

# **The Virtual TEAL World - An Interactive and Collaborative Virtual World Environment for Physics Education**

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at

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submitted by

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Graz, February 2013

**Virtual TEAL World –  
Eine interaktive und kooperationsfördernde  
Virtuelle Welten Umgebung für den  
Physikunterricht**

Masterarbeit  
an der  
Technischen Universität Graz  
vorgelegt von  
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Graz, Februar 2013

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## Abstract

Technology Enabled Active Learning (TEAL) is a learning approach designed based on the interactive engagement learning method. It was developed at the Massachusetts Institute of Technology and successfully improves the efficiency of teaching freshmen physics. TEAL uses especially designed classrooms, hands-on experiments, and the simulation software TEALsim for three-dimensional visualizations to enhance the conceptual understanding of students. It provides different teaching methods and scenarios to advance the effectiveness of interactive engagement. Nevertheless, not every institution or university is able to fund the according renovations of the classrooms. Also, this teaching model does not support distance learning possibilities teaching model.

The Virtual TEAL World is an attempt to design a virtual three-dimensional learning environment that integrates the educational valuable components and scenarios of the TEAL approach to provide a flexible, competitive, and economic reproduction of the original TEAL environment, which also supports distance-learning scenarios. Tools, experiments, videos, and the 3d simulations used by TEAL were especially implemented or adapted for the collaborative virtual world environment Open Wonderland to assimilate the original TEAL environment. The main objective of the Virtual TEAL World is to provide a virtual learning environment that accomplishes learning achievements as good as the TEAL environment so that students who are learning in the Virtual TEAL World can achieve the same conceptual understanding. The practical work includes the adaption of the existing integration of TEALsim and the first implementation of a module simulating concept questions in Open Wonderland, with regard to the defined requirements, such as usability, interactivity, and collaboration.

Three-dimensional virtual worlds, however, are still unfamiliar and seen as controversial by teachers and learners. In particular, issues such as technical requirements, lack of user acceptance, and lack of technical expertise are hindering factors to use 3d virtual worlds for educational scenarios. Therefore, the main objective of the design and the corresponding evaluation is to raise the users' motivation, to enhance usability and to show that students learning in the Virtual TEAL World can achieve conceptual understanding. A first evaluation was conducted in two phases with the main stakeholder groups and integrated questions focusing on usability and stakeholder requirements. First, physicists and instructors evaluated the world with a focus on pedagogical objectives. In the second phase, student groups conducted a supervised learning roundtrip with respect to learning progress and motivation. This first evaluation shows advances of motivation by enhancing interactivity and collaboration, and indicated a minimized user frustration by focusing on enhanced usability of the system. The majority of the participants would use this system for learning, but pointed out the need of an increased performance and enhanced graphics.

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## Kurzfassung

Technology Enabled Active Learning (TEAL) ist ein Lernmodell, basierend auf der Interactive Engagement (IE) Lernmethode. TEAL wurde gestaltet, um das physikalische Verständnis von Studienanfängern am Massachusetts Institute of Technology zu verbessern. Dabei werden multimediale Visualisierungstools wie TEALsim, eigens konzipierte Klassenräume, praktische Experimente und unterschiedlichste pädagogische Lehrmethoden verwendet, um die Effizienz von IE zu steigern. Aber nicht jede Organisation oder Universität kann die für TEAL notwendigen Renovierungen der Klassenräume und Anschaffung der benötigten Hilfsmittel finanzieren. Auch potentiellen Fernunterrichtsszenarien können nicht unterstützt werden.

Die in diesem Dokument vorgestellte Virtual TEAL World ist der erste Versuch, eine virtuelle und dreidimensionale Lernumgebung zu schaffen, welche die pädagogisch wertvollen Komponenten und Szenarien des TEAL Modells in einem kostengünstigen und flexiblen Umfeld integriert. Vorhandene Tools, Experimente, Videos und dreidimensionale Simulationen wurden speziell für das Kooperations fördernde Virtuelle Welten Framework Open Wonderland implementiert oder adaptiert, um die vorhandene TEAL Umgebung bestmöglich zu imitieren. Die Virtual TEAL World zielt darauf ab, Studenten ein interaktives Lernerlebnis, welches das konzeptuelle Wissen gleich erfolgreich wie die originale Umgebung vermitteln kann. Der praktische Teil dieser Arbeit beschäftigt sich vor allem mit der Adaptierung der existierenden TEALsim Integration und der Implementierung eines Tools zur Simulation von Konzeptfragen in Open Wonderland, wobei der Schwerpunkt auf den zuvor bestimmten Anforderungen wie Benutzerfreundlichkeit, Interaktivität und Kollaborationsfähigkeit liegt.

Dreidimensionale virtuelle Welten sind aber immer noch unübliche Hilfsmittel im Erziehungsbereich. Vor allem Probleme, wie hohe technische Anforderungen, fehlende Benutzerakzeptanz oder auch geringes technisches Know-how hindern Lehrer und Lernende daran, auf diese virtuellen Lernszenarien zurückzugreifen. Daher war das Hauptziel des Design und der Evaluierung der Welt, die Motivation der Benutzer und die Benutzerfreundlichkeit zu erhöhen und einen Lerninhalt zu vermitteln. Eine erste Evaluierung wurde in zwei Phasen mit den Haupt-Stakeholdern durchgeführt. Dabei lag der Fokus auf der Überprüfung der Benutzerfreundlichkeit und der Erfüllung Stakeholder-spezifischer Anforderungen. In der ersten Phase evaluierten Physiker und Lehrende die Welt mit einem Schwerpunkt auf pädagogische Aspekte. In der zweiten Phase führten Studenten zusammen mit Partnern einen Lernrundgang durch, wobei ihr Lernerfolg und ihre Motivation gemessen wurden. Diese erste Evaluierung zeigt unter anderem, dass eine Steigerung der Motivation mittels Interaktivität und gemeinschaftlichen und kooperativen Aktivitäten und eine Verringerung der Benutzer-Frustration durch die Erhöhung der Benutzerfreundlichkeit, die Akzeptanz und das Interesse der User fördern können. Der Großteil der Teilnehmer würde diese Virtual TEAL World verwenden, empfiehlt aber insbesondere eine Verbesserung der Performance und der allgemeinen Grafik.

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I would like to express my very great appreciations to my supervisors from CECI, John Belcher, Philip Bailey, and Judson Harward, who have been most supportive and patient throughout the entire period. After the stay at CECI, we were still able to collaborate smoothly using the first versions of the Virtual TEAL World. This was not only extremely helpful, but also very motivating. I owe special thank to my co-advisor, John Belcher, director of the CECI, for his inspiring ideas, and enthusiasm about my project, steering me in the right direction, and providing guidance at key moments in my work. Phil Bailey patiently guided me through this project, providing technical expertise and insights for the work. He made this work a wonderful learning experience. His door was always open whenever I ran into problems or had questions.

