each protein model can be visualized in a different way by activating the proper radio button in a popup window next to the in-world model. Differences can be shown between *Stick*, *Ball and Stick*, *Cartoon (Ribbons)* and *Surface*, displayed in Figure 3.13. After entering the PDB ID in the same popup window, the avatars are able to change the protein to any other one. Figure 3.14 shows a protein loaded as a ribbon model of 1QM2 (Human Prion protein fragment), Figure 3.15 shows the surface representation of the same protein. Consequently, the PDB file associated with the ID is converted into an X3D model, which will be imported into the viewing room in real time[27]. The protein gallery has been developed as an extension to traditional courses, allowing for immersive exploration of protein structures to achieve a better understanding of concepts of bioinformatics and biology. Therefore, Project Wonderland turned out to be suitable as a collaborative and useful educational tool to create the virtual learning space. Due to the provided high fidelity, immersive audio and text communication, users are able to analyze proteins and gain experience in a collaboratively way.
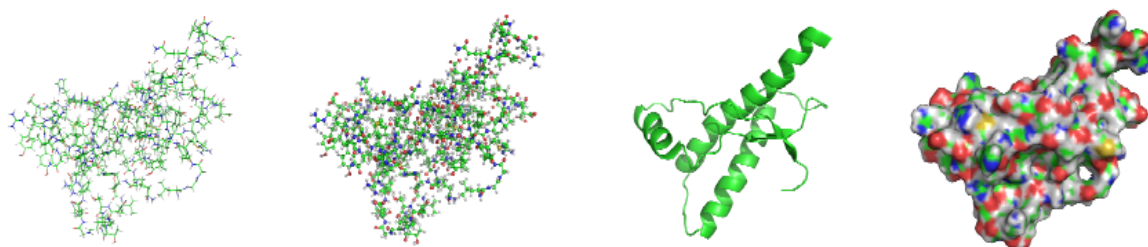
Figure 3.13: The different visualizations of a protein (1QM2), left to right: 1. Stick 2. Ball and Stick. 3. Cartoon. 4. Surface (Retha, 2008).

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[25]The RCSB Protein Data Bank is an archive of experimentally determined three-dimensional structures of biological macromolecules, `http://www.rcsb.org/pdb/home/home.do`

[26]Web3D Consortium (X3D), `http://www.web3d.org`

[27]`https://elgg.leeds.ac.uk/bms4a2r/`
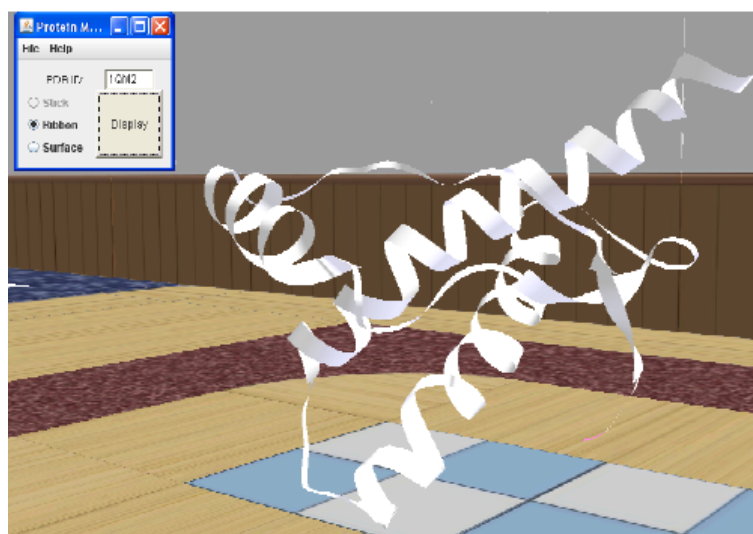
Figure 3.14: The ribbon model of 1QM2 (Retha, 2008).
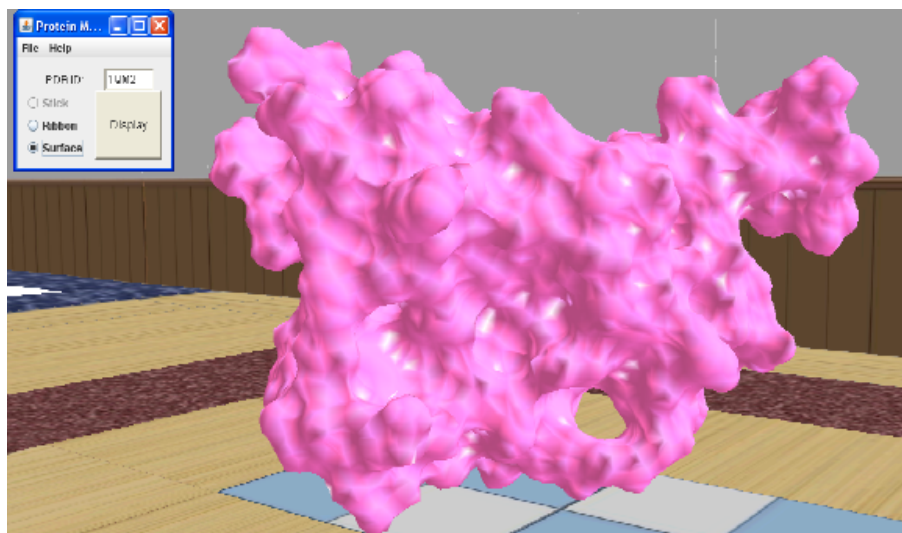
Figure 3.15: The surface model of 1QM2 (Retha, 2008).

3.3.3.6   3D Visualization and Simulation of Biomolecules - Project Wonderland

The objective of this project was to create biomolecules and molecular dynamics (MD) simulations within a collaborative virtual environment for learning purposes, developed in the course of a bachelors thesis, at the *'Freie Universität Berlin'*[28]. Generally, movements of molecules are simulated with methods of molecular dynamics, consequently, the results of this simulation are displayed in a three-dimensional environment. Therefore, Wonderland's toolkit[29] has been

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[28]http://www.fu-berlin.de/index.html
[29]https://lg3d-wonderland.dev.java.net/

chosen, to create a three-dimensional virtual world for the integration of this interactive simulations. The molecule models are visualized as *Ball and Stick*, atoms are displayed as colored balls and covalent bonds as stretched cylinders, which constitutes the most popular used type in traditional lessons. The space within the simulations take place constitutes a sort of aquarium. Figure 3.16 is showing an avatar exploring MD simulations within Wonderland. The user is allowed to start and stop the molecule simulation by a simple click on the molecule model itself.
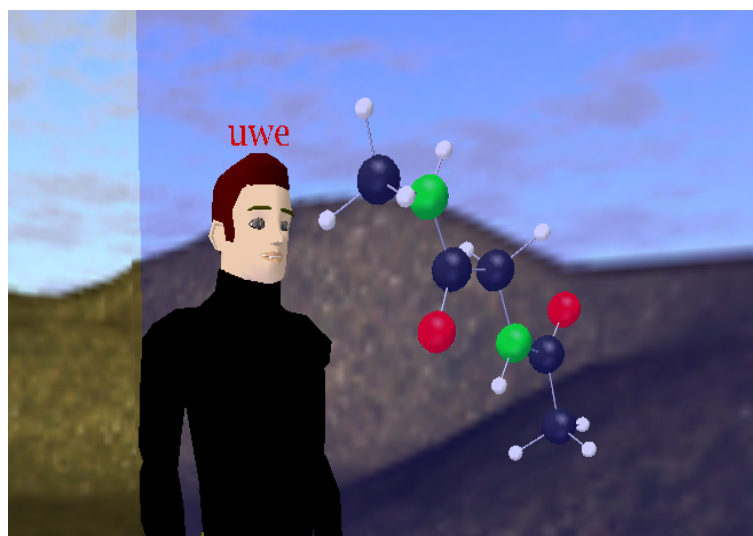
Figure 3.16: Visualization an avatar exploring a simple molecule in Project Wonderland (Kamper, 2008)

Since MD simulations are one of the important tools within the biochemistry and molecular biology-curriculums, virtual simulations are a helpful way to complement experimentation in real laboratories. In this context, Project Wonderland emerged as a suitable environment, due to the provided comprehensive, intuitive navigation and interaction, Wonderland is able to visualize those simulations. The molecular models have been pre-simulated with a simulation software GROMACS[30]. Such molecular simulation trajectory was then loaded into the virtual world to be rendered there correctly, showing how dynamics of a biomolecules behave. This approach offers the possibility for hands-on experience without the need to be physically in a real laboratory. Consequently, the user is able to interact with the molecules as well as explore and discuss the displayed MD simulations in a group. (Kamper, 2008).

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[30]`http://www.gromacs.org/About_Gromacs`

3.3.4 Limitations

This Section has introduced the desktop-immersive CVE as shared environment providing avatar-based intuitive communication and collaboration using non-immersive desktop technology. Moreover, some related research work of the defined environment in the subjects of science is outlined. The presented projects *C-Vision*, *Virtual Campus* and *Chemeet World*, are based on the use of avatars and chat(typed) functionality on the web to enable participants to immerse in the virtual environment. The overall goal of those projects was to achieve a better understanding of the corresponding education field by providing an intuitive feeling about abstract science concepts and phenomena, when being in a three-dimensional world in company with other students. However, although those CLEs approaches synchronous communication to allow students collaborative work in real-time, text-based chat is not always a meaningful way to discuss science concepts or misunderstandings. The user has to continuously monitor the chat window, when a teacher or another peer is explaining something, thus could lead to a lack of attention and confusion within the virtual classroom. Consequently, the research work of the *EduAction* project, the presented *Protein Gallery* and *3D Molecular Simulations* in Project Wonderland have shown CLEs supporting high fidelity audio in addition to text-based chat communication. Especially in situations in science education, when complex questions arises and explanation of abstract concepts are required, therefore the ability to talk is a crucial factor. Finally, related work in CLE providing immersive audio are mostly used for simulating natural phenomena rather than providing remote access for hands-on experimentation. In the light of the advantages remote laboratories offer, more research in this direction has to be done to facilitate intuitive remote experimentation by means of immersive communication and collaboration.

3.4 Summary

In consideration of the fact that science-based phenomena are typically not visible in real settings, through the use of the third-dimension they can be visualized in a virtual world to support and extend students' active learning processes (Dori & Belcher, 2005). During the last few years, many virtual laboratories have been developed to provide applications simulating abstract science concepts. At the same time development of remote accessible laboratories has been increasingly popular due to the fact that students are connected to real laboratories, which transfer a more realistic process compared to virtual laboratories. Thus, the combination of both types of laboratories seems to be an effective approach, meaning direct interaction with real equipment connects a real-time visualization of actually unvisible science phenomena. Nevertheless, research in such hybrid forms of laboratory environments as well as many virtual and remote laboratories has shown a high demand for better communication and collab-

oration tools. In this context, experiencing complex systems phenomena, constructing theories, models, and experiments and learning trajectories for deep understandings and explorations, together with encouraging collaboration, discussion, and reflection are discussed as design principles for possible environments and facilitate learning of complex science systems (Jacobson & Wilensky, 2006). Consequently, the development of three-dimensional environments for educational purposes has become increasingly important, especially in distance education of science. However, research work in such VEs indicates great potential for supporting collaboration in the three-dimensional learning process within a non-immersive desktop environment, due to the multi-user synchronous communicative opportunities combined with visual 3D representations. Related work in avatar-based CLEs indicates that the visualization of avatars enables the management of learning, consequently, the collaboration with others support the constructivist process of knowledge construction. Based on this theoretical review and motivated by the promising potential of three-dimensional CVEs providing multiple communication channels to enhance the learning process in science education, a prototype has been developed overcoming the limitations that related work in 3D CLEs faces. Providing a more high level communication medium like audio chat, as used in multi-user 3D games, combined with text-chat may enhance group-based learning in collaborative laboratory environments. Users are able to talk with their peer learners when conducting experiments instead of text-chatting which may distract. Additionally, the combination of a simulated visualization of a natural phenomena that is generated when accessing the related real equipment remotely may overcome the lack of realism. Thus, the planned prototype is based upon an existing three-dimensional CVE integrating both a virtual simulation and a remote experiment of an actual electromagnetic equipment. The following Chapter presents a conceptual approach of the developed prototype to get an idea of the provided functionalitiy.

Chapter 4

Conceptual Approach and Applied Projects

4.1 Background Idea

This chapter provides the idea of a prototyped three-dimensional CLE for physics education, based on the conclusions drawn in the preceding chapter. In general, the environment is planned to provide undergraduate students, during their outlined curriculum, with the ability to conduct a physics experiment remotely and explore generated phenomena by means of a 3D visualization whithin a shared space. Consequently, collaboration and communication tools are desired to conceive of the scenario, allowing students to work together with other students or professors in the laboratory. Hence, a group of learners conducting the experiment, discuss misunderstandings and review results in a collaboratively way.

In retrospect, the previous chapter has reviewed web-based media supporting distance learning of complex science. In this context, laboratory environments like virtual and remote laboratories have been introduced to indicate great potential for science education. As outlined in chapter 3.2.2, virtual applications providing visualizations and simulations can support meaningful learning by enabling the presentation of spatial and dynamic images and portray relationships among complex concepts (Dori & Belcher, 2003). Nevertheless, simulated virtual laboratories are actually not designed to provide direct interaction to real laboratory equipment, consequently, the touch of reality is missing when simulating real world phenomena. Remote hands-on experimentation on the other hand, discussed in chapter 3.2.3, allows for direct interaction with real apparatus from anywhere, at any time, without the need to be physically present in a real laboratory (Harward et al., 2004). Comparatively, remote laboratories ful-

fill this need for more realism. Therefore, the planned prototype approaches a combination of remote experimentation combined with a simulated 3D visual representation of generated phenomena, to establish a kind of hybrid laboratory work. To keep things simple, an already existing application approaching the combination of both technologies is the basis for realizing this prototype. Thus, this application originally provided a graphical user interface allowing users to interact with a actual electromagnetic equipment in a real laboratory. Additionally, an applet is provided, visualizing the three-dimensional model of the experiment. Consequently, when interacting with the experiments' settings via a user interface remotely, an accurate representation of the invisible electromagnetic field lines is generated and simulated synchronously.

Nevertheless, since communication and collaboration are not provided sufficiently within this particular application, which are identified as key strengths of distance learning, the idea of a online CLE was born providing a range of different media like audio, live chat and streamed video to offer communication and collaboration in different ways. Consequently, identified benefits of both technologies can be enforced and limitations better balanced to bring the learner to a higher achievement level. Unlike other ICT-based solutions for distance learning, the required three-dimensional VE has to provide the participants with a compelling experience of spatial learning and high sense of presence, a feeling of 'being there'. In addition, learners must be provided with the feeling that other participants actually exist and are really present in the environment. Therefore, the avatar-based approach within a CVE is desired to allow the learners the feeling of collaborating with real people and being a part of a group. That means, participants are represented by means of an avatar, navigating and interacting inside the three-dimensional VE as well as exploring the visual representation of the experiment from different perspectives. Consequently, a virtual environment was required providing interface and rendering software which allows for user controlled movement through the environment as well as smooth view changes. Due to the simulated visualization of the experiment, smooth changes of object positions has to be provided allowing an intuitive experience. Therefore, in order to create an effective learning environment, high level requirements are defined and reviewed in the following:

- expand face-to-face laboratory activities during outlined curriculum

- provide a shared virtual environment for experimentation activties in small groups

- virtual representation of each student by means of an avatar

- communication in multiple ways using stimulated multimedia

- complement virtual environments with the possibility of remote experimentation accessing real laboratory equipment

- synchronized 3D visualization of simulated phenomena

- tutoring and teacher consultation

- support laboratory tasks with appropriate toolsets

In summary, the planned CLE should provide the ability to help students develop better intuition about, and conceptual models of, electromagnetic concepts through providing simulations and visualizations as well as remote experimentation. Consequently, students are enabled to get hands-on experience through experimentation, and immersion in a electromagnetic phenomena while collaboration in different ways is established to enhance working and learning together. Since this extended experiment approach depends on two separate projects, the original application together with the applied projects and their underlying technologies are introduced and discussed in the subsequent sections. Additionally, the chosen three-dimensional environment is presented and introduced in detail.