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# 1 Introduction

Teaching natural science, in particular such conceptual subjects as physics, is challenging. While conventional teaching approaches like classroom lectures focus on presenting solutions and concepts, physics education should focus on teaching how to solve problems (Freedman, 1996). Even if students can remember the formulas, traditional passive-students introductory physics courses have difficulties in teaching conceptual understanding (Hake, 1988). Different pedagogical models try to solve this issue by adding different interactive learning experiences, such as hands-on experiments, simulations or concept questions to their curriculum. A well-tested and researched pedagogical model to enhance the conceptual understanding of students is the *Technology-Enabled Active Learning (TEAL)* approach, which is used at Massachusetts Institute of Technology. It focuses on creating collaborative lectures, which integrate different interactive activities, such as hands-on laboratory experiments, visualizations or concept questions (Dori et al., 2003; Dori & Belcher, 2005). This approach uses three-dimensional physics simulations to enhance the understanding of students and to enable the conceptualization of physical problems. To “*make the unseen seen*” (Belcher et al., 2004) the active simulation framework TEALsim was designed as a means to support the TEAL concepts by visualizing and simulating physical phenomena (TEALsim Website, 2004). The implementation of the TEAL environment is a cost-intensive task, due to the necessity of particular devices and classroom designs. Not every institution is able to fund such an environment. Another drawback of TEAL is the lack of distance learning opportunities. Conventional e-learning tools do not provide the required social and collaborative features (Kruse, 2004; Welsh, Wanberg, Brown, & Simmering, 2003). Immersive, collaborative environments such as 3d virtual worlds can overcome this issue effectively. The virtual world framework Open Wonderland (OWL Website, 2007) already supports many collaborative features and activities required in the TEAL approach. A first prototype by Scheucher (2010) proved the feasibility by integrating internet-accessible laboratories (iLabs) combined with the TEALsim simulation toolkit in Sun’s virtual world environment Project Wonderland, the predecessor of Open Wonderland. Also, a stand-alone integration of the simulation framework TEALsim tool into Open Wonderland is already implemented (Berger, 2012) but it is neither well tested nor adapted to requirements of students such as simplicity and usability. A virtual environment adapted to their needs and linked to the TEAL approach is missing. Using such an interactive environment also students and educational institutions without the required funding and resources can profit from the well-defined teaching model.

## 1.1 Goals and Objectives

The main objectives of this work are the design, implementation and evaluation of a virtual environment, which supports the processes and learning strategies of the TEAL model. The first prototype of the *Virtual TEAL World (VTW)* focuses on being a collaborative and interactive virtual learning environment for students and introduces the course section ‘Faraday’s Law’ as a first prototype. The implementation of the VTW in Open Wonderland includes:

- The design and conception of the TEAL approach in the three-dimensional virtual world environment Open Wonderland
- The extension and improvement of the Open Wonderland TEALsim-Module to provide a stable, fast and user-friendly visualization of electromagnetic simulations, in particular the visualization describing Faraday's Law
- The implementation of necessary learning tools to provide an interface with conventional e-learning tools and learning management systems such as Moodle

The implementation of the Virtual TEAL World should enable a first realization of the single course unit 'Faraday's Law'. Therefore, the work especially addresses the integration and adaptation of the TEALsim simulations Falling Coil and Faraday's Law.

## 1.2 Methodology and Structure

This thesis is structured into three main parts. The first part outlines the theoretical background of the work (Chapter 2). The second part focuses on the practical approach, the design (Chapter 3) and the implementation (Chapter 4). The third part addresses a first evaluation of the learning environment (Chapter 5). Figure 1 gives an overview of the single steps of this work.

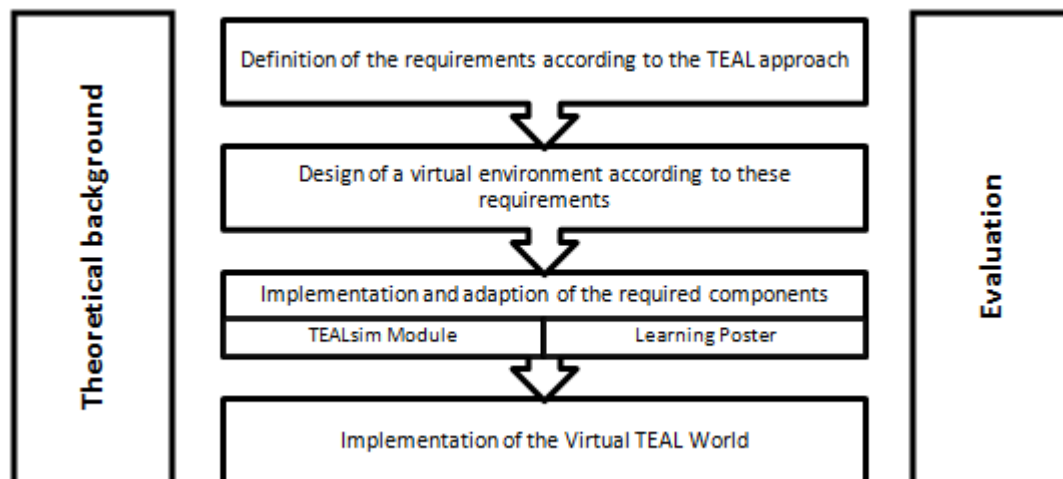


Figure 1: Structure of this work: Theoretical background as a basis for the proceeding of the design and implementation of the Virtual TEAL World. The last part is the evaluation phase.

In chapter two, the main principles and the theoretical background and literature survey used for this work are introduced. After the comparison of different pedagogical models used in science and STEM education, the TEAL approach is described. In addition, different technology-enhanced learning possibilities in science, with a focus on physics, are outlined. In this context, the advantages and disadvantages of videos, animations, and simulations are discussed, and digital game-based learning models and collaborative learning environments are outlined. Finally, three-dimensional virtual worlds (VW) are introduced for the first time. After a common definition of VWs, different objectives, such as gaming or educational scenarios, are outlined. To

visualize the concepts, the last section will introduce different showcases focusing on examples of STEM education.

In chapter three, the conception of the design and implementation of the TEAL approach in a virtual environment is outlined. This section focuses on identifying the requirements and lists the different challenges of the Virtual TEAL World's design, without focusing on a particular virtual world environment. After that, the realization of the TEAL approach in the three-dimensional virtual environment Open Wonderland is explained. It will focus on the introduction of Open Wonderland, outlines the modules necessary for the integration of TEAL and discusses functionalities, which are already available. Finally, the conceptual design of required technical components, such as TEALsim, the TEALsim-Module and the Concept Question-Module are defined.

In chapter four, implementation details of the required components and modules are provided. Based on OWL's cell client-server-architecture, the single implementation steps of the additional modules, the TEALsim-Module and the Concept Question-Module, are discussed. Also, a web-based interface to assess student activities is explained. A first implementation of the Virtual TEAL World in Open Wonderland integrates a single physics course focusing on introducing the basic physical concepts of Faraday's Law.

In chapter five, evaluation details of the first experiment setup are outlined. The setup of the two different experiments for the different stakeholder groups is explained. First, physicists and instructors did a small roundtrip to evaluate the environment with a focus on pedagogical objectives. In the second experiment, students were invited to conduct a simplified learning roundtrip in the Faraday's law scenario together with a peer. With respect on the three research objectives, usability, motivation, and learning progress, the different evaluation results are explained and discussed in detail.

In chapter six, explored ideas and problems of the theoretical background are outlined. Also, explored problems during the design and implementation phase are discussed. Chapter seven provides explains different ideas for future development and advancements. The final chapter summarizes research results and outlines potential outcasts.

Appendix A summarizes the content of the CD to this thesis. Appendix B contains a detailed explanation of the installation process of the Virtual TEAL World and describes the setup of the required applications and modules.

## 2 Background and Related Work

Learning and teaching natural science, in particular such a conceptual domain as physics, are both challenging and demanding tasks. Using traditional teacher-centered didactic approaches, it is hard to impart conceptual understanding, problem-solving ability, and the know-how of the domain (Hake, 1988). Especially designed teaching models, which use interactive activities, can help students understand these concepts and phenomena. Examples of these activities include hands-on experiments and active and collaborative learning scenarios. However, appropriate approaches also have drawbacks, such as high environment and equipment expenses and the lack of remote learning possibilities. E-learning tools facilitate learning at a distance and enhance cost effectiveness, but achieving learning goals via activities such as collaborative assignments and hands-on experiments are difficult to accomplish (Kruse, 2004). Finding an appropriate learning approach for the given research question, the following sections will focus on introducing different learning models and different technology-based learning tools, including three-dimensional virtual worlds as an e-learning tool. The next section addresses the challenges of natural science education with an emphasis on physics and introduces different teaching models and activities facing the associated difficulties.

### 2.1 Physics Education

Science, from Latin '*scientia*' means 'knowledge'. Feynman (1969) emphasized in this context: *"When someone says, 'Science teaches such and such,' he is using the word incorrectly. Science doesn't teach anything; experience teaches it."* According to the Oxford Dictionaries (2012), science is *"the intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment."* To overcome these issues, the entire modern STEM (Science, Technology, Engineering, and Mathematics) education is mainly grounded on constructivism (Sanders, 2009), which is described as a theory of learning, trying to build on knowledge already known by the students (Dougiamas, 1998). Glasersfeld (1989) refers to two main principles asserted by constructivism: *"(1) knowledge is not passively received but actively built up by the cognizing subject; (2) the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality"*. Using constructivism for education, the following principles defined by Bruning, Schraw, Norby, & Ronning (2004) should be considered:

- Learning is a constructive, not a receptive, process.
- Motivation and beliefs are integral to cognition.
- Social interaction is fundamental to cognitive development.
- Knowledge, strategies, and expertise are contextual.

In particular in conceptual domains such as physics, it is crucial to teach not only formulas, but also to enhance the understanding, raise the problem-solving performance, and improve the ability to apply mathematics in physics. Lee, Guo, & Ho (2008) differ between the following

learning activities in physics education: expository instructions, autonomous learning and hands-on experiments. While expository instructions are rather known as traditional lecture methods, interactive experiences using hands-on experiments are receiving increasing interest in modern classrooms. The next sections first revisit traditional physics education with respect to traditional lecture methods and introduce different interactive teaching methods.

### **2.1.1 Traditional Physics Education**

The most common and ancient teaching method is the lecture, often misused to present solutions to physics problems instead of teaching the skill how to solve these (Freedman, 1996). Describing phenomena that are often invisible and connecting these with corresponding equations is a pedagogical challenge. Already early studies in physics education demonstrate that traditional passive-student physics courses, even given by talented professors with sophisticated teaching styles, imparted only moderate conceptual understanding (Hake, 1988). A famous quote by Confucius says, “*I hear and I forget. I see and I remember. I do and I understand*”. Hands-on experiments, visualizations, and simulations can help students understand concepts and enable them connecting the abstract principles to even more abstract equations. In the last few decades, physicists have approached different teaching strategies, and varying teaching models have thus emerged (McDermott & Redish, 1999). Most of these models promote active learning activities, such as group activities, discussions, exercises, debates, brainstorming, or questioning. This promotes the student from being an ordinary auditor to an active participant in the lecture (Feynman, 1969; Active Learning, 2009). Several studies show that teaching strategies that use active learning activities are superior for the development of the skills of students in thinking and writing (Bonwell & Eison, 1991). The next section introduces different teaching approaches with a focus on combining different active learning activities in the physics application domain.

### **2.1.2 Interactive Engagement**

In particular, in the physics education domain, quantitative research promotes the effectiveness of *Interactive Engagement* (IE) to improve the students’ motivation and understanding in face-to-face lectures. IE strategies focus on challenging students to think about a question and to interact with each other (MacKay & College, 2006). Hake (1998) demonstrates within a student survey with more than 6000 participants that IE methods can enhance the problem-solving ability and the conceptual understanding well beyond traditional courses (Hake, 1988). The following section introduces different popular IE techniques and strategies (Hake, 2002; MacKay & College, 2006).

### **Microcomputer-based Laboratories**

In Microcomputer-based Laboratories (MBL), students conduct real-time experiments and monitor the results on a computer. MBL tools enhance the effectiveness of learning by

investigating the physical world, making the abstract concrete, verifying the students' physical intuitions, and encouraging collaboration and learning from peers (Thornton, 1987).

### Just in Time Teaching

The Just in Time Teaching (JiTT) strategy uses web-based assignments prior to class to prepare and motivate students for the class (see Figure 2). According to the pre-recorded answers of the students, the teacher can adapt the lesson level and content. This maximizes the efficacy of the lesson and the out-of-class learning benefits (Novak, 1999).

**Preflight Check** Lesson 12  
Hamilton's Principle and Lagrangian Mechanics

Name: etp Section: M2 Start Time: 9:17:7 Instructor: pate Course: 355

**1)** Hamilton's Principle says that a dynamical system traces out a path that minimizes the time integral of the difference between the kinetic and potential energies. Please try to explain this **in your own words**. What is the "path of the system" to which the statement refers? (Hint: Think about how you'd try to explain this to a fellow physics major who comes to you and asks you to decipher the textbook-ese for him or her.)