4.2 Fundamental Experiment: Force on a Dipole

The particular experiment that has been chosen to realize the idea of CVLE is called *Force on a Dipole (FOD)*[1] and is used for freshmen physics at MIT, teaching electricity and magnetism. The experiments' actual apparatus consists of a small magnet suspended vertically by a spring in the center of two horizontally mounted coils. An electrical current may be directed through the top or, through both coils, generating constrained electromagnetic field lines. Therefore, students are allowed to controll the real experiment apparatus and vary the frequency and amplitude of the altering current as well as to specify to which coils the current is directed. Consequently the direction of the invisible electromagnetic field lines are changing. Based upon this experiment, which is actually located at the Center for Educational Computing and Initiatives (CECI) at MIT, CECI developed an application providing student's remote access for the FOD experiment as well as a simulated visual representation of the electromagnetic field lines, consequently, to make unseen seen. Since this application approach is based on the iLab project's infrastructure and the TEALsim simulation toolkit, both initial projects and related technologies are discussed in the following. Subsequently, the experiment's application is presented and explained in detail.

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[1] https://wikis.mit.edu/confluence/display/ILAB2/teachspin_ilab

4.2.1 The iLab Project

The iLab project's[2] vision is to share lab experiments among schools and universities on a worldwide scale. An infrastructure is provided to allow students access to actual equipment remotely. In the last decade the overall goal of this project was to increase the laboratory experiences available to university students worldwide, providing a technical solution to make online laboratories more scalable and more pedagogically effective (Harward et al., 2008). In fact, the project has already established multiple strong international partnerships with universities in Europe, Australia, Africa, Asia, and the United States[3]. With those partners the iLab faculty are working to develop and expand the range of experiments that students use in courses in the undergraduate and graduate levels.

Since the project was started at M.I.T. in 1998, online laboratories have been developed in several fields including physics and electrical, chemical, and nuclear engineering (Harward et al., 2004). Beside the development of new iLabs and the maintenance of existing labs, the project is trying to determine the pedagogical value of online laboratories, therefore they carried out evaluations of the use of iLabs in undergraduate courses. Results of surveys and interviews, which were examined in each of the semesters, were very encouraging. Students perceptions have shown evidence of improvement in teaching and learning with the iLab architecture. Harward et al. (2008) stated that the students indicate that controlling lab equipment remotely did not interfere with learning rather they were able to reinforce individual styles of learning in multiple ways and enhance conceptual learning.

Furthermore, there is no need to be physically in the laboratory, the equipment can usually be made available 24 hours a day and students can often spend more time exploring an iLab than in the corresponding hands-on traditional lab. Since the system automatically queues student requests on a first-come, first-served basis, students no longer have to wait for equipment availability and spend unnecessary time. Through an open source development kit and a public service broker, M.I.T. encourages educators worldwide to develop their own iLabs and then share them with other academic institutions with the consequence that the cost of a laboratory equipment can be reduced, because only one piece of equipment needs to be acquired for sharing it with many users. Through these initiatives, the iLab Project is delivering the educational benefits of hands-on experimentation to students anywhere, at any time.

The *iLab* Project concept is to virtualize the real laboratory experience by means of an infrastructure which is provided for the design and sharing of internet accessible laboratory ex-

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[2]`https://wikis.mit.edu/confluence/display/ILAB2/about+iLabs`
[3]`https://wikis.mit.edu/confluence/display/ILAB2/ilab_partners`

periments. This distributed service infrastructure, termed the iLab Shared Architecture (ISA), divides an online lab into three distinct parts: the Lab Client, the Service Broker and the Lab Server (see Figure 4.1. The lab client constitutes the user's interface to the iLab, the lab server connects to the lab hardware and the Service Broker provides the functionality to all iLabs. Online labs which are based on the ISA framework are allowed to be available to users worldwide using standard network protocols (Hardison et al., 2008).
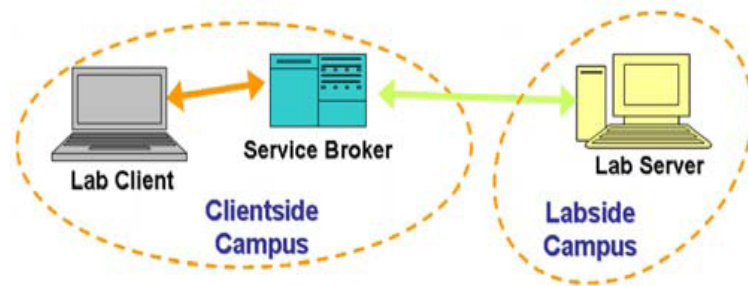
Figure 4.1: iLab Shared Architecture (ISA) (Hardison et al., 2008).

The iLab project is focused on different experiment typology including 'Interactive Experiments'. Harward et al. (2008) defines interactive experiments as those in which the user monitors and controls one or more aspects of the experiment during its execution. That means interacting with such an experiment requires real-time control, the user must be online, and large bandwidth between the lab client and the lab server. When a user conducts an interactive experiment, the user client controls virtual lab equipment by means of a graphical user interface (GUI). The proprietary toolkit, which the iLab project is using to conduct experiments in real-time is the National Instruments' LabVIEW product[4]. Through this web–accessible software interface, realized by an application server which is running on a computer, the user can directly connect to the laboratory apparatus. The user is allowed to define parameters and observe results which means the experiment is run on-demand and real data is transmitted back to the user. In the following chapter an interactive lab for physics education, developed at MIT for deployment on the ISA, will be introduced.

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[4]http://www.ni.com/labview/

4.2.2 TEAL Studio Project

The overall goal of the Technology Enabled Active Learning (TEAL) Studio Procject[5] is to help students conceptualize phenomena and develop better intuition about electromagnetism. The TEAL approach is to reformat the teaching of freshman physics at MIT by merging lecture, recitations, hands-on laboratory experiments and a range of simulations into a single common experience (Dori & Belcher, 2003). At the end of 2000 the project was started with a small prototype course taught to 150 students and by the end of 2005, all freshmen were taught introductory physics in this format. The project's classroom setting divides students into groups of nine at round tables, see Figure 4.2. Instructions and laboratory work are interspersed with desktop experiments and collaboration work in smaller groups of three students (Belcher, 2001). Those teams of three share one networked laptop, where they can follow the instructor's Power-Point presentation. These formal and informal instructions are aided by media-rich interactive software for simulation and visualization (see next section) to conceptualize the direct experience with phenomena's, generated by desktop experiments. Hence, student lab groups have the ability to interact with the model using their desktop input devices, control input values, and then see how the simulation is effected by their changes. In addition, three-dimensional simulations can be carried out as often as needed to give the students a better understanding for physics concepts.
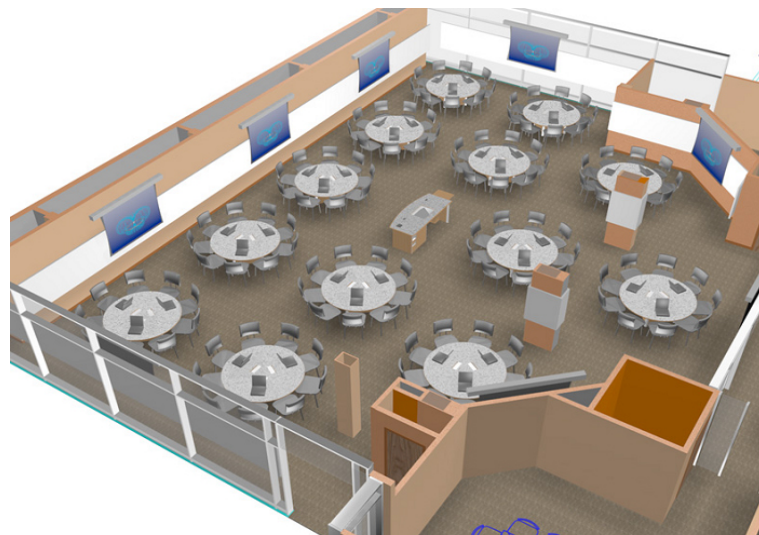
Figure 4.2: A rendering of the TEAL classroom (Belcher, 2001).

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[5] http://web.mit.edu/8.02t/www/802TEAL3D/teal_tour.htm

The TEAL Simulation System (TEALsim)

TEALsim is an open source simulation toolkit, developed at CECI (MIT) as a component of the *'Studio Physics' TEAL project*. The TEALsim simulations are effectively integrated into the TEAL curriculum. They are used to illustrate abstract physics concepts visualized by means of a three-dimensional model. Dori & Belcher (2003) emphasize that students need to understand the importance of the models that they are taught, consequently, to construct their own models. These visualizations enable students to develop intuition about various electromagnetic phenomena by making the unseen seen in experimentation. To give one example, electromagnetic fields and phenomena are typically not visible in real settings, but by using such a simulation engine, students can nevertheless view a synchronized visualization that renders an accurate representation of the invisible field lines (Dori & Belcher, 2005). The provided visualizations are organized into five categories: Vector Fields, Electrostatics, Magnetostatics, Faraday's Law, and Light. Furthermore, all visualizations range in format from passive mpeg animations to interactive Shockwave simulations and Java 3D applets[6]. The following figures are showing three different examples in the field of Magnetostatics. First of all, Figure 4.3 displays a magnetic field animation of a current-carrying coil. Then, Figure 4.4 represents an example of an interactive shockwave simulation, showing a model of a bar magnet and a compass sitting on a table in the TEAL classroom. The interaction between the magnetic field of the bar magnet and the magnetic field of the earth is simulated. Finally Figure 4.5 displays a 3D applet which illustrates the forces on a current carrying coil.

In summary, a study which has been conducted based on the TEAL curriculum, has shown that the combination of direct hands-on exposure to the electromagnetic phenomena, 2D/3D visualization of those phenomena, and active learning in a collaborative setting, significantly enhanced students' ability to transfer the concepts of electromagnetic field lines and associated phenomena from the abstract level to the concrete level (Dori & Belcher, 2005). Fact is, the assessment shows that learning within the TEAL classroom gains a factor of two higher than traditional instructions, due to the contribution of better conceptual understanding of these physical phenomena. In the range of the assessments pre- and posttests, which have been asked to assess the effect of visualizations and experiments, students commented in the way, that experiments conducted in a traditional laboratory were interesting, but often not easy to learn from. Subsequently, students state that three-dimensional visualizations are supporting conceptual understanding of phenomena through visualizing how electric and magnetic fields interact with charged wires, and what affects, creates, and changes them (Dori & Belcher, 2005).

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[6]The main index of visualization categories: `http://web.mit.edu/8.02t/www/802TEAL3D`
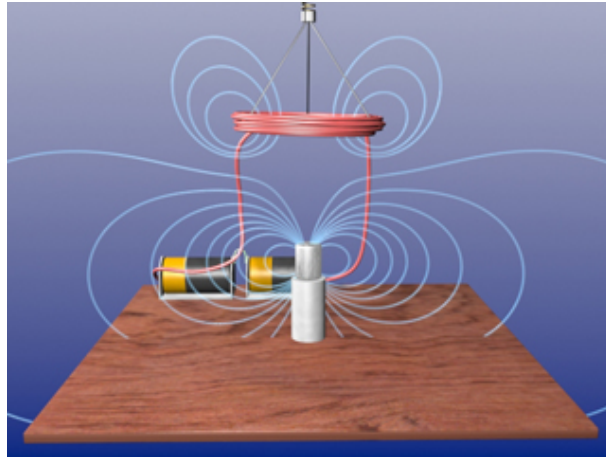
Figure 4.3: Animating the magnetic field of a current-carrying coil (MIT, 2009).
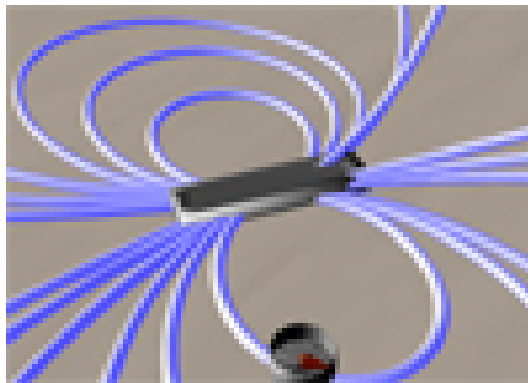
Figure 4.4: A Bar Magnet in the Earth's Magnetic Field (MIT, 2009).
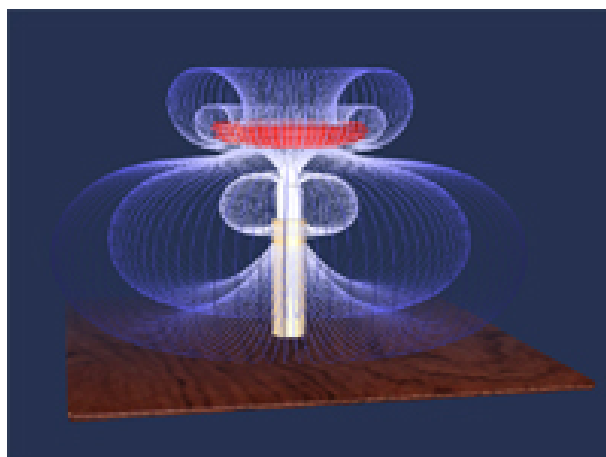
Figure 4.5: This applet illustrates the forces on a current carrying coil (MIT, 2009).

4.2.3 FOD Application

The FOD application combines an interactive iLab with a correspondent visualization of the TEALsim simulation toolkit. To controll the apparatus settings, a LabVIEW client application (see Figure 4.6) is provided that displays the input current, the current of the top coil and the position of the magnet. Additionally, the experiment permits students to observe the position of the magnet, by a stationed video camera next to the experiment (see Figure 4.7), and measures the motion of the magnet suspended in the center of the coil. (DeLong, 2009).

Based on their measurements and a few known parameteres, students acquire the ability to determine the magnetic dipole moment of the magnet and to develop a sense of the electromagnetic forces at work. The latter is possible with the live video stream of the real lab equipment and the aid of synchronized visualizations (Hardison et al., 2008). Since this experiment extends the TEAL emphasis on visualization to online experiments using the iLabs infrastructure, a real-time virtual representation of the experiment on the student's computer is provided. Hence, when controlling the FOD experiment remotely, a data stream is subscribed to the application over the web and used as input to drive a real-time visualization of the experiment. The visualization, as displayed in Figure 4.8, shows what is physically happening through representing simulated magnetic and/or electric field lines. Consequently, students are allowed to gain insight into the way in which fields transmit forces by watching how the motions of objects evolve in time in response to those forces (Dori & Belcher, 2003).

In retrospect, although the TEAL Studio project achieved the desired effect on the students' learning outcomes, from a distance learning view this approach does not yields the desired results since TEAL assumes that students are physically collocated. Thus, direct interaction with desktop experiments is not feasible because TEAL's original did not consider using remote laboratories. The combination of both technologies applied on the FOD experiment, provides a powerful tool to enhance understanding of abstract physics concepts using active and passive visualizations, especially in areas where we can make the "unseen seen", as in electromagnetism. Definitely, iLabs is not a perfect a replacement for a traditionally laboratory because of the missing experience of touching and feeling of actual equipment but combined with a TEALsim visualization this approach is best suited as a replacement in situations where no other options are available, like distance learning.

However, the iLabs vision of sharing laboratory experiments beyond a campus and across the world to students at other institutions together with the proper visualization of the related experiment, may increase the educational opportunities of those students but at the same time aspects of collaboration are disappearing. Since the iLabs infrastructure was designed for one student in particular and based on the fact that collaboration plays a major part in the learning process, a collaborative learning environment was desired.
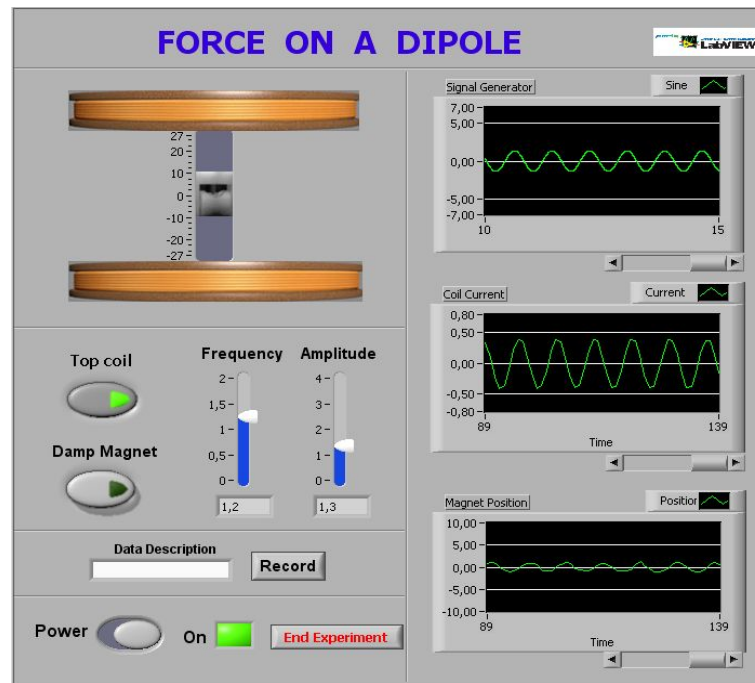
Figure 4.6: LabVIEW-based client interface (DeLong, 2009).
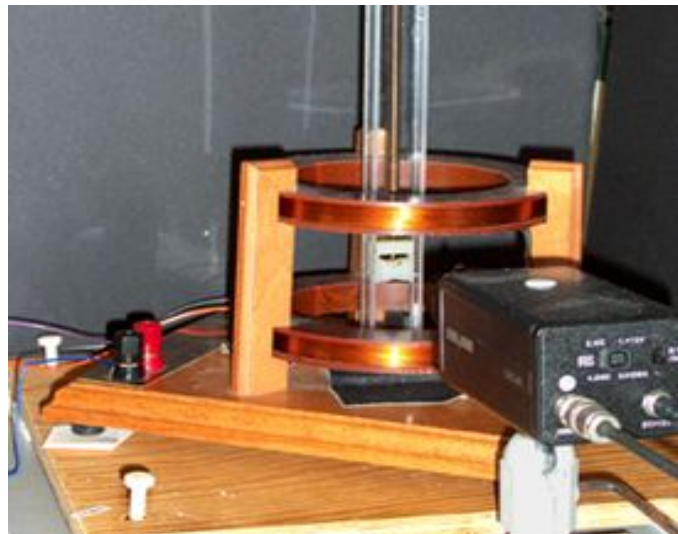
Figure 4.7: Webcam observing the the real apparatus (DeLong, 2009).

4.3 Delivery Platform

Since the realization of this prototype is primarily focusing on the improvement of the collaborative abilities of laboratory environments, this fact has led to the decision to use an already existing 3D environment, a platform-based solution rather then to develop a new 3D environment. However, a platform is a fully contained, specialized environment within a solution which may be developed, tested, and executed. Due to the potentials of online collaborative virtual en-
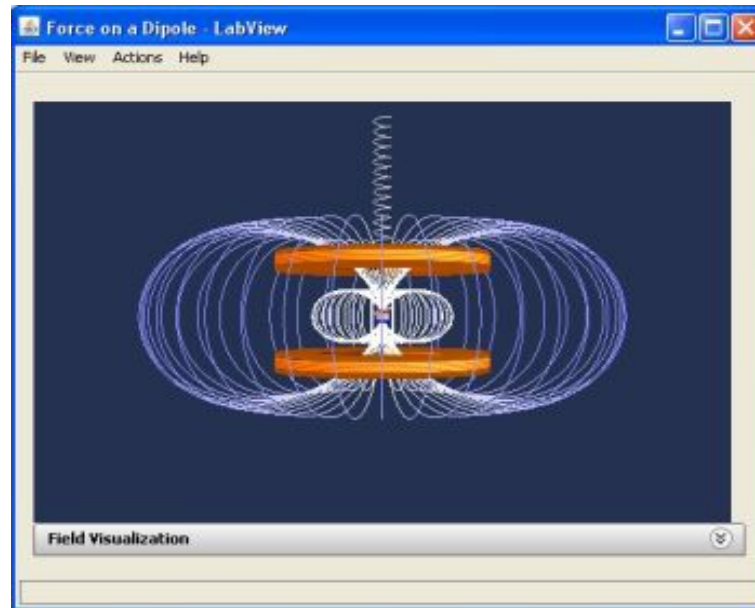
Figure 4.8: The visualization of the FOD experiment driven by the data stream (DeLong, 2009).

vironments in the domain of education, as discussed in Section 3.3, as well as the availability of open source toolkits to build virtual environments have confirmed the decision. Moreover, the provided multi-user architecture in such platforms enables deep collaboration between teams of users. This section introduces Project Wonderland[7] as a dedicated toolkit to undertake our prototype work for this thesis. The compelling reasons for the chosen version 0.4 of Project Wonderland are discussed as well.

4.3.1 Introducing Project Wonderland

Project Wonderland[8] is a free, open source Java toolkit for creating collaborative 3D virtual worlds, developed by Sun Microsystems Inc[9]. Motivated by perceived deficiencies in collaborative experience, Wonderland has been developed as a multi-user environment which incorporates 3D and desktop virtual reality technology with digital media. Specifically, Wonderland's vision is to leverage CVE technology as a means to better integrate remote users through immersion and engage them in the same way 3D games grab and keep the attention of players is. By means of mulit-user capabilities with avatars, organizations and institutions in educational

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[7]https://lg3d-wonderland.dev.java.net

[8]https://lg3d-wonderland.dev.java.net

[9]http://www.sun.com

as well as business fields want the ability to create a virtual presence for better communication with other peers. Additionally, the provided digital media allows for collaboration by means of high fidelity spatially localized audio chat, text communication, shared whiteboards, HTML and pdf viewers, streaming video, and shared virtual desktops. In other words, a three-dimensional virtual space for working and learning collaboratively without the need for a separate collaboration tool is provided.

However, because the system is open-source, it offers the potential to be extended with user-created contents and new tools as much as needed. Consequently, tools can be "easily" embedded in web pages to provide precise control of the 3D world. Since the entire project is implemented in java and leveraging the Java3D API for graphics rendering, Project Wonderland offers a substantial platform for building CVEs.

4.3.2 Wonderland Version 0.4

At the time, when the design and development phase has been started, Wonderland's newer version 0.5 was issued as a series of monthly developer releases. The expected end-user release, at that time, was inconsistent with the defined time line of this work. Consequently, version 0.4 was chosen for this project, since it was a stable version at that time. Additionally, given that both the TEALsim engine and Wonderland 0.4 are leveraging the Java3D API, this fact has contributed to this decision, but was not a crucial factor. From the operating system view, due to the availability of the TEALsim simulation system in Microsoft Windows together with the Java's cross-platform nature, which makes Project Wonderland available for several operating systems, the Windows platform was chosen for prototyping the CLE.

4.3.3 Architectur of Project Wonderland

Project Wonderland comes as a fully functional CVE and it is largely client-server oriented in its architecture. The server software is based upon Project Darkstar[10], a multi-player "gaming" technology. The client constitutes a desktop Java application based upon two technologies, Project Looking Glass 3D (LG3D) and Java3D, for rendereing 3D contents to the screen. Important details on Java3D are explained in chapter 5.1. (Slott, 2008). Project Looking Glass[11] provides a 3D desktop environment and a set of APIs to build 3D applications.

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[10]http://www.projectdarkstar.com
[11]Project Looking Glass: https://lg3d-core.dev.java.net/

4.3.3.1 Project Darkstar

The server-side software Project Darkstar is actually a game server providing the infrastructure to implement a virtual world application, including multi-user communication and an event processing system. Darkstar manages a collection of geometric objects and provides APIs for synchronized updating of objects states. The major components of the Darkstar infrastructure are a transaction model and a network protocol. The transaction model manages access to the Darkstar server. Thus, if mutiple clients want to performm an action and update the server at the same time, the server has to synchronize the client updates so they do not interfere with each other. If any modification happens at the client-side, the server-side is updated in a thread-safe manner. Then the server has to communicate the change to all the other clients in the world via a message send. The network protocol assures that the message is received by the recipient. (Slott, 2008).

4.3.3.2 World Cell Structure

Wonderland's organizes the three-dimensional virtual world in discreet volumes called "cells". A cell represents a volume of space in the world, such as part of a scene or an object. The virtual world is a cell, the room is a cell, each object is a cell and so is the Avatar. In the following Figure 4.9 the cell structure of the prototyped learning environment is displayed to clearly indicate how the virtual world works.
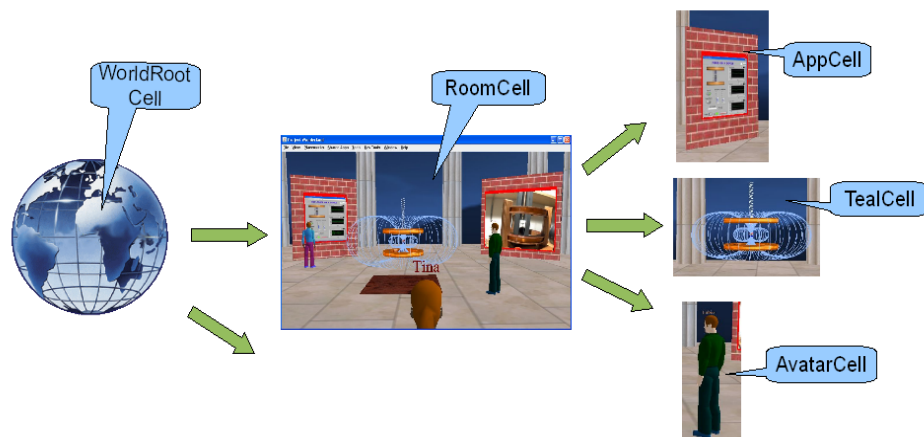
Figure 4.9: How the world works: cell structure of the prototyped learning environment!

Cells can be distinguished between stationary and moveable, whereby a virtual world mostly consists of stationary cells, objects or regions which do not move. Avatars, for instance, constitutes moveable cells. The Cell's state and properties are stored on the Darkstar server in a "Game Logic Object", a GLO, responsible for alle modifications occured. Each Cell has an exact position within the virtual world, which defines the cell's center by world coordinates. In addition, a *Cell Coordinate System* is provided, where the cell's center is at (0,0,0). A cell incorporates the source code, which is executed on the server and the client-side, as well as defines, how client and server change states via messages. (Slott, 2008). More details about creating a new type of cell are given in chapter 5.3.2.

4.3.3.3 Wonderland File System (WFS)

A Wonderland-File-System (WFS) is a hierarchical structure consisting of XML-formatted files, representing Java classes. Generally, such a XML file consists of the following cell information:

- class name of the cell

- 3D coordinates of the cell's origin within the virtual world

Additionally, further parameters can be added within a XML file, for instance, size, texture or rotation which modifies each cell. Once the Darkstar server has been started, the server memorizes the WFS and for each cell, the proper client as well as server cell classes are produced. Thus, Project Wonderland expects the implemented GLO-class in the server-side classes since those objects get parameters transferred from the related XML file, which defines the cell's behavior. (Slott, 2008).

4.4 Summary

This chapter has introduced a conceptual approach to realize the prototype implementation of a CVLE facilitating the FOD experiment's application. Consequently, the applied projects iLab and TEALsim are explained as technologies, providing remote accessible experimentation combined with a three-dimensional visualization of the simulated electromagnetic field lines which are generated synchronously. Subsequently, Project Wonderland as a platform-based solution is presented and used to create the required virtual environment supporting collaboration and communication by means of an avatar-basaed interaction within a desktop-immersive space. In addition, Wonderland's architecture and important components are outlined which form the basis when discussing implementation details in the following chapter.

Chapter 5

Prototype Implementation of a CVLE

In this chapter implementation details of the prototyped CVLE in Project Wonderland are discussed. First of all the API used is introduced called Java3D. Using this Application Programming Interface (API), a 3D virtual universe can be created efficiently, providing high-level constructs to create and manipulate 3D geometry, and to build the structures used to render that geometry. Subsequently components of the used TEAL simulation system are discussed in order to get an overview about the concurrence of each part. Afterwards configuration details of Project Wonderland's 0.4 version are given, differing starting Wonderland from source code and creating a web start client. Consequently steps for creating a new cell type are discussed in order to understand the creation of particular cell types, outlined in the implementation details section besides other important steps which were necessary during the implementation process. This section is partly presented in a full conference paper published during the thesis work (Scheucher, Bailey, Gütl, & Harward, 2009). For the purpose of an overview of each component which are discussed in the previous chapter and integrated in the implementation, Figure 5.1 outlines a conceptual approach of the prototype's architecture.

5.1 Java 3D API

Java3D is a Application Programming Interface (API)[1] being developed by Sun Microsystems and provides 3D graphics capabilities to Java applications and applets using packages. A 3D virtual environment is constructed by graphics models and their relations, which can be represented

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[1] http://java.sun.com/javase/technologies/desktop/java3d/
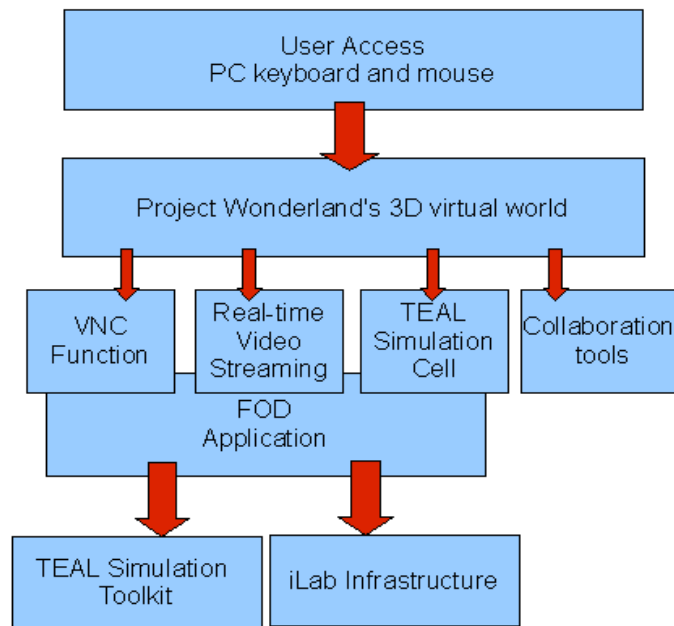
Figure 5.1: Conceptual architecture of the CVLE

by an abstract tree structure, called scene graph. Java3D provides a collection of high-level constructs for creating, rendering and manipulating 3D geometric objects in the three-dimensional world, managed by a scene graph architecture, which is explained in detail in the following subchapter. The Java3D API is built on top of OpenGL or Microsoft's DirectX Graphics to render images, see Figure 5.2. This low-level API handles the native rendering at the vertex and
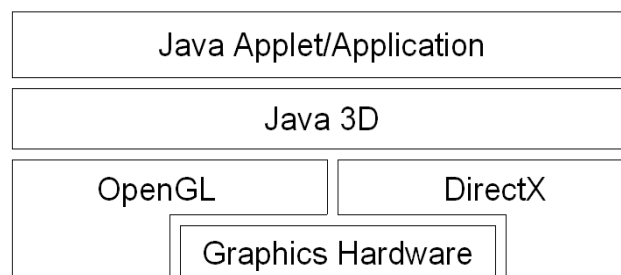
Figure 5.2: Structural view of a Java3D rendered application or applet

pixel levels, while the 3D scene, application logic, and scene interactions are carried out by Java code. This dual approach, using high-level and low-level API, encourages application portabil-

ity, hardware independence, and high-speed rendering (Chen, 2008). Since both projects, the TEAL simulation engine and Project Wonderland, are based on a Java3D rendering engine, the basic steps to create a 3D application which are important for implementation details later on, are discussed in the following.