**2)** Probably the thing that takes the most practice in order to develop expertise in using "Lagrangians" (also called "Lagrange functions") is figuring out what

Figure 2: Example webpage with assignments submitted prior class (Novak, 1999)

### Modeling Methodology

Using the Modeling Methodology, students are engaged in the usage and development of scientific models, which enables them describing, explaining, and predicting physical phenomena, and designing the corresponding experiment setups (Hestenes, 1996).

### Ranking Task

Ranking Task (RT) exercises use a set of variations and different arrangements, which are ranked and afterwards explained by students. This methodology enhances their ability of



comparative judgments and enables them to utilize their natural ideas of the concepts instead of simple memorizing (O'Kuma, Maloney, & Hieggelke, 2000).

### **Peer Instruction**

Peer Instruction (PI) with concept tests is a teaching model introduced by Eric Mazur at Harvard University. It achieves learning goals by including 3-4 small concept tests, also known as clicker questions, in each lecture hour. The students can answer the multiple-choice questions using especially designed devices called clickers (see Figure 3). The instructor reviews the responses, thereafter he motivates students to discuss the problem with their neighbors, and answer the question again (Redish, 1996; Mazur, 1996).



Figure 3: Classroom response system to answer multiple-choice questions (Active Class Webpage, 2012)

### **Interactive Lecture Demonstrations**

In Interactive Lecture Demonstrations (ILD), physics experiments without data records are presented during the lecture. Students make first predictions about the outcomes and discuss their results with peers before the experiment is repeated, and the real data are recorded and displayed (Duffy, 2000).

### **Animations and Simulations**

Animations and simulations are used as interactive engagement method to enhance conceptual understanding and visualization of abstract phenomena. In particular for the application domain STEM education, many simulation resources have been developed to visualize and explain different phenomena. Section 2.2.3 will cover this topic in more detail, focusing on different examples in the field physics.

The next section introduces the learning model, known as TEAL, which is based on the IE idea and combines different introduced activities to an entire learning and teaching model and environment.

### 2.1.3 Technology-Enabled Active Learning

“*Make the unseen seen*” (Belcher et al., 2004) is the main purpose of teaching magnetism and electricity at Massachusetts Institute of Technology. The TEAL (Technology-Enabled Active Learning) project is a teaching model for natural science, in particular developed for physics courses in higher education. When starting the 5-year project, it was motivated by good results of educational innovations such as interactive-engagement methods to support interactive, engaging, hands-on, and collaborative learning environments (Dori et al., 2003). The first objectives of the TEAL project were the transformation of the way physics was taught at large enrollment physics classes at MIT, the decrease of the failure rates in these courses, the creation of an engaging and technologically enabled active learning environment, the reduction of passive lecture formats, the increase of students’ conceptual understanding, and the fostering of their visualization skills. The TEAL project tries to integrate mini lectures, recitations, hands-on laboratory experiments, and visualizations in an active and collaborative learning environment (Dori & Belcher, 2005). Active learning is enhanced in particular by collaborative learning activities in an especially designed environment. Students work together in small working groups on desktops with shared laptop computers, setups desktop experiments with data acquisition links to their computers, and visualization and simulation software. Students answer regular concept questions using a personal response system (PRS). These questions also induce group discussions and interactions. Web-based home assignments and textbook reading should help students foster the concepts or prepare for the class (TEAL-Project, 2006). An especially designed classroom enhances the collaborative experiments and supports technology-enabled activities. Figure 4 gives an impression of the TEAL learning environment and shows a model of the corresponding d’Arbeloff Studio classroom.



Figure 4: Real TEAL Learning Environment and 3d model of the d’Arbeloff Studio classroom (TEAL Casestudies, 2005)

Group discussions and collaborative assignments are contributing to a deeper understanding. Comments of students regarding the in-class discussions are for instance: “*The in-class discussions were particularly helpful because people had the opportunity to defend their opinion and try to convince others that they were right. In doing so, I picked up more practical explanations (without use of equations) to problems.*” (Dori & Belcher, 2005) The provided experiments,

visualizations and simulations help enhance the conceptual understanding. The implementation of the TEAL format at the MIT was remarkably successful and studies conducted with MIT students have shown that the format had positive effects on the learning outcomes; the failure rate has decreased, learning gains have doubled and students gain a better conceptual understanding of the taught physical phenomena (Dori & Belcher, 2005). The only drawback of this approach is the dependency to the corresponding framework to provide students an active and collaborative environment. Expensive classroom renovations and adaption to new teaching and assessment methods are necessary to introduce TEAL successfully. The expense of the d'Arbeloff Studio classrooms were noted with \$1.5M each (TEAL Casestudies, 2005).

However, not every institution is able to fund such renovations and adaptations. In addition, potential distance learning scenarios cannot be conducted. An e-learning solution would not only be helpful as enhancement to the existing TEAL solutions in order to provide course participants with the possibility of redoing a single class or training experiments again, it would also give institutions and universities without the necessary resources the possibility of providing such an environment with such powerful outcomes. The next section introduces and discusses different e-learning solutions for this purpose.

## 2.2 Technology-enhanced Learning in Physics

As mentioned in the previous section, finding an appropriate teaching and learning approach depends on several aspects. Additional difficulties and issues in this scope can be, for instance, the need of distance learning possibilities, insufficient financial resources related to high environmental expense, and the lack of sufficient space and time. To overcome these issues it is crucial to consider e-learning environments supporting technology-enhanced learning activities that can be conducted on a networked infrastructure. The Oxford Dictionaries (2012) defines e-learning as *"learning conducted via electronic media, typically on the internet"*. Especially designed e-Learning tools, *learning management systems (LMS)*, *course management systems (CMS)*, or *virtual learning environments (VLE)* such as Blackboard or Moodle can be a cost-effective and beneficial extension or replacement of traditional face-to-face instruction. There are many possibilities of distinguishing between different e-learning activities and modes. Asynchronous e-learning defines pre-recorded training activities, whereas synchronous e-learning happens in real-time (Welsh, Wanberg, Brown, & Simmering, 2003). Horton (2011) differs between different variations of e-learning activities such as standalone courses, learning games and simulations, mobile learning, social learning and virtual-classroom courses. In addition, blended learning solutions are receiving increased interest. Graham (2006) defines blended learning systems as a combination of face-to-face instructions with computer-mediated instructions. He defines four dimensions of interaction in face-to-face and distributed learning environments (see Figure 5).