A Java 3D virtual environment is created from a scene graph. This is a directed acyclic graph, that permits efficient storage of, and access to graphics data, like geometry, materials, lights, sounds, location, orientation, and appearance of visual and audio objects (Bouvier, 2000). Furthermore, a Java3D scene graph is constructed of node objects in parent-child relationships, forming a tree structure. Each node can have multiple children, but only one parent. A Node without a parent is called root and nodes without children are called leaves. Nodes within the graph are instances, which define the attributes of each visual object. Leaves represents the visual object itself.

The basis for creating a virtual environment wherein 3D content can be realized constitutes the Java3D *Virtual Universe*. This *Virtual Universe* is the top node in every scene graph, and represents the virtual world space and its coordinate system. Below the *Virtual Universe* object is a *Locale* object. The *Locale* object defines the anchor position, in high-resolution coordinates, of its attached branches of 3D content in the universe. There can be multiple branches of 3D content per locale. A BranchGroup is basically the root of a subgraph, called branchgraph of the scene graph. A scene's subgraph is divided into the *view branch graph*, a branch for viewing-related nodes (Transformation, ViewPlatform etc.), and the *content branch graph*, a branch for 3D content (shapes, sounds, etc.). Figure5.3 and Figure 5.4 are showing a typical Java3D scene graph structure with view and content branchgraphs. The right BranchGroup has a single subgraph that consists of a TransformGroup node and a ViewPlatform leaf node. The TransformGroup specifies the position (relative to the Locale), orientation, and scale of the ViewPlatform. This transformed ViewPlatform object defines the end user's view within the virtual universe. However, the ViewPlatform is referenced by a View object that specifies all of the parameters needed to render the scene from the point of view of the ViewPlatform. Also referenced by the View object are other objects that contain information, such as the drawing canvas into which Java 3D renders, the screen that contains the canvas, and information about the physical environment. Complementary, *Canvas3D* is a Java GUI component that allows the 2D image to be placed inside a Java application or applet, consequently, to view the virtual world through this 2D image plane on a monitor, which is often the case across different applications. Figure 5.5 shows the composition of 2D image plane, the eye position, and the virtual universe. The eye position is behind the image plane. Consequently, the visual objects in front of the image plane are rendered to the image plane. The four projectors projects the visual objects to the image plane. (Bouvier, 2000). Further details in terms of Java3D are outlined by Bouvier (2000).
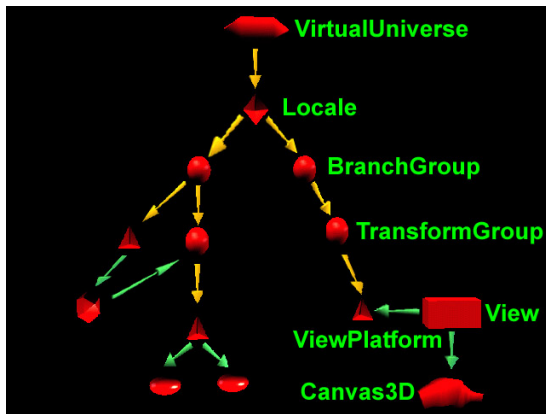
Figure 5.3: View Branch Group (Vuylsteker, 2004)
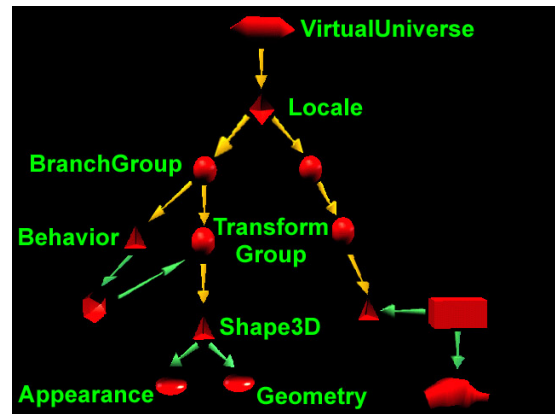
Figure 5.4: Content Branch Group (Vuylsteker, 2004)
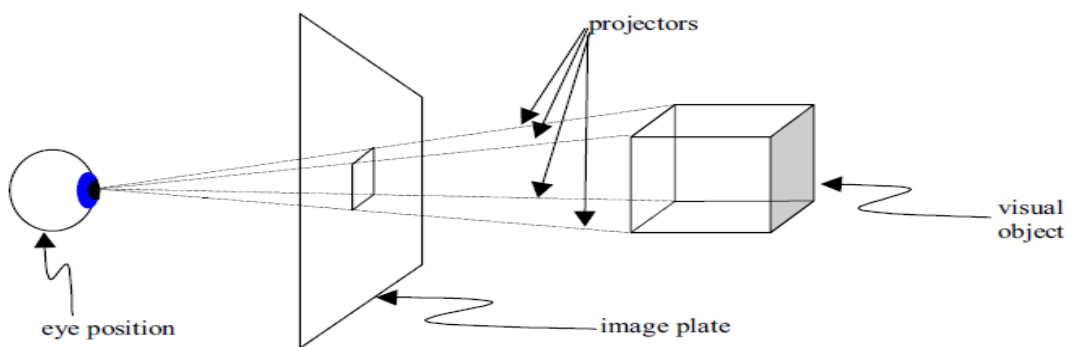
Figure 5.5: Conceptual Drawing of Image Plate and Eye Position in a Virtual Universe (Bouvier, 2000)

5.2   Components Overview of TEALsim

The TEAL simulation system (TEALsim) as a framework designed for authoring, viewing and controlling simulations, primarily in the domain of physics but with extensions to biochemistry and other domains. TEALsim has been developed using Java[2] version 1.5.0_12, Swing[3] and Java3D[4] 1.4.0_01 extensions.

The architecture of TEALsim consists of several major modules represented by three main components, which are combined into a complete simulation. Each component is defined by a set of interfaces that suggest the required functionality of that component. These three major components (see Figure 5.6), as overviewed in the following, make up the entire user experience (Belcher et al., 2007):
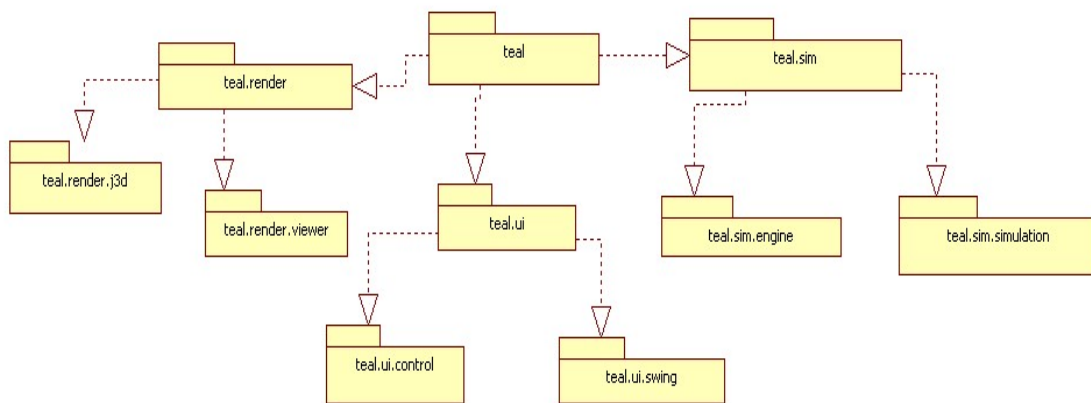
Figure 5.6: Structure of the three major compononets in TEALsim

- *The Simulation Engine (SimEngine):* The physics in a TEALsim simulation is contained in a SimEngine object, which represents the simulation engine itself. The simulation engine is responsible for all the computation involved in the system being simulated, including dynamically processing and updating simulation objects to the simulation model. Generally, actions performed by the Simulation Engine are listed as follows:

  1. Computes values of dependent simulation variables

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[2]The Source for Java Developers: `http://java.sun.com`
[3]Swing GUI Creation: `http://java.sun.com/docs/books/tutorial/uiswing/`
[4]Java3D API: `http://java.sun.com/javase/technologies/desktop/java3d/`

2. Updates simulation objects to reflect new values

3. Informs the renderer of any visual changes to the simulation.

This continuous loop represents the main application thread for a TEALsim simulation.

- *The Rendering Engine (Viewer and Viewer3D):* The Viewer is the window into the simulation space and is responsible for rendering the visual elements of a simulation to the screen in real-time 3D. Additionally, the viewer manages user interaction with the rendered image. If any changes to a simulation object by user manipulation occurs, the simulation engine informs the viewer. Therefore, the simulation engine is tightly coupled to the *Viewer*.

- *The User Interface Elements (UI):* The UI is responsible for the user interactions with the application and for the received feedback a user gets regarding to the simulation properties. Consequently, producing the types of controls and read-outs necessary to manipulate a simulation are the UI's major tasks.

5.3 Wonderland Configuration and Components

5.3.1 Platform Settings and Installation

The primary Operating System used for this thesis was Windows XP[5]. The version 1.6.0_05 of the Java Development Kit (JDK) and runtime environment[6] (JRE) was used to compile and run the project. Moreover, the IDE used to work on this prototype was Eclipse 3.4.0 SDK, getting Wonderland to run in Eclipse was processed following the instructions on the Wonderlands 0.4 developers website[7]. In Eclipse, the Wonderland project folder can be downloaded using a CVS[8] Eclipse plug-in[9] to "checkout" the project "lg3d-wonderland". Another project that needs to be checked out via CVS, in the same way as lg3d-wonderland, in order to load files, specifically models and textures, from the own hard drive is "lg3d-wonderland-art". Due to this download, the development within Project Wonderland is more efficient instead of having to download the necessary art-files from the Internet. Additionally, personal artwork and models

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[5]http://www.microsoft.com/windows/windows-xp/default.aspx
[6]http://java.sun.com
[7]http://wiki.java.net/bin/view/Javadesktop/ProjectWonderlandEclipseHowTo
[8]Concurrent Versions System: http://www.nongnu.org/cvs/
[9]Eclipse CVS client: http://www.eclipse.org/eclipse/platform-cvs/

can be added and used in Wonderland. The third project that needs to be checked out is "Wonderland Modules". Therefore, a 'Subversion[10]' plugin for Eclipse[11] was necessary in order to check out via the address: *https://wonderland-modules.dev.java.net/svn/wonderland-modules*

5.3.1.1 Starting Wonderland from Source Code

Once all those projects have been checked out in the correct location folder proximal to lg3d-wonderland, the full development environment was compiled. Hence, *wonderland-modules* and *lg3d-wonderland-art* are placed outside the *lg3d-wonderland* folder in the same directory. Consequently, lg3d-wonderland constitutes as the 'main project' and when compiling it in Eclipse also lg3d-wonderland-art and wonderland-modules are compiled. After the successfull compilation of the Wonderland source code, another plug-in, Apache ant was necessary in order to run Wonderland from source. Ant directs the compilation and running of the wonderland projects. Generally, Wonderland source code can be build either by running the ant command in a terminal window. Consequently to run the application, three ant targets are provided to start the voice bridge, Wonderland server, and the client respectively. In separate terminals, first the voice bridge and then the server is started. When the server is ready, the Wonderland client is started in another terminal. In addition to this execution, those Ant targets can also be configured and run from within eclipse. Thus, the Ant plug-in for Eclipse was necessary to execute Ant buildfiles from Eclipse and consequently, to tell Eclipse about the desired Ant targets. The three Ant configurations are started one after the other from Eclipse:

- *run-bridge*
- *run-sgs*
- *run*.

Finally, the Wonderland client should appear and display a login dialog allowing the user to enter the name, as displayed in Figure 5.7. A password is not mandatory, an empty password by default can be used.
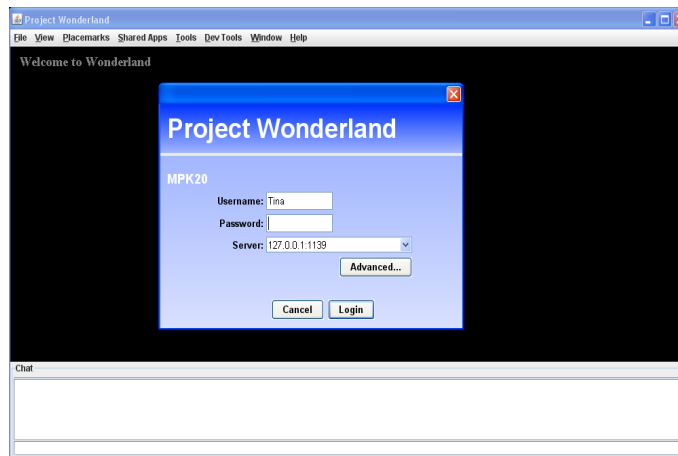
Figure 5.7: Log-in window to enter Wonderland's virtual world

5.3.1.2 Configure Java Web Start Client

Project Wonderland features a Wonderland World Builder (WWB), a web-based administration for easy deployment of clients, as well as to build and modify the world. Consequently, after successfull installation of the web administration, users are allowed to launch the Project Wonderland client from a web browser. That means, users simply click on a link in their browser to automatically download and launch the latest version of the Project Wonderland client.

Therefore two steps are necessary to preceed the web administration:

1. *Building combined Wonderland.war* Since this project is build from Wonderland source code, your own copy of the Wonderland.war has to be built in order to be used for the web administration. The necessary steps are explained on the related Wonderland website[12]. To avoid a likely heap size problem, instructions are provided on this website to overcome this issue. Though, it turned out that slightly different steps were necessary for building the proper *wonderland.war*. The necessary commands are listed in the following:

   - *set ANT_OPTS=-Xmx256m-Xms256m*

   - *ant clean*

   - *ant pkg-webstart*

   This maintained WAR file is a self-contained web application archive file that must be run on a web server and consequently, viewed through an Internet browser.

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[12]http://wiki.java.net/bin/view/Javadesktop/ProjectWonderlandWebAdmin

2. *Installing the Jetty web container* In addition, a web container is needed, served as a servlet server supporting Java servlets in order to run the WAR file. Therefore Jetty server, version 6.1.9, is used for this implementation, following the related installation instructions[13].

Finally, to run the Wonderland World Builder, the WAR file must be placed in the "webapps" directory of the Jetty server. Therefore the Jetty server needs to be started up firstly, consequently to open a web browser wherein the user can access to the latest Wonderland application by going to *http://grisu.mit.edu:8080/Wonderland/.*

5.3.2 Creating a New Cell Type

A new cell type is created via the wonderland-modules project that relies on the parent wonderland project lg3d-wonderland and does not operate as a stand-alone project. Basically, the wonderland-modules workspace provides the infrastructure to create and add new modules, wherein new cell types are compiled. Each cell type consists of three folders, packages, in which the classes are placed accordingly, and these are client, common, and server. The *server package* consists of all class-files which are necessary on the server. Like the GLO class, which is very important, since it illustrates the interface between the Cell and the server infrastructure. The *client package* consists of all classes which are responsible for the visualization as well as for the source code, which is necessary for the user-interaction and communication with the server. Finally, the *common package* consists of classes, which are required both from the server and the client. For instance, the message classes, which defines the data structure of the message being sent between client and server. Additionally a "newCell-wlc.xml" cell descriptor file has to be created to signal a new cell which is recognized and registered at the server as a GLO object. Following Figure 5.8 overviews the cell architecture, displaying the server-side *CellGLO*, the client-side *Cell* as well as the messages passed between, and the XML-formatted cell descriptor file informing the server. Consequently, this XML file is then localized in the -wfs folder of the WFS. Thus, the cell is displayed on the client and any changes that are made to the cell state are passed as a message from the client to the server. Subsequently, the servers task is to maintains the shared state of the cell across all client participants. The client part contains the important class providing code in order to update the state of the cell and is responsible for rendering and displaying the cell in-world by using the Java3D API.

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[13]http://wiki.java.net/bin/view/Javadesktop/ProjectWonderlandWebAdmin
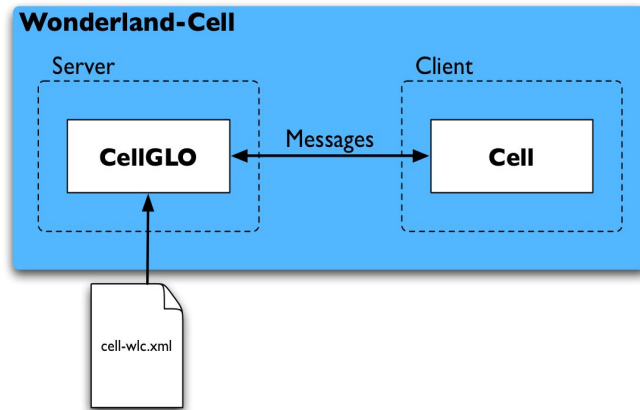
Figure 5.8: Architectur of a Wonderland Cell (Slott, 2008).

5.4 Implementation Details

5.4.1 The TealCell

Integrating the geometry model of the Force on a Dipole experiment in Project Wonderland 0.4 requires the creation of a new type of cell. Therefore a new module was created in the optional modules workspace 'wonderland-modules' in a folder, called *Tealsim*, representing the new module which is exactly located in the wonderland-modules/src/modules/apps/3d path. Within this folder the necessary client, common and server packages are realized. Once the wonderland application is started, the server-side cell, called *TealCell* has to communicate with the client-side cell, called *TealCellGLO*, in order to setup the cell's properties. For this purpose, a class called *TealCellSetup* is implemented in the 'common' package and compiled both into the server-side and client-side code. This *TealCellSetup* constitutes as a container of configurable information that is transported from the *TealCellGLO* to the *TealCell*. At the same time, within the setup the initialisation of the actual experiment is processed in a separate created class, called the *TealModel*.

The proper Teal application is instanced through importing the associated Teal package and providing access to the necessary classes. Thus, at the same time, the setup of the teal application is processed and the necessary components, the Java3D viewer, the simulation engine and GUI components, are instanced as well. Consequently the model's scene graph is constructed, in order to visualize the simulation model in the applet's window. In the following Figure 5.9 the class structure of the Tealsim module is overviewed, displaying *TealCell.java*. However, through the created instance of the Teal application, the TealCell gets a pointer to the root of the Force on A Dipole simulation's scene graph. Consequently, this scene graph needs

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Client

Server

TealCell

~bg: BranchGroup = null
~fakeBG: BranchGroup = null
~wlandBG: BranchGroup = null
-baseURL: URL = null
-shapeType: String = null
-texturePath: String = null
-cellName: String = null
-state: String = null
-changeVar: boolean = false
~cellstuff: CellStuffStorage = CellStuffStorage.getInstance()
~wlstuff: WonderlandStuff = WonderlandStuff.getInstance()
~second: SecondTealCell
-tealmodel: TealModel
-activeState: boolean = false
-receiveMC: boolean = false
-button: int = 0
-start: int = 0
-logger: Logger = Logger.getLogger(TealCell.class.getName())

+TealCell(cellID: CellID, channelName: String, origin: Matrix4d)
+setup(setupData: CellSetup)
-setTealSetup(tealsetup: TealCellSetup)
-getTealSetup(): TealModel
-setupSceneGraphTSA()
+reconfigure(origin: Matrix4d, bounds: Bounds, setupData: CellSetup)
+setChannel(channel: ClientChannel)
+leftChannel(arg0: ClientChannel)
+receivedMessage(client: ClientChannel, session: SessionId, data: byte)

TealCellGLO

-tealModel: TealModel
-cellName: String = null
-state: String = null
-filename: String
-hostCellID: CellID

+TealCellGLO()
+TealCellGLO(bounds: Bounds, center: Matrix4d, hostCellID: CellID, tealModel: TealModel)
+updateTealState(state: String)
+getSetupData(): TealCellSetup
+setupCell(setupData: CellGLOSetup)
+reconfigureCell(setupData: CellGLOSetup)
+getCellGLOSetup(): CellGLOSetup
+getClientCellClassName(): String
+openChannel()
+receivedMessage(client: ClientSession, message: CellMessage)

Common

0..1

0..1

TealModel

-instanced: boolean = true
~bg: BranchGroup = null
-wlandBG: BranchGroup
~branchGroup: BranchGroup = null
~state: String = null
-countStart: int = 0
-sim: TeachSpinLV = null
~host: String = "localhost"
~port: int = 43970
~numLines: int = 2
~numCoils: int = 168
~debugLevel: int = -1
-logger: Logger = Logger.getLogger(TealModel.class.getName())

+TealModel(instanced: boolean)
+TealModel()
+getTeachSpinAppBranch(): BranchGroup
+startSocket()
+stopSocket()
+checkConnection(state: String)
+getBGfromTeal(): BranchGroup
+getStoppedTeal(): BranchGroup
+isInstanced(): boolean
+setInstanced(instanced: boolean)

TealCellSetup

-shapeType: String = null
-baseURL: String = null
-cellName: String = null
-state: String = null
-tealmodel: TealModel
-hostCellID: CellID
-modelFile: String
-checksum: String

+TealCellSetup()
+TealCellSetup(modelFile: String)
+TealCellSetup(hostCellID: CellID, tealmodel: TealModel, baseURL: String, modelFile: String, checksum: String)
+TealCellSetup(baseURL: String, modelFile: String, checksum: String)
+getModelFile(): String
+setModelFile(modelFile: String)
+getChecksum(): String
+setChecksum(checksum: String)
+compareChecksum(checksum: String): boolean
+getCellID(): CellID
#setCellID(cellID: CellID)
+getTealModel(): TealModel
+setTealModel(tealmodel: TealModel)
+getState(): String
+setState(state: String)
+getCellName(): String
+setCellName(cellName: String)
+getShapeType(): String
+setShapeType(shapeType: String)
+getBaseURL(): String
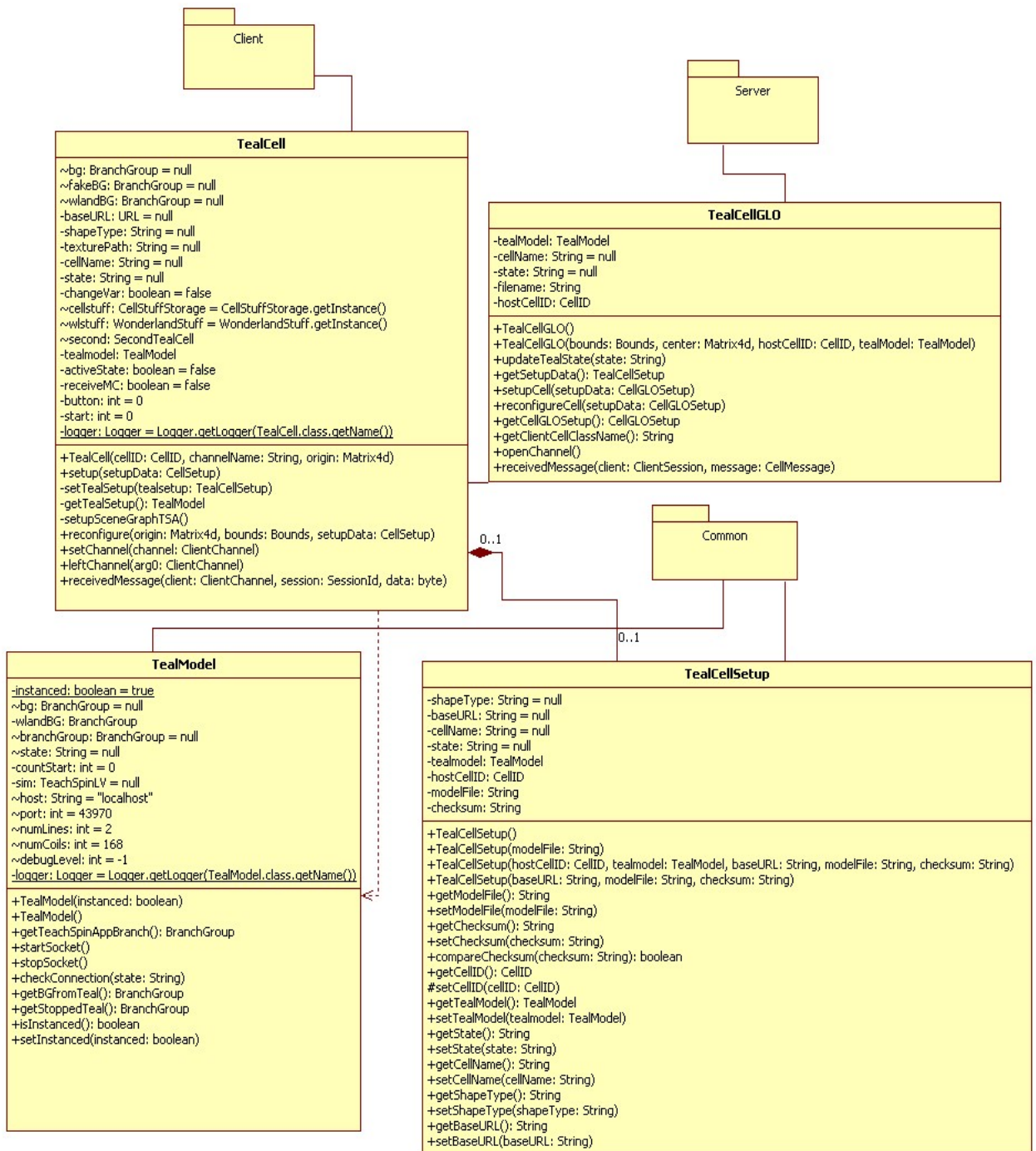+setBaseURL(baseURL: String)

Figure 5.9: Class diagram for the wonderland classes

to be integrated into the entire scene graph of Wonderland's universe. Since both, the TEAL's and Project Wonderland's scene graph are based on Java3D, the integration process is straight foward. Within TEAL's viewer a Java3D virtual universe was constructed, in order to attach the defined branch graph which represents all necessary visual objects for the simulation's model. In Project Wonderland, on the other hand, a Java3D virtual universe was also created, after the application has been started. Consequently, detaching the TEAL's sub graph from the *Locale* in TEAL's scene graph is necessary, to attach it in the Wonderland's scene graph afterwards. Finally, this entire sub graph is then said to be live[14] in Wonderland's world and the simulation model is visualized at the first time when the application is opened.

5.4.2   Changes to the Teal.render.viewer

As mentioned above, at that time the FOD application is instanced in Wonderland's *TealCell*, a Java3D universe is instanced within TEALsim. This universe, called *Viewerj3d* is based on a Teal interface TViewer, which defines a set of functionality including rendering properties and tasks, camera controls, visual effects, maintaining lists of rendered objects and handling mouse-based events. Additionally, the explicit rendering of the scene as a major functionality (Belcher et al., 2007). However, when integrating the simulation model of the FOD experiment within Project Wonderland, this geometry model is already part of the *virtual universe* created in the TEAL source package. To overcome this issue, a separate Viewer class was implemented in the Teal source package, wherein instead of creating a new *virtual universe*, an instance of Wonderland's *virtual universe* is provided. Henceforth, Wonderland's universe is responsible for rendering the FOD model. For this purpose, a class was created which serves as a database providing access to the Wonderland's universe, called *WonderlandStuff*, which is actually fed when the client is started and the setup processed. Figure 5.10 shows a class diagramm overviewing the concerned classes, *WonderlandViewer.java* and *WonderlandStuff.java* within the Teal source package.

5.4.3   Starting the Actual Experiment and Connected Simulation

Once the geometry model is integrated in Wonderland's virtual world, the actual experiment must be started, consequently to process the simulation. Therefore, the LabView User Interface is needed inside Wonderland, to allow users to connect to the actual FOD experiment and control

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[14]A branch graph and its nodes become 'live' when added to a *Locale* containing a ViewPlatform referenced by a View
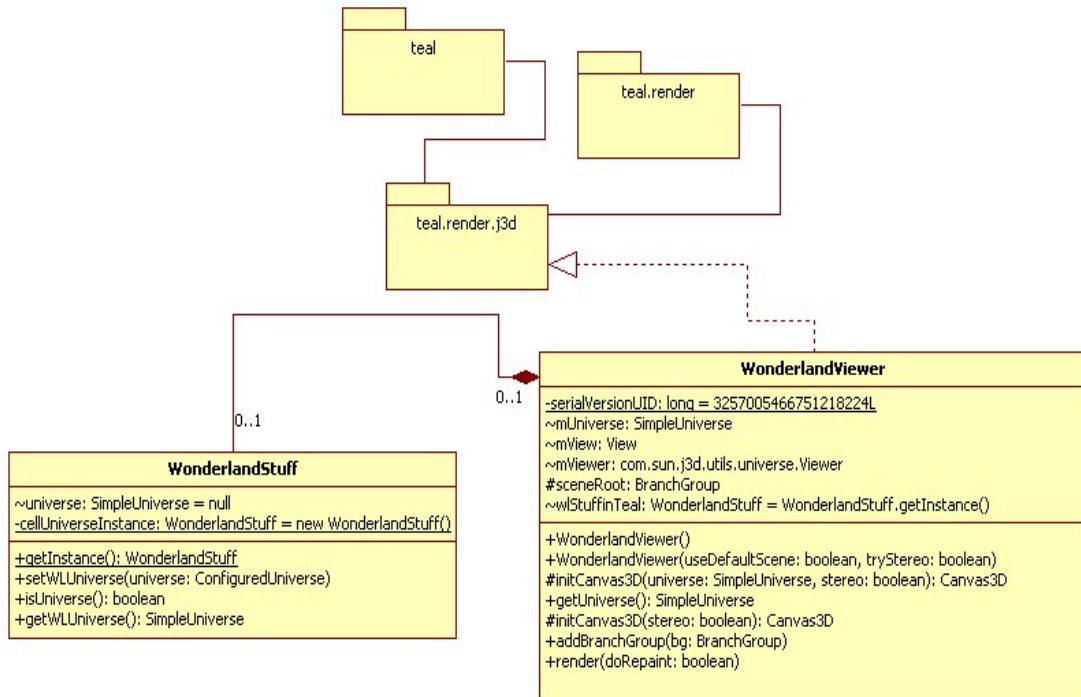
Figure 5.10: Class diagram for the WonderlandViewer in TEALsim

the appearance of the 3D simulation as they are used in the original application. Consequently, the integration of the LabView interface is discussed in the following section. The actual start of the FOD hardware is realized by means of a 3D Button provided and located next to the Labview visualization inside the virtual world.