Several studies on the outcomes of e-learning methods report very good learning results, sometimes even better than gained from traditional methods. Hoag and Baldwin (2000) evaluated e-learning and online collaboration activities and reported positive learning differences as outcomes: *"Compared to the classroom model, students acquired greater experience*

*in areas other than knowledge of course content: teamwork, communication, time management and technology use. Evidence emerged that satisfaction and learning outcomes may be more related to a student's positive outlook than to factors such as grade point average, prior experience with teams or with technology."*

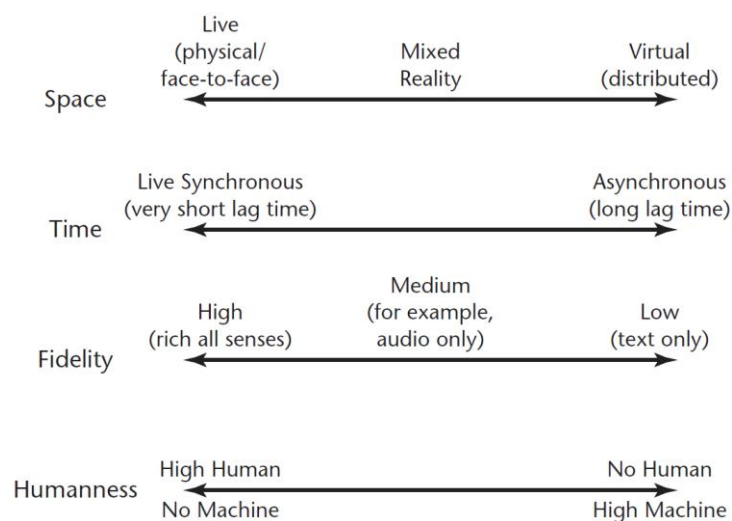


Figure 5: Dimensions of interaction in face-to-face and distributed learning environments (Graham, 2006)

Means, Toyama, Murphy, Bakia, & Jones (2009) found the following results after a literature research of studies from 1996 through 2008: *"Students in online conditions performed modestly better, on average, than those learning the same material through traditional face-to-face instruction."* They also found out that: *"Instruction combining online and face-to-face elements had a larger advantage relative to purely face-to-face instruction than did purely online instruction."* The following advantages of e-learning for institutions and learners can be summarized:

- Flexible learning possibilities regarding learning time and place (Kruse, 2004) and as a consequence a potential increase of the learner convenience (Welsh, Wanberg, Brown, & Simmering, 2003)
- International learning groups (Chang, Gütl, Kopeinik & Williams, 2009)
- Consistent training possibilities (Welsh, Wanberg, Brown, & Simmering, 2003)
- Accommodation of different learning styles and types such as auditory, visual and kinesthetic learners and self-pace possibilities (Kruse, 2004)
- Cost reduction such as rents for teaching rooms or travel costs for institutions and learners (Kruse, 2004; Welsh, Wanberg, Brown, & Simmering, 2003)
- Learning time reduction (Kruse, 2004)
- Reduction of the delivery cycle time such as quick training possibilities (Welsh, Wanberg, Brown, & Simmering, 2003)
- Learner engagement through interactivity (Kruse, 2004)

- Improved tracking of activities and mastery of the material (Welsh, Wanberg, Brown, & Simmering, 2003) and facilitated assessment possibilities (Kruse, 2004)
- Development of computer skills (Niegemann, 2008)

A literature review also identifies several issues and difficulties connected to the use of conventional e-learning solutions. Different potential drawbacks result from aspects such as technical demands and the introduction of new systems, the lack of social interactions, which also leads to motivational throwbacks and gives learners the feeling of isolation:

- Need of technological know-how of learners and technology infrastructure support for institutions (Kruse, 2004)
- High implementation and up-front costs (Kruse, 2004; Welsh, Wanberg, Brown, & Simmering, 2003)
- Cultural acceptance of the use of e-learning tools or computers at all (Kruse, 2004)
- Lack of social interactions such as lack of collaborative assignments, peer-to-peer learning opportunities, and different communications channels such as body languages (Kruse, 2004; Welsh, Wanberg, Brown, & Simmering, 2003) and feeling of isolation (Gütl, 2011)
- Procrastination (Gütl, 2011)
- Technical demands such as internet connections. These technology-related problems and interruptions can result in the increase of the learners' frustration (Welsh, Wanberg, Brown, & Simmering, 2003)
- Lack of possibilities for self-directed learning (Gütl, 2011) and self-determination of the learning environment and variables (Niegemann, 2008)
- Lack of multiple communication channels (Gütl, 2011)
- Self-motivation and organization of learners necessary (Niegemann, 2008)
- Lack of hands-on experiences (Gütl & Pirker, 2011)
- Little personal contact to instructors (Gütl & Pirker, 2011)

Considering the potential drawbacks, Welsh, Wanberg, Brown, and Simmering (2003) identified different future trends and improvements, which include a growth in synchronous learning, prevalence of blended solutions, improved technologies, and the integration of information provision, performance support, peer collaboration, and training. To overcome some of these issues in the application domain physics education, the next sections will focus on introducing different motivating, interactive, and collaborative technology-enabled activities:

- **Social Collaboration** (Collaborative Immersive Environment)
- **Interactivity** (Remote Laboratories, Animations and Simulations)
- **Motivation** (Game-based Learning)

Thereby, interactive activities and hands-on experiences such as remote laboratories, animations, and simulations enhance the active participation of students. Social collaboration

should reduce the dropout rate and should enable learners to discuss problems and collaborate in immersive environments. All these activities should enhance the learners' motivation, but to enable also playful motivators, game-based learning models will be introduced.

The next section introduces the advantages of using remote physics laboratories for educational purpose with a focus on natural science education.

### **2.2.1 Collaborative Learning Environments**

Collaborative learning can be defined as *"an abstract concept involving joined intellectual effort by the learning community built of students and teachers in a wide range of settings. The learning group mutually searches for understanding or meaning, explores solutions or creates some sort of product"* (Gütl, 2011; Dillenbourg et al., 1996). Dillenbourg (1999) adds a focus on uncertain outcomes to the definition, *"a situation in which particular forms of interaction among people are expected to occur, which would trigger learning mechanisms, but there is no guarantee that the expected interactions will actually occur"*. Many computer-based tools support collaborative learning activities and tasks. Revisiting disadvantages of conventional e-learning tools mentioned in section 2.2, *computer-supported collaborative learning (CSCL)* can overcome issues such as the lack of social interactions and the feeling of isolation and can help students to motivate each other to reduce the dropout rate. Different tools, simulations, games, and remote laboratories use collaborative elements to enhance social activities.

### **2.2.2 Remotely Controlled Laboratories**

Using a constructive pedagogical approach, interactive hands-on experiences with the help of experiments in laboratory setups settings can help build up conceptual understanding by adding interactive and demonstrative elements to the course. Laboratory setups can be categorized into traditional real (1) *hands-on laboratories*, (2) *simulated laboratories*, (3) *remote laboratories* or hybrid forms that combine different aspects and advantages of the different approaches (Gütl et al., 2012; Corter et al., 2007). Because of high expense of equipment, necessity of space and maintenance, many institutions prefer alternatives to hands-on laboratories. In addition, the increased numbers of distance learning courses require web-based alternatives such as remote laboratories. (Corter et al., 2007) Advantages of remote laboratories include flexibility, cost-effectiveness, security of persons and objects, and the possibility of conducting dangerous experiments. They enable international collaborations, support autonomous learning, are observable by many people at the same time, can be used either as a supplement or as a replacement of hands-on labs. They also enable the accessibility for handicapped people and local and temporal availability (Gravier, Fayolle, Bayard, M., & Lardon, 2008; Gomes & Bogosyan, 2009). Corter et al. (2007) compared within a study with 306 students the different lab formats according to the learning outcomes and showed that *"students do express preference for traditional hands-on labs, but learn the relevant concepts as well or better with the newer forms of laboratories"*. Ma & Nickerson (2006) compared different hands-on, simulated and remote laboratories articles according to their focus on the predefined learning goals: conceptual

understanding, design skills, social skills and professional skills. While all educational goals are well addressed by articles on hands-on labs, the dimensions design and social skills are ever more disregarded by articles as to simulated and, in particular, remote labs (see Figure 6).

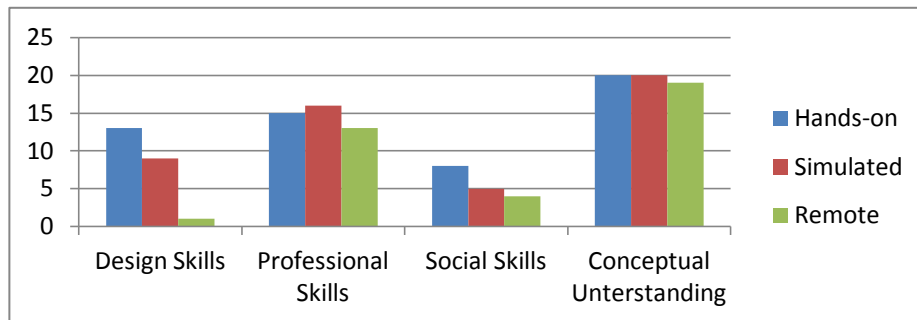


Figure 6: Educational goals of hands-on, simulated and remote labs (Ma & Nickerson, 2006)

The following sections introduce the computer-based visualizations videos, animations, and simulations for educational purpose.

### 2.2.3 Videos and Animations

Edison once mentioned: *"I believe the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks."* (Monke, 2004) Simple videos and *computer-based visualizations* (CBV) such as animations or interactive simulations can facilitate conceptual understanding and help students visualize and memorize abstract concepts. These forms of media can be used either stand-alone or connected to different exercises or concept questions. While videos are a cost-effective possibility of showing recorded events, animations can help visualize phenomena that are not or hardly recordable and adding additional information. Niegemann (2008) summarizes different didactic advantages of animations such as motivational aspects, provision of additional information, demonstration of dynamic properties, acquisition of procedural knowledge, and points out drawbacks such as potential distraction, problems to focus on relevant information, difficult comparison of different states, high cognitive load, and overestimation of one's own understanding of the topic.

Niegemann (2008) also outlines different aspects and theories to enhance the understanding and learning effects of animations. He states that before implementing an animation, it is crucial to question the benefits and necessity of using dynamic images in this context instead of static ones. Animations only for decorative motives should be avoided. As a means to support the cognitive processing, the viewers' attention has to be focused on important and essential aspects of the animation. Relevant information can be emphasized by visuals such as arrows or via verbal instructive commentaries, which can be used either in a descriptive ("The animation shows") or directive ("Watch the movement of") way. When adding commentaries and verbal explanations to videos, animations, or simulations, several design aspects should be considered to improve the learning outcomes (Niegemann, 2008):

- **Modality Effect**

The modality effect in multimedia instruction refers to the learning improvement of students when presenting verbal information in an auditory way, instead as on-screen text. This applies to sequential, but also to concurrent presentations (Koumi, 2012) and results from a decreased working memory load (Tabbers, Martens, & Merriënboer, 2001).

- **Redundancy Principle**

To avoid cognitive overload, this principle asserts that, when using verbal commentaries, the presentation of the transcript should be avoided (Niegemann, 2008). *“Students learn better from animation and narration than from animation, narration, and text if the visual information is presented simultaneously to the verbal information”* (Koumi, 2012). Tabbers, Martens, & Merriënboer (2001) add at this point, *“...experiments show that replacing onscreen text with audio will only increase the effectiveness of multimedia instructions if the student has no control over the pacing of the instruction and the pace is set by the time of the narration”*. Transcripts should be provided for deaf users. Potential solutions can include on-demand transcript in the videos, related to the corresponding screens (Koumi, 2012).

- **Personalization of commentaries**

Personalized, natural language spoken by human and native voices should be preferred to objective commentaries to improve motivation (Niegemann, 2008).

- **Contiguity of commentaries**

Commentaries should be isochronal to the corresponding visual presentation to enhance the learner’s understanding and connection of the contents (Niegemann, 2008).

Depending on the degree of interactivity, we differ between static videos and animations and interactive simulations, which will be introduced in the next section.

## 2.2.4 Simulations

In comparison to videos and animations, simulations have interactive aspects so that the user can influence the behavior of the animations. Because of their interactivity, simulations can motivate students to active participation and exploration of the topic. In addition, advantages over traditional experiments can be listed. Phenomena can be observed more easily, due to their potential stretch of time and space. Also, dangerous and impossible experiments can be conducted (Lunce, 2006). Especially in conceptual application domains such as physics, different studies show that the use of CBVs can help students understand different physical phenomena by making invisible behavior and concepts visible. Interaction with simulation can help students get feedback and link formulas to corresponding reactions. Many free educational tools are already available to support different learning experiences. Besides providing a broad basis of potential animations and simulations, most of these tools are designed to be extensible and



adaptable, also with minor programming skills. *Physlets* are non-commercial, web-based, flexible Java applets with a focus on simulating and animating physical phenomena. Christian (2005) and Cox, Belloni, Dancy and Christian (2003) summarize advantages of Physlet-based activities such as interactive visualization of abstract concepts, motivation of students to move beyond novice problem-solving strategies, and the provision of a quick way of seeing the effects of changing the parameters of different systems. Physlets can be used as a means to support JiTT web-based assignments, ranking task exercises, and also PI. Figure 7 shows a Physlet explaining the moment of inertia motivating the user to rank the different simulations. Figure 8 shows a simulation of the *Open Source Physics* (OSP) platform. OSP is a project providing different open source (Java) libraries, modeling tools and simulations for physics (OSP, 2003). PhET is a collection of free interactive physical simulations at the University of Colorado (PhET, 2011).