5.4.3.1 LabView Interface Integration

The interactive LabVIEW application, launched by the remote iLab LabServer, provides access to the actual hardware executing the experiment and to a GUI front panel which controls the output and input parameters of the experiment. In order to start and control the actual experiment in world, the GUI front panel needs to be displayed. First of all, Wonderland's version 0.4 does not provide means to create three-dimensional user interfaces, therefore another solution was needed to integrate LabVIEW functionality in-world. For this purpose, Wonderland supports a graphical desktop sharing system, called Virtual Network Computing (VNC), that allows for controlling another computer's application remotely. Since the LabVIEW application is located on a separate workstation to provide unrestricted access within the iLab infrastructure, by means of VNC functionality the GUI front panel of the LabVIEW application can be visualized in-world. The graphical desktop sharing system consists of a VNC viewer as welll

as a VNC server. Whichever workstation the VNC server has been installed, a modifiable frame provides to allow the VNC viewer access to this particular workstation. In this context that means, a VNC viewer, integrated as a cell in Wonderland, can connect to a VNC server on the same or another computer. Hence, applications outside Wonderland's virtual world can be made accessible in-world by means of a displayed 2D application (Scheucher, Bailey, et al., 2009).

However, the VNC server is located on the same server where the LabVIEW front panel is running. Additionally, a new type of cell has been created that is used to realize the VNC viewer in-world. Consequently, user interaction is provided through keyboard or mouse events, which are transmitted from the computer on which the Wonderland client is running to the computer where the LabVIEW application is hosted. Multiple clients may connect to the VNC server at the same time but only one client can have access to the VNC viewer, in order to interact with the GUI front panel of the LabVIEW application. Therefore, avatars have the ability to launch and interact with the real experiment just as students using the original FOD application have, controlling the frequency and amplitude of the current.

5.4.3.2   Inter-Cell Communication

After the GUI front panel of the LabVIEW application is provided in-world, the real FOD apparatus is needed to start in order to simulate and interact with the virtual representation of the experiment in Wonderland. In the TEAL framework, this action is triggered by selecting a menu item within the LabVIEW application. But within Wonderland a solution was desired that clearly indicates this task. Therefore the learning space provides a 3D button next to the VNC application displaying the LabVIEW frontpanel. By pressing the button the actual FOD hardware is activated and the simulation is started.

Since Wonderland's version 0.4 is not designed to change the state of another cell type, an own inter-cell communication mechanism was implemented. Originally, the message mechanism provided in Wonderland 0.4 is designed in such a way that the Wonderland server-side cell automatically sends a message to each client-side cell to trigger the updating of the client's state. Hence, if an update of another special cell is desired, a communication channel between different cells is required. For this purpose, a so called inter-cell communication was needed to press the button and an action has to be triggered in the VNC viewer cell. Therefore the button, created as a new type of cell, implements an inter-cell communication mechanism. The following Figure 5.11 displays a class diagramm overviewing both the *Tealcell* and the *SecondTealCell*, which represents the button cell. Important operations for the inter-cell communication mechanism are tagged and the inter-cell communication process is explained subsequently.

The implemented communication process approaches an extra data binding using the Darkstar data manager. Therefore, the server-side Teal cell *TealCellGLO* makes a binding to a particu-

Figure 5.11: Class diagram inter-cell communication mechanism!

lar string value *this.cellName=TEAL*, defined in the XML-file within the WFS-directory, in the Darkstar database when it is created. Additionally the state "UNCONNECT" has been defined in the proper XML-file *tealcell-wlc.xml* (see Listing 5.1)) Then the button cell *SecondTeal-*

```
<?xml version="1.0" encoding="UTF-8"?>
<java version="1.6.0-dp" class="java.beans.XMLDecoder">
 <object class="org.jdesktop.lg3d.wonderland.darkstar.server.setup.BasicCellGLOSetup">
  <void property="cellGLOClassName">
   <string>org.jdesktop.lg3d.wonderland.tealsim.server.TealCellGLO</string>
  </void>
  <void property="cellSetup">
   <object class="org.jdesktop.lg3d.wonderland.tealsim.common.TealCellSetup">
    <void property="shapeType">
     <string>SPHERE</string>
    </void>
    <void property="cellName">
      <string>TEAL</string>
    </void>
    <void property="state">
      <string>UNCONNECT</string>
    </void>
   </object>
  </void>
  <void property="origin">
   <void index="0">
    <double>44.0</double>
   </void>
   <void index="1">
    <double>1.0</double>
   </void>
   <void index="2">
    <double>40.0</double>
   </void>
  </void>
 </object>
</java>
```

Listing 5.1: XML-formatted cell descriptor file *tealcell-wlc.xml* in the WFS-directory of lg3d-wonderland

CellGLO, when it receives a message from its client-side counterpart *SecondTealCell* after the button has been pressed, can search for this binding and manipulate another cell type directly. Therefore, the server-side code in *SecondTealCellGLO* then asks Darkstar's data manager for the server-side Teal cell *TealCellGLO* by means of the predefined value, and updates the state of the teal cell from "UNCONNECT" to "CONNECT". The server-side teal cell then sends a message to all of its clients requesting that the client's simulation model "CONNECT" to the

LabVIEW application (VNC viewer) now, each simulation opens a data socket to the LabVIEW application.

5.4.3.3 Processing the Simulation Changes

The simulation engine thread of the TEALsim simulation gets data via the socket channel and updates simulation objects to reflect these new values. Furthermore, the viewer's rendering engine is informed of any visual changes to the simulation. Consequently, to reflect the effect of the user's input on the simulation in Wonderland, the world's scene graph must be updated. After the socket is started initially, as explained above, the actual branch graph of the rendering engine is connected again and appended to the world's scene graph. In order to update the client itself and all other client's, thus, to reflect the user input in the simulation, the TealCell sends a message to the TealCellGLO. This server side implementation has the important task of passing the message to all clients. When the client-side representation of the start button is initially pushed, the server cell must start the connection on all other client cells. Conversely, if the button is pressed again, clients have to be informed to stop the socket in order to end the simulation's connection. For visualizing purposes, the button is displayed red when a user pushed for starting the simulation, and green after the user pushed the button again to stop the simulation.

5.4.4 Additional Live Streaming and Tools for Collaboration

Wonderland's toolkit also provides real-time videostreaming by means of a webcam. Since the original FOD application is also supported by a video camera to observe the changes of the FOD apparatus during a remote experimentation, this feature makes it possible to provide the same functionality in the Project Wonderland's prototype as the original application. Realized in a separate cell, students are allowed for live-streaming the actions of the real hardware (Scheucher, Bailey, et al., 2009). This cell facilitates a video screen in world where avatars are able to see the working experiment via the nework camera. The specified camera in the proper .xml-file of the WFS-directory is called *AXIS212PTZCamera*, but it was possible to add support for other Axis network camera easily, like the Axis 211 which is used by the FOD experiment observation. The video is streamed to all clients and played concurrently in the browser of all avatars in the same world, as long as the actual experiment is still connected. Additionally, control buttons allow the avatars to terminate and control the video.

Consequently, full functionality of the actual FOD experiment application is provided in the prototyped virtual world. Due to the support of text chat as well as audio chat, student-to-student, student-to-educator or educator-to-educator communication is established, which turned out to

be important for discourse-based collaborative learning (Scheucher, Belcher, Bailey, Dos Santos, & Gütl, 2009). Wonderland also incorporates collaboration tools to support higher level representation and participant co-awareness for coordinated learning activities. Since a chalkboard, which is used in most classrooms, is definitely one of the most basic forms of instructional media and best used for emphasizing essential information and developing ideas as the class progresses, Wonderland facilitates such a subject in the virtual world. For this purposes, a shared electronic whiteboard has been realized in a new type of cell and takes place within this prototyped learning environment.

5.5 Summary

Within this Chapter implementation details are outlined as key tasks for the realisation of the prototype CVLE supporting remote accessible experimentation facilitated by a three-dimensional visualization of electromagnetic phenomena. Before, the used Java 3D API is introduced and essential information is given, regarding high-level constructs to build virtual universes and the usage of Java3D branchgraph's. Subsequently, configuration steps for building Wonderland's 0.4 either from source or due to a web start client. Generally, configuring a web start client was important because at some point the application had to be tested running on several desktops, in order to conduct a planned initial study of the application's prototype. The interface critical issues between Project Wonderland and the TEAL simulation system are discussed as well as the integration tasks within Wonderland's cell architecture are explained. It should be mentioned that the task of changing the TEAL architecture in order to merge the TEAL relevant parts into a Wonderland cell required much more time and effort than expected. Hence, the connection and start of TEAL's simulation engine within wonderland are described in detail. Finally, provided collaboration and communication tools within Wonderland's virtual world are presented and linked for their usage within the learning environment. As a consequence, the following chapter outlines the mentioned user study to assess the prototype's applicability in terms of collaboration and usability as well as learning values. In this context, a glimpse of the prototype-based outcome in Project Wonderland is given at the beginning.

Chapter 6

User Study

Within this chapter an user study is outlined which is processed in order to assess the prototype's applicability in terms of collaboration and usability as well as learning values. In this context, a glimpse of the prototype-based outcome in Project Wonderland is given first, followed by evaluation details concerning exeperiment setup, methodology and findings. It is worth noting that this section is partly presented in a full conference paper puplished during the thesis work (Scheucher, Belcher, et al., 2009).Finally short term as well as long term future work is discussed and conclusions are drawn.

6.1   A Glimpse of the CVLE

In this section a glimpse of the prototyped CVLE, realized in Project Wonderland, is presented in order to get an idea of how the learning environment looks like. Figure 6.1 is showing avatars acting within the environment. Consequently, the LabVIEW GUI front panel, the real-time video streaming of the actual FOD apparatus as well as the simulated virtual representation of the created electromagnetic field lines is displayed. The green button, next to the LabVIEW front panel is visualizing that the simulation is not started yet. Each participant is allowed to start the real FOD apparatus by pressing the provided Button. After this action the Button has changed color for red, as shown in Figure 6.2. Thus, the started simulation of the generated electromagnetic fields can be manipulated through changing input parameters at the LabVIEW front panel.

In this context users get the ability to access to the visualized LabVIEW application when pressing "Shift" on the keyboard together with a left mouse click within the border of the visualized window. The border will turn from red to green after the user is in control. If the user wants to

get free of control, the user has to press "Shift" plus "F12" on the keyboard. Figure 6.3 shows two participants discussing their planned input parameters. However, only one participant can have access to the LabVIEW application at a time.

Figure 6.1: Prototyped CVLE in Project Wonderland - Overview of components.

Furthermore, a real-time video streaming of the apparatus behavior is realized through a webcam streaming, as shown in Figure 6.4. This allows users to observe the moving magnet and compare with the simulated visual representation of the generated electromagnetic field lines, visualized in Figure 6.5.

Finally, a whiteboard application is provided additionally, to allow users emphasizing essential informations or developed ideas. This tool might be very useful when audio or text-chat is not effectual and drawing might be the only way to explain abstract concepts. Figure 6.6 displays the provided whiteboard application in the prototype.

Following Evaluation details and outcomes outlined in the subsequent sections are partly presented in a full conference paper published during the thesis work (Scheucher, Belcher, et al., 2009).
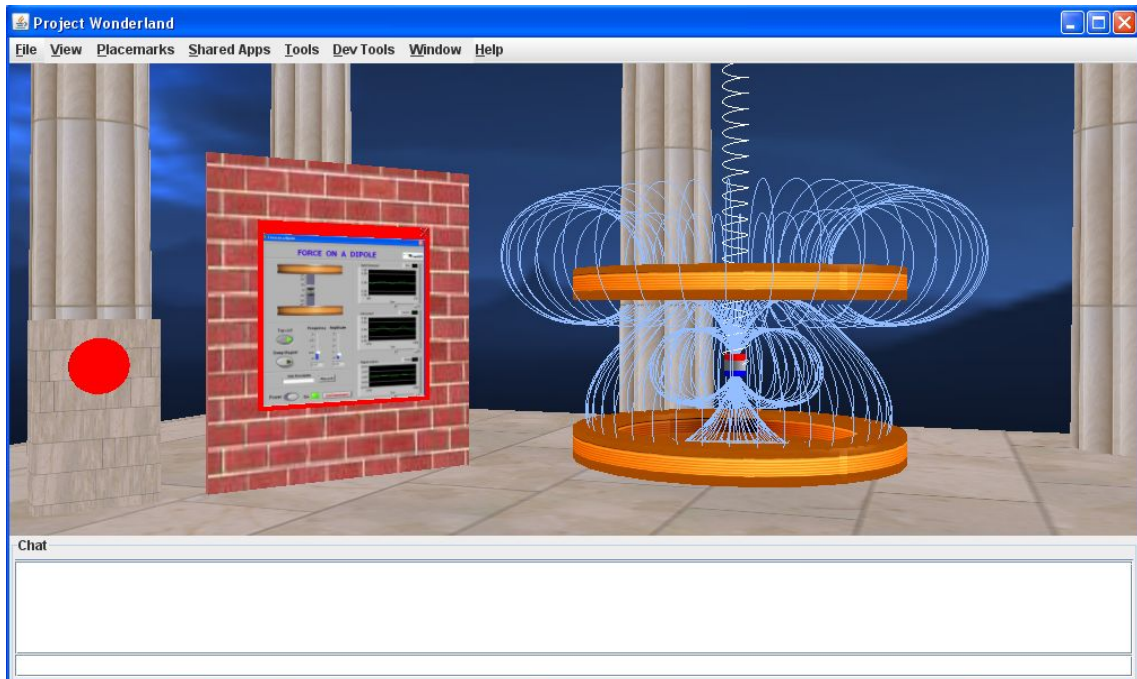
Figure 6.2: Environment visualizing the red button signalizing the real hardware is started.
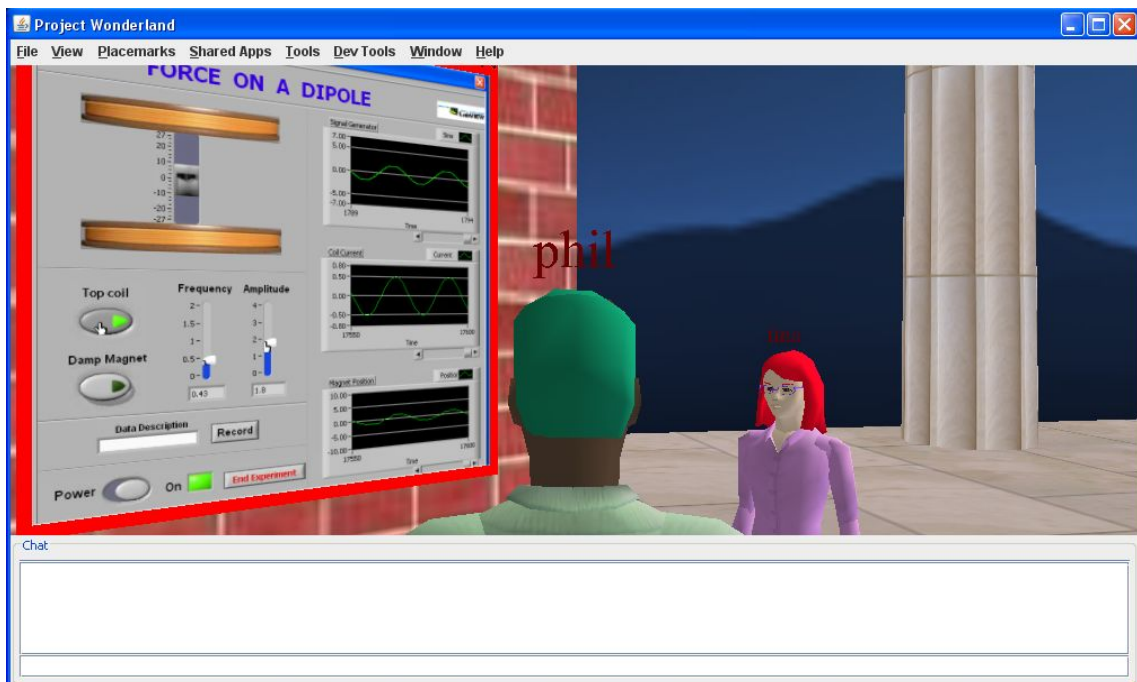