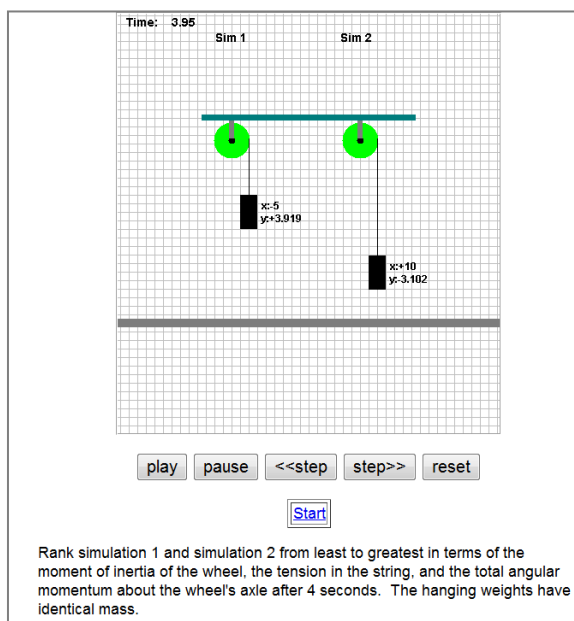


Figure 7: Physlet describing the moment of inertia of a wheel supporting a ranking assignment (Christian, 2005)

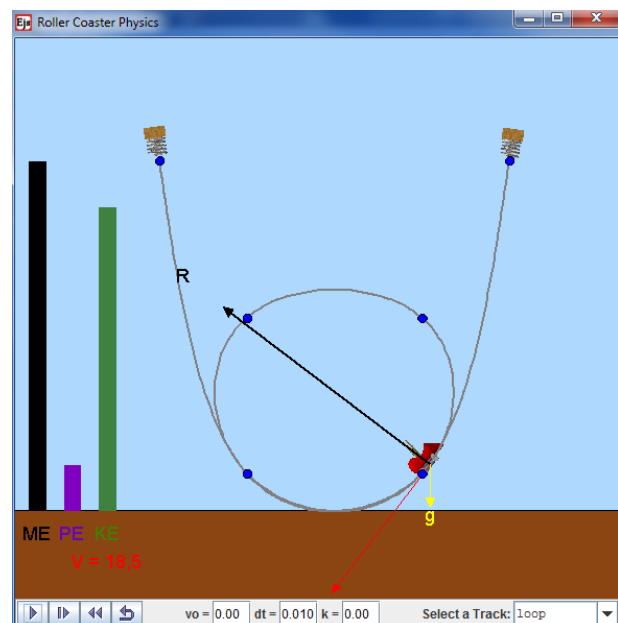


Figure 8: OSP Simulation demonstrating an interactive roller coaster model showing the relation between kinetic, potential and total energy (OSP, 2003)

*TEALsim* is an open source, Java-based, three-dimensional, extensible simulation framework representing physical and mathematical concepts and was developed at MIT (TEALsim Website, 2004). Figure 9 shows TEALsim's desktop application demonstrating a three-dimensional simulation of the generation of electromagnetic plane wave radiation.

As other educational tools, also simulations are limited with regard to the way they are used and different aspects and limitations have to be considered. Bell & Smetana (2008) identified different guidelines of the usage of computer simulations in education: "(1) Use computer simulations to supplement, not replace, other instructional modes. (2) Keep instruction student centered. (3) Point out the limitations of simulations. (4) Make content, not technology, the focus." Another aspect is a focus on an explorative approach instead of providing students too detailed procedural instructions to solve given problems.

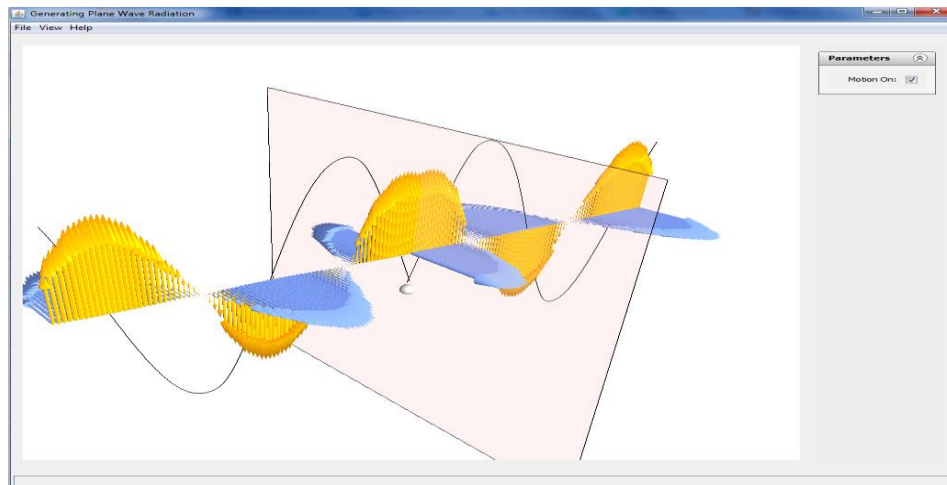


Figure 9: Three-dimensional TEALsim simulation demonstrating the generation of electromagnetic radiation (TEALsim Website, 2004)

In a study with approximately 250 students Windschitl & Andre (1998) compared exploratory (constructivist) simulations with confirmatory (following clear instructions) simulations and found out that the exploratory approach was “*more effective in altering learners’ misconceptions*”. Even if simulations are a useful tool to enhance the learners’ understanding of a topic, often the lack of motivation hinders students to use this tool actively and voluntarily. Considering the interactivity of simulations, the according design and implementation of corresponding games is a pedagogical measure to raise the motivation and engagement of the learners. The next section will briefly introduce learning games and their purpose.

### 2.2.5 Digital Game-based Learning

When using appropriate and well-tested teaching methods, it is still challenging to make learning fun and also to motivate students to learn outside the classes. Schell (2008) defines a game as “*a problem-solving activity, approached with a playful attitude*”. Games with educational purpose are trendy, but the idea is not a new one. Especially the military used traditional games for many years and computer-based simulations and games in recent years (Zichermann & Cunningham, 2011). In particular, video games are receiving more interest. Already 65% of US households play video games, gamers spent an average time of 18 hours per week playing video games and not only men do play. According to Online Education (2012), two out of five gamers are female. The generation born after 1965 is already also known as the *Gamer Generation* and combines the Gen X and Millennial generation. This generation is defined by growing up with sophisticated technologies such as mobile phones, video games, and laptops, complex television systems, and new media such as internet and cable TV (Emrich, 2004). During the last years, an increasing trend was born towards adding computer game design elements to non-game contexts, or “*gamifying*” those, as it is also being referred to. Figure 10 distinguishes between use of games in a non-game context, pervasive games, and playful interactions. According to this representation, the term gamification can be defined as single but important element of games: gameful design (Deterding, Dixon, Khaled, & Nacke, 2011).