Figure 6.3: Close up view of the LabVIEW application and avatars discussing their intentions.
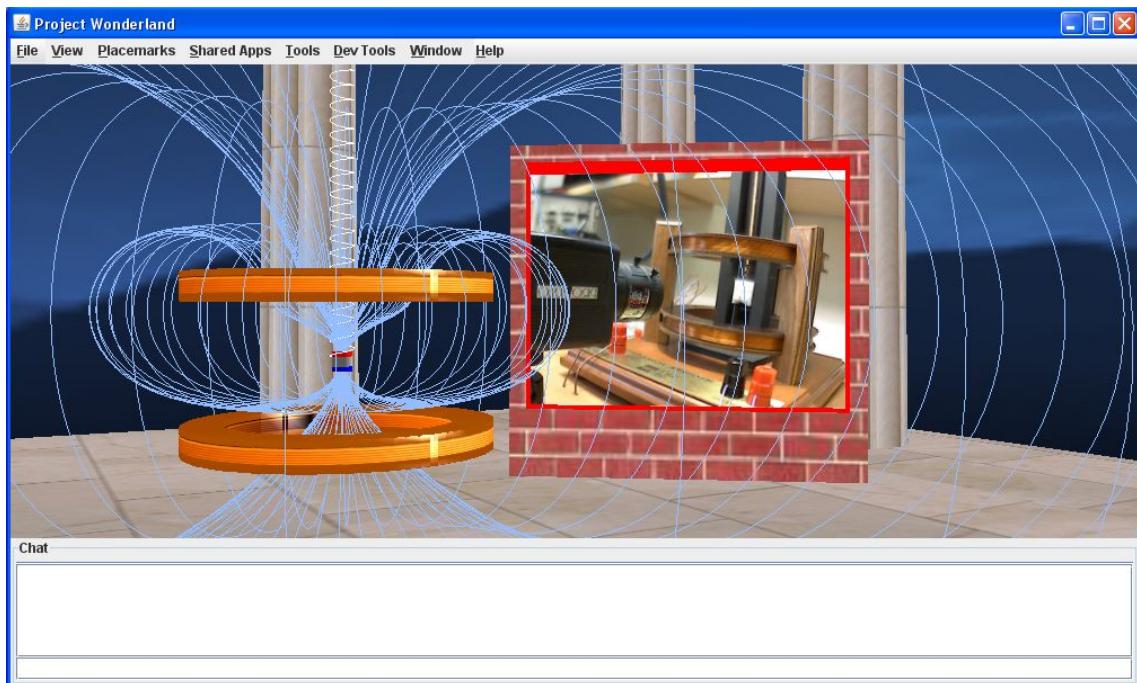
Figure 6.4: Webcam window within the environment.

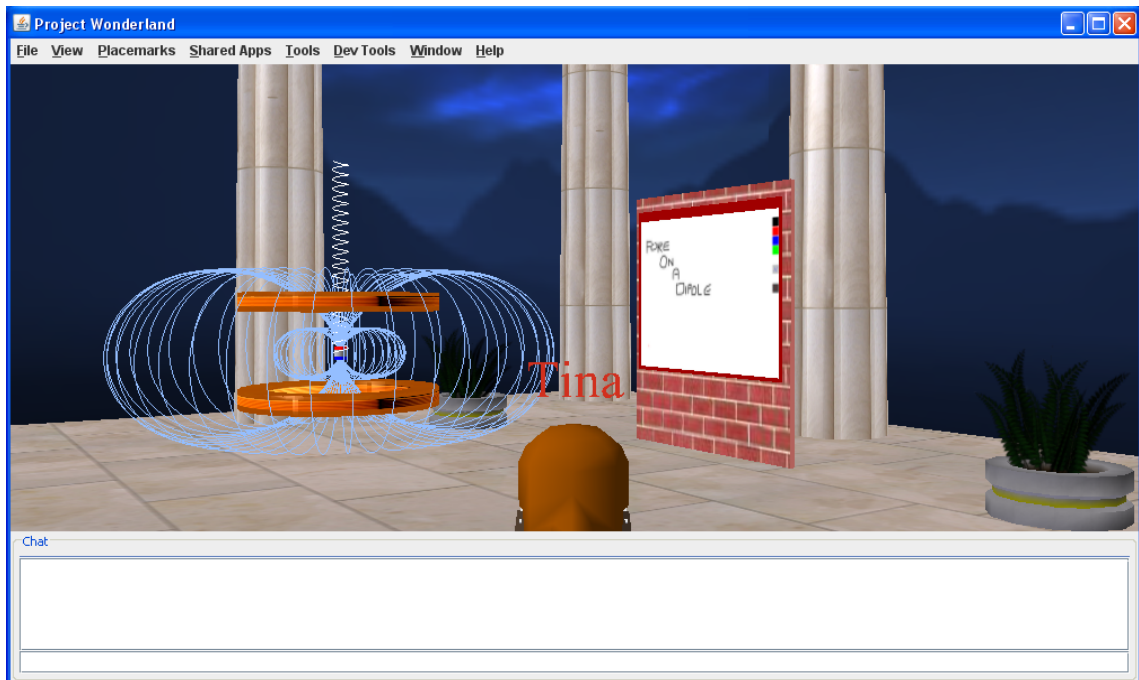**Figure 6.5:** Comparing real and simulated behavior.

Figure 6.6: Provided whiteboard in Wonderland.

6.2 Motivation

Due to the high-potential in 3D CLE for learning complex science at a distance, as outlined in chapter 3.3, an initial evaluation was conducted to discover whether teaching and learning abstract electromagnetic concepts using desktop VR technology combined with avatar-based interaction is supportive. Based on the development of the prototype CVLE described previously, the aim of this evaluation was to determine the appropriateness by means of a laboratory learning scenario assessing the collaborative value in such environments as well as the desktop-immersive VR's affordances as a means to facilitate the mastery of complex, abstract concepts. From the usability design perspective, the user-friendliness of the environment and which modifications concering the CVLE would be meaningful, are assessment criteria as well. Thus, to uncover usability problems concerning the communication and collaborative functionalities as well as the basic functionality of the provided laboratory work within the learning environment:

- Are the communication and collaboration functionalities satisfying? Can the prototype develop collaborative student' skills in the same way or even better as usual non-immersive laboratory environments?

- Does the hybrid approach of virtual and remote laboratory environments within a 3D space bring the learner to a higher achievement level?

Therefore, suggestions for improvements are objectives, and would be a considerable contribution for the future development of this prototype implementation. Regarding the evaluation process, an evaluation methodology is needed in order to assess the prototyped CVLE. In this context, an evaluation workflow is proposed in the next section, followed for evaluating learning and usability values within the prototyped CVLE.

6.3 Experiment Setup and Methodology

A total of 6 subjects had participated in this study including both female and male MIT undergraduate students between the ages of 18 to 24. Precondition for participating in this study was that the participants already had attended the 8.02 electricity & magnetism course. Thus, the comparison conducting experiments when being immersed in a 3D environment is more effective in understanding physics phenomena than in traditional classroom settings, was feasible. Six students fullfilled the preconditions and had participated in the survey. Consequently, the participants were grouped in sets of three. The evaluation methodology was conducted one per

group and took place at CECI/MIT providing separate rooms, one subject per room. Each subject was provided with a notebook using version 3.5.2 of the Mozilla Firefox browser[1] running either Windows XP or Mac OS X 10.5.8. (Scheucher, Belcher, et al., 2009).

From the content perspective, the evaluation environment as well as the evaluation methodology was the same for both groups. The amount of time for each process step of the evaluation in minutes, quoted in the following, is constituted in parenthesis. At the beginning, subjects needed to sign a document in order to give informed consent before they participated in the survey. Additionally, subjects are provided with a protocol, decscribing important information about the evaluation procedure(10). Hence, the workflow of the evaluation process was conducted as follows:

- Introduction of the real 'Force on a Dipole' experiment (20), located in a separate room.

- Answering a web-based pre-questionnaire (15),

- Familiarization time and Co-presence test (10),

- Learning scenario-based session (35), and

- Answering a web-based post-questionnaire (15).

After finishing the introduction to the experiment, the subjects were directed to their workplace. Before participating in the evaluation, subjects were asked to complete a pre-questionnaire. Therefore, the web-browser on each laptop opened the predefined address *http://web.mit.edu/viz/* to the questionnaire, which consisted of 22 multiple choice and factual short answer items and two open-ended short answer items. From the content perspective, the questionnaire regards students familiarity with distance collaboration and 3D virtual environments in general and as a learning environment as well as their level of knowledge concerning the fields of electromagnetism, in particular the attendance of the 8.02 E&M course. After the subjects have completed the pre-questionnaire they were requested to log-in to Project Wonderland. Therefore, the latest version of the Java web start client of Project Wonderland was launched by simply clicking on the link *http://grisu.mit.edu:8080/Wonderland/* in an provided web browser. Thus, the client application is automatically downloaded and the subject was able to enter the learning environment. At the beginning, the subject was given a few minutes to become familiar with the 3D space by moving around and learning how to navigate through the environment, together with the other participants, as well as to test out the communication within Project Wonderland. After 10 minutes of exploring and familiarizing the subjects were

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[1]`http://www.mozilla.com/en`

requested to take part of a learning scenario-based session that is held as an online tutorial taught by MIT Physics Professor John W. Belcher. He is the creator of the TEAL project (Belcher, 2001).

Following the learning session, the participants were asked to complete a post-questionnaire at the very end, that is designed in order to assess both usability and learning issues. The post-questionnaire consisted of seven multiple choice and factual short answer items and five open-ended short answer problems. Both pre- and post-questionnaires are electronic based. In this context ethics clearance was reviewed and approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES)[2] for research involving human subjects that is performed under the auspices of MIT. The Information Statement and Consent Form provided to participants for the study can be found in Appendix X. The voluntary nature of participation was stressed to participants in the written information statements and consent forms. Additionally, participants were informed that they were free to withdraw from the study at any time.

In the following, each component of the evaluation process is discussed in detail.

6.4 Pre-Analysis

The pre-questionnaire confirms that all subjects fulfill the preconditions as well as 66.7 % of the subjects have used the FOD application in its previous form. This certainty allows for a meaningful comparison with the current use of Wonderland's application. Figure 6.7 outlines the first results regarding the student's familiarity with electromagnetism and 3D simulations.

The majority of the participants responded that they had never used an e-learning framework in the past (4 out of 6). After inquiring more in detail, two of the subjects did not even know what an e-learning framework was. The others had known about it and found that tools like unit outline, discussion board and collaboration with other students were useful in their course of study. One of the subjects mentioned, when asking if there were any features lacking in the used e-learning framework, that audio or video conferencing would be helpful.

In addition to the previous experience questionnaire, the subjects were asked regarding to their learning preferences. Results indicated that the subjects prefer to learn individually as well as in groups of two or more. In the event that a problem occurred in understanding a particular topic, the majority of the subjects preferred to ask peers for help (4 out of 6) during studying at home. Having asked them which means of communication they prefer, most of the participants (5 out of 6) answered "peer to peer". Regarding the use of a web-based medium for the communication

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[2]http://web.mit.edu/committees/couhes

Familiarity with electromagnetism & 3D Simulations
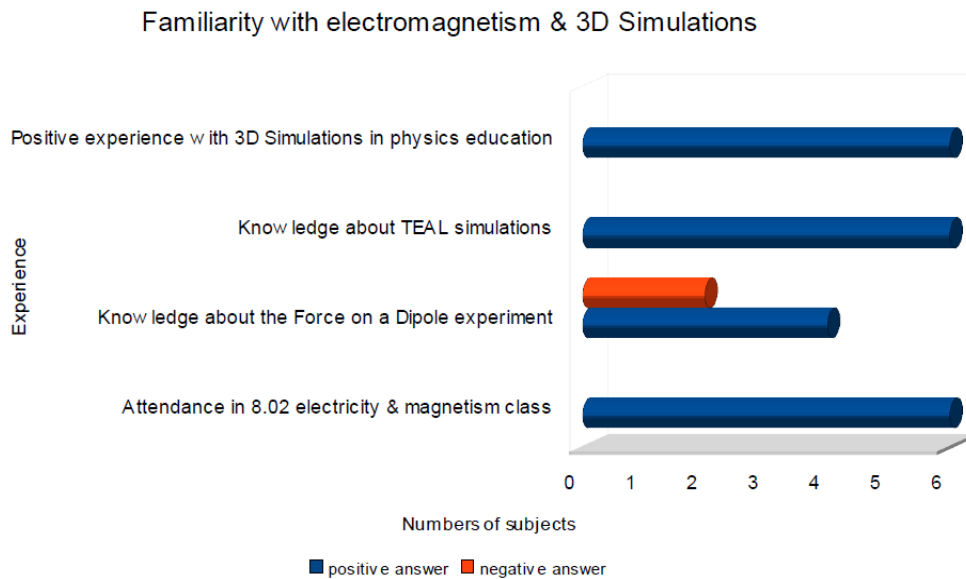
Figure 6.7: Familiarity with electromagnetism and 3D simulations (Scheucher, Belcher, et al., 2009).

with peers in terms of learning purposes (4 out of 6) answered in the negative. Those subjects which answered in the affirmative (2 out of 6) named the voice over IP application *Skype* and the high-speed Internet provider *Comcast* as web-based communication tools.

In terms of familiarity with 3D virtual environments like Project Wonderland or Second Life, the half of the subjects (3 out of 6) had kown about these kinds of environments previously. However, the majority of the subjects (4 out of 6) had never used those environments before. Consequently, through this questionnaire conclusions can be drawn that the majority of the participants are not very familiar with 3D virtual environments as well as conventional e-learning frameworks. Furthermore, web-based communication tools are not conversantly on the majority. Thus, results indicated that most of the participants will be exposed to learning environments for their first time.

6.5 Class Scenario and Observations

Following the completed pre-questionnaire, subjects entered the learning environment developed in Project Wonderland and had a chance to become familiar with the 3D space by moving around and learning how to navigate through the environment. Within this familiarization session subjects explored the environment already in the group. Thus, subjects were asked to test out communication tools as the provided chat window, audio chat as well as collaboration tools

as the provided whiteboard.

After 10 minutes of experimenting, Professor Belcher took over and began the learning session with an explanation of what the student had seen in Project Wonderland:

1. First he explained the provided real-time video streaming of the actual experiment's apparatus

2. Then he explained the control panel of the LabVIEW application for the real experiment, and how to get access to it and how to get free of it. Since, when being in control of the experiment the user cannot move in the world.

3. Thus, Professor Belcher started the experiment and showed how he got access to the LabVIEW front panel window afterwards. All participants were requested to watch him adjusting the amplitude and the frequency. Meanwhile he explained the top curve in the front panel, representing voltage in the coil, the second panel current in the coil, and the third panel the vertical position of the magnet, from pattern recognition.

4. Afterwards he explained the simulated visualization for the experiment: how to turn it off and on, and what it represents.

5. Then, Professor Belcher stopped the experiments setting and and put the LabVIEW parameters back to default values.

Consequently, the tutorial started and the professor wanted each student, one by one, to turn the experiment back on and answer them following phenomena related questions by running the experiment:

- When the current is in the right handed positive in the upper coil at maximum, is the magnet below its equilibrium position or above its equilibrium position?

- Can you come to an understanding among yourselves from the basics of what you know about current loops as little magnets as to why your answer above is the way it is?

- Can you come to an understanding from the field configuration shown in the visualization as to why the magnet moves up and down as the current in the top coil changes?

Meanwhile the professor was working with one student, the other students listened to the conversation between professor and student. During this scenario, students were watching the provided webcam to see how the magnet was moving in real time while the other student was interacting with the front panel. Some other students drew on or chatted via the whiteboard,

which conveyed that students like this kind of tool. The gravity aspect turned out to be a powerful tool as well, when observing subjects flying above the visualization to examine the electromagnetic field lines in detail. Other than 2D applications, users are allowed to explore the 3D space analyzing TEAL simulations from different locations in the room.

6.6 Findings of Usability and Learning Experience

From the usability point of view, one goal of the post-questionnaire was to uncover usability problems, regarding the experience and basic functionality within the developed environment. As well, usability problems in terms of collaborative and communication functionalities of this prototype are aimed to uncover. Basically, results indicate a positive initial reaction to the general feel of the environment as outlined in Table 6.1, showing a summary of factual short answer items.

Table 6.1: Factual short answer items regarding User Experience in WL

Experience in Project Wonderland	Strongly Disagree	Disagree	Agree	Strongly Agree
My experience in Project Wonderland was positive.			66.7%	33.3%
I think Project Wonderland can improve distance learning.			33.3%	66.7%
The feeling of being there with other students and having the ability to communicate with them as in the real world was pleasant.			33.3%	66.7%

Functionality such as the ability to change the viewpoint and the interaction with 3D windows gathered positive reviews, all participants answered in the affirmative when asking them about the simpleness of using the environment. Nevertheless, opinions are divided regarding the ease of controlling and interacting with the LabVIEW application. Some students mastered the controls without any noticeable delays, while others mentioned a slow interaction. This perception may depend upon the VNC application, since the LabVIEW application is not controlled directly the interaction due to a VNC viewer may suffer from failing performance, not always but sometimes.

However, when asking the participants about the main advantages and disadvantages they experienced with using this 3D space as a collaborative environment, all participants indicated that the feeling of being there with other students and having the ability to communicate with them in the real world was a pleasant experience. The students enjoyed not being in a classroom, though, to be able to talk to other peers or even have a professor in the environment explaining some abstract concepts. Having asked them which communication tool they preferred to use, besides whiteboard and text chat as popular tools, all participants favour on using voice over IP. In this context, a participant commented this way: *"I enjoyed the sound because talking is one of the best ways for me to learn through others."*. Nevertheless, half of the participants showed some hesitation about working within this kind of virtual environment. Although subject's are conscious of the high-potential of exploring 3D simulations of physics phenomena in such an environment, believing that working in real laboratories cannot be replaced, is commented in this way:

- *„ It allows for a great experience when distance is a problem. While I don't think there will ever be a perfect substitute for real-life interaction, I think this is a vast improvement over phone calls, video chats, and simple interactive whiteboards."*

- *„Sometimes it's just nice to touch stuff and set up the experiment yourself. Hands on is really fun, and students will miss out on that part of the experiment."*

In terms of the important parts within the environment, having the FOD application components as 3D objects within a shared environment, consequently, being there with other students and having the ability to communicate with them as in the real world, was a pleasant feeling for all participants. Moreover, getting detailed information from the professor while the 3D simulation was running was confirmed as a useful experience in the majority (5 out of 6). As well, most of the participants (5 out of 6) perceived the interactiveness within the 3D space in a much more interesting and easier way to learn compared to traditional lecture styles. Table 6.2 outlines comments in terms of subjects perception concerning the prototype as a learning environment.

Table 6.2: Open-ended short answer items regarding the learning process

Question	Answers(selection)
Aspects that you enjoyed and impeded your learning are ..	„..the much quicker and more interactivness than a traditional experiment. No time was wasted setting up the experiment, and you are effectively able to use and see the graphs, the physical experiment, and visualizations. Also, the antigravity was a lot of fun." „..that all information is in one place: graphs, video, simulations." "I enjoyed how each user had control, and it was not dominated by one user, like some real-life labs." „..that its easier to ask for clarification of miscommunications or misunderstandings, being able to see the same data at the same time and have it explained." „I really appreciated the explanation for the magnet that Prof. Belcher provided. I never thought that you could treat the coil as another magnet." „..that it kept my interest and helped me form a better mental image of the real-time dynamics of electromagnetism."

Having asked the subjects what they would improve within the learning environment, some usability problems were uncovered. Most of the participants (5 out of 6) were not able to make a realistic comparison using the using the camera view of the actual experiment. Subjects commented in this way: *„I really enjoyed the interaction but would like it if the experiment were arranged in a more compact view, so I could easily read all the details at once without having to move my avatar around to gain a better perspective."* or *„ I wish the informational items could have been arranged so that users could see all of them at once, close up. "* called attention and provided an indication of a new arrangement of the environment setting. Additionally, subjects suggested the augmentation of communication through gestures and facial experession for avatars, commented in this way: *„Provide a more efficient means of physical communication (like gestures). Sometimes I wished I could point at an object, but instead I had to verbally identify it, which was painstaking."* or *"Sometimes hard to know what everyone is doing/looking at unless they tell you or their avatar is clearly looking at one thing"*.

6.7   Conclusions and Findings

This section outlined the evaluation that had been conducted in order to assess the exploitation of the prototyped CVLE in Project Wonderland for supporting a computer supported collaborative laboratory scenario. Therefore, an evaluation methodology has been applied, which was organized by a pre-questionnaire and a post-questionnaire in order to evaluate usability and learning issues during the processed tutorial session. Findings of this evaluation process indicate that the subjects generally enjoyed being in the CVLE. Subjects comments on the CVLE as a learning environment to help to understand the concept of electromagnetism pointed out an enhancement of learners intuition. In this context, the fact that Professor Belcher worked together with the students turned out to be a useful experience for them. Having asked the professor, after the finished tutorial session, about his general feeling and perception concerning the CVLE as learning and laboratory environment, he expressed enthusiasm and mentioned that he really enjoyed being there with the students conducting together the experiment as well as being immersed at the same time. Nevertheless, Professor Belcher mentioned that he had the feeling that the environment was larger than necessary, because it was hard for him to get the students together for an explanation.

Furthermore the post-questionnaire results in terms of avatar appearance and behaviour suggest porting from version 0.4 to the newer version 0.5, since this version is based upon a new and more modern avatar system. Additionally, independent from the platform version, modifications within the environment are needed. Besides the uncovered problem of rearranging the environment setting, participants made suggestions for additional items which could enhance the learning process. For instance, arrows placed on the field lines may clarify the direction of the magnetic field, commented in this way: *„I really enjoyed seeing the experiment through the eyes of learning (with the field lines, and poles, etc) if more of these types of details (the type you would find in a physics textbook diagram) could be applied to the 3d simulation in real time, I think it would be a tremendous benefit to student abilities in comprehension, convention, and critical thinking.".* Following this idea, a provided screenshot displaying what the students are working on during the simulation in order to share this work with other participants in Project Wonderland may be an improvement as well and enhance the effectiveness of the prototyped learning environment.

Finally, due to the development of the collaborative learning environment in Project Wonderland the goal of providing multiple communication channels for laboratory experimentation in a computer generated shared space has got a step closer. Although, the negative aspects which were uncovered, the CVLE was considered by most students both inspiring and entertaining. Thus, students comments and answers indicate that the interaction in 3D enriches the

previous FOD application providing 2D windows, making it more interesting and intuitive. By implementing subjects suggestions, the learning process of complex science systems could be revitalized through the use of this kind of technology.

Chapter 7

Lessons Learned

The insights and experiences gained during the research and development on the theoretical and practical parts of this thesis investigates how desktop-immersive environments can facilitate learning of complex science. Through the practical part, the author has been tried to identify, use, and evaluate desktop-immersive VR affordances as a means to facilitate the mastery of complex, abstract concepts in physics education. In doing so, the author has determined collaboration as a major key factor for shaping the learning process and learning outcomes for laboratory experimentation at a distance. Furthermore, the work with physicians, computer scientists and 3D computergraphics specialists at the Center for Educational Computing Initiatives (CECI) at the Massachusettes Institute of Technology (MIT) offered important and interesting insights into various areas of virtual technologies supporting laboratory work and learning of physics concepts using the third dimension. The integration into a professional team, including the attendance at team meetings or seminars, has been another valuable experience.

Moreover, the close contact to the Sun's developer team of the used 3D platform Project Wonderland has given important inputs for the development of the implemented CVLE prototype. Firstly, when the practical part of the thesis started, Wonderland's new version 0.5 was issued as a series of monthly developer releases. Due to detailed discussions with the developer team, the author was encouraged to use the more stable and functional version 0.4 of Project Wonderland because of the defined timeline. However, despite the partial lack of documentation on building the 3D environment in Project Wonderland 0.4, the author was able to make good progress due to continuous support on the part of Wonderland's developer team as well as CECI team members. Thus, starting work on version 0.4 was the right decision, because the development of the prototype VLE in Wonderland was able to be accomplished within this short time period.

Most of the problems that were experienced during development had been to find a way to con-

nect the different applied projects. It was a huge effort to engage in both TEALsim and Wonderland's architecture in order to integrate the proper TEAL simulation in Wonderland's virtual world. Therefore several important changes within parts of the TEAL infrastructure were necessary for running the desired experiment application within Wonderland's virtual world. Moreover, Wonderland's virtual universe was examined carefully to integrate visual representation of the electromagnetic field lines in order to run the simulation. Most of the development time was invested in this integration process as well as work for positioning the geometry model into the right position and size. Because the defined geometry settings within the TEAL framework highly differ from Wonderland's virtual universe.

Additionally, since Wonderland 0.4 is based on the Java3D rendering engine, which is primarily not developed for managing such a hugh amount of graphics content, the application's prototype is adversely affected by performance issues. It should be mentioned that this fact strongly depends on a stable internet connection but also on the amount of avatars being in world at the same time. Which is another issue caused by Java3D. Therefore the Wonderland developer's team had been started to release the newer version 0.5, based on JMonkeyEngine (JME). JME is a full featured 3D game engine which is already in use by professional game companies. Consequently, JME should cure the limitations imposed on Wonderland by the visual and design constraints of Java3D as well provide higher performance and graphics capabilities.

As far as this thesis is concerned, intensive research in the fields of laboratory environments and collaborative desktop-immersive technologies have delivered important insights into distance education using 3D web-based learning environments. Thus, the author gained enhanced knowledge in using open source frameworks using Java and Java3D. Furthermore, the author received an opportunity to submit selected results of this thesis to international conferences.

Chapter 8

Conclusion and Outlook

A three-dimensional web-based learning approach aiming to facilitate collaborative laboratory work in the context of complex science was presented in this thesis. The approach is based on a desktop-immersive technology providing remote experimentation and three-dimensional visualizations to enhance students understanding of complex systems in the fields of science. Motivated by the real potential for allowing widespread use of distant laboratories through reducing the number of expensive physical laboratories and in allowing students remote access to real laboratory equipment at any time. Additionally, computer-generated visualizations of natural phenomena and simulating their behavior enable students to compare theoretical with experimental results, since they embody learning by doing. Thus, by providing multiple communication channels and collaborative tools, students are encouraged in the learning process additionally.

From a constructivist perspective, collaborative learning can be viewed as one of the pedagogical methods that can stimulate students to discuss complex problems from different perspectives. Since the theoretical analysis of the thesis has shown that most laboratory environments do not provide sufficient means of collaboration, three-dimensional environments constitute a meaningful way to support collaboration when attending laboratory sessions is not possible because of the distance. This kind of three-dimensional environment provide multi-user support, therefore, users are represented as avatars and allowed for interaction within the 3D space by means of keyboard and desktop-mouse. Consequently, users can interact within the virtual environment similar to what is happening in the real world.

In summary, desktop-immersive virtual environments have the potential to integrate laboratory work and on-line learners seamlessly in a shared learning experience, regardless of their locations in the real world. These environments can do this in a way as they deliver a laboratory

experimentation session while communicating in real time remotely to other peers who are represented by avatars. Therefore CVLE improves the potential effect of virtual laboratories by allowing collaboration between students and teachers and between students themselves. Additionally gloabal collaboration between students is enabled by forming learning teams across continents in order to solve problems. Besides providing a technical solution to realize a CVLE, research in this direction turned out that it is crucial to establish a new learning culture with horizontal communication structures. In order to contribute to the studies promoting online collaboration in physics education, the thesis investigated and documented the needs for more effective communication and collaborative tools. Active participation and meaningful discussion are the collaborative values which are supported by means of the prototyped CVLE.

8.1   Suggestions for Future Work

As discussed in the previous chapters, findings has outlined suggestions for improvements within the prototypical CVLE. In the following those findings are summarized again as suggestions for short-term future work:

- Rearranging the environment setting

- Integrate additional items, for instance arrows, to enhance the learning process

- Shared screenshots displaying laboratory activities of the students in Wonderland's virtual world

- Improvement of avatar appearance and behaviour

Concerning avatars in the prototype implementation of the thesis, in Project Wonderland's version 0.4, meanings are sometimes lost due to lack of supporting cues such as body language and gestures, including handshakes and nodes. This fact was confirmed by evaluation results of the initial study which was processed within the scope of the thesis and outlined in Chapter 6. However, 3D avatars can help to express emotions and provide a better environment for collaboration activities. Since Project Wonderland's newer version 0.5 has become stable and functional during the last couple of months, a more modern state-of-the-art avatar system is provided including new bone models and advanced skinning features. Thus, porting from 0.4 to 0.5 is suggested in order to achieve a richer 3D experience meaning to bring the avatars appearance to a higher level.

Not only the avatar issue is reason alone for changing to Wonderland 0.5, also moving from the Java3D rendering engine to the JMonkeyEngine (JME). JME is a full featured 3D game engine

providing higher performance as well as better graphics capabilities in version 0.5. Therefore, JME should cure the limitations imposed on version 0.4 by the visual and design constraints of Java3D. In this context, another suggestion can be made for future development concerning the provided LabVIEW interface within the prototype CVLE. Since the only way to establish interaction to the LabVIEW front panel in 0.4 was via VNC functionality, version 0.5 provides embedded swing functionality for general user interface construction. With this feature, the ability to create a personal swing-based user interface to interact with the experiment is facilitated, instead of using a VNC-viewer showing the LabVIEW application. Thus, since evaluation results has indicated some time delays during the processed learning session, a more accurate time-invariant interaction may be achieved.

Furthermore, observations during prototyping has determined some performance issues when running TEAL simulations and having many avatars present at the same time in Project Wonderland. Regarding the game-based engine of JME, moving to version 0.5 may overcome the platform-based issues as well and establish a more robust CVLE.

In the long-term, the next steps in the future will be to first extend the learning space by populating the virtual learning environment with more TEAL simulations. Hence, provide students with a compelling experience when conducting multiple simulated experiments. Furthermore, the idea of direct interaction with the simulated electromagnetic field lines is suggested. In other words, pick and move TEAL simulation elements as well as activate sensors in order to see how those changes affect simulation behavior. Consequently, changes would be updated in real-time. As a consequence, providing LabVIEW front panel controls as elements in a heads up display (HUD) might be a future target as well. Thus, the student gets the possibility for a more flexible interaction with the simulation without the need to move to the LabVIEW interface in the event of changing parameters.

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