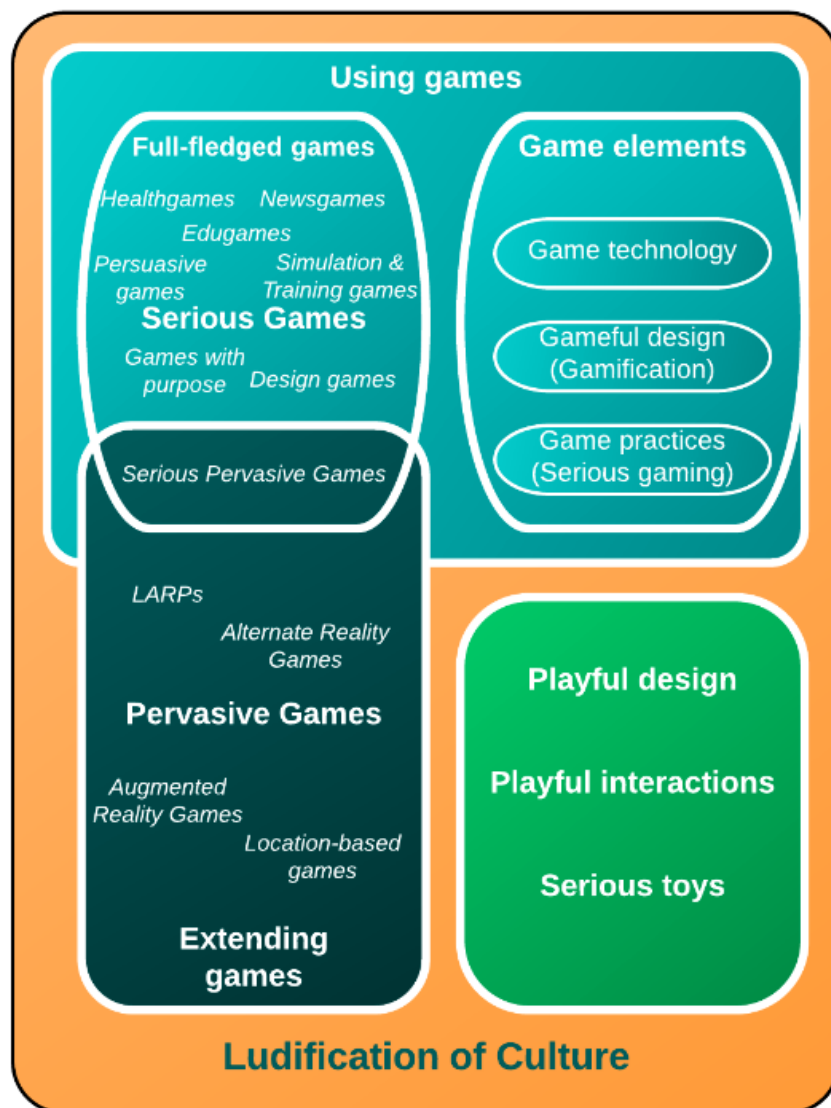


Figure 10: Different game components and categories with respect to the actual trend of ludification (Deterding, Dixon, Khaled, & Nacke, 2011)

It is obvious that also pedagogical approaches seek to integrate game-based activities into their models to profit from this trend. *Game-based learning* (GBL), also known as *edugaming*, becomes more popular. Even if serious teaching and learning do not seem to be an appropriate model for a fun game-based approach, most of the courses use the same or similar characteristics. The student can be visualized as a player of this course (level), who has to master quizzes and assignments as goals, receiving grades, which can be compared with points. These assignments become harder until the final exam as a crucial factor for passing the course. Spoken in game language, it can be interpreted as the quest becoming harder until the boss fight that is a crucial factor for accomplishing the level (Schell, 2008). Figure 11 gives an overview on the comparison of a learning course and the traditional game scenario.

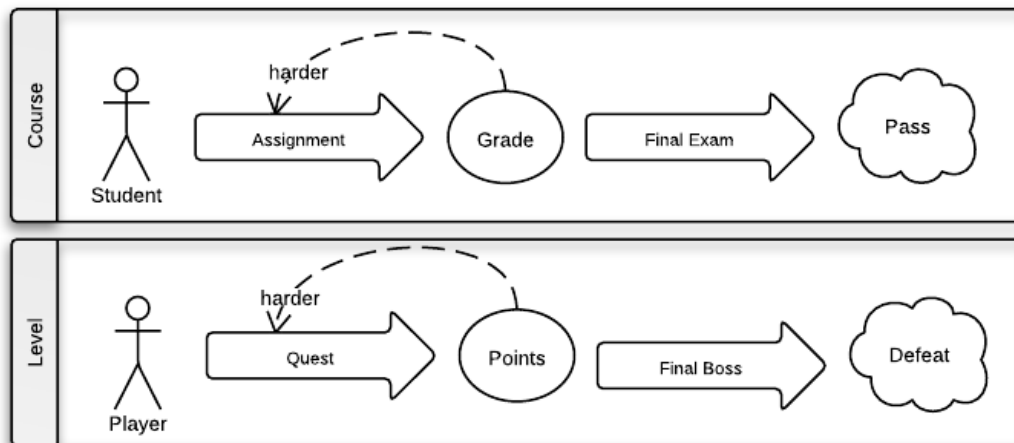


Figure 11: Simplified comparison of a learning course and a game level

Teed (2012) summarizes different activities to support GBL. Competitive elements, such as team playing and scoring, should motivate the students. Learners should be engaged by intrinsic instead of extrinsic motivation. While extrinsic motivation is connected with different outcomes and distinctions, intrinsic motivation is driven by its own sake, fun, and interest. Rewards can help build a game-based entertaining framework.

However, there are many challenges of creating a game-based learning experience. Implementing a fun game should be the result from a well thought out design process. Beside the design challenge, Schell (2008) summarizes different drawbacks and challenges of implementing game in classrooms:

- Time constraints: educational games often take longer than traditional lessons.
- Age constraints: GBL concentrates on the gamer generation. People born before 1965 do have problems using computer games because they are not used to this kind of multimedia.
- Design challenge: Designing a good and fun game is a extremely challenging task. Games should be fun and players should be motivated to play voluntarily, but designing different fun adventures for each lesson is not easy
- Expenses: Derived from the design challenge, high expense can be perceived. Implementing interactive, flexible and visual attractive games is not affordable by every institution.

Klopfer, Osterweil and Salen (2009) also mention four different barriers slowing and stopping the development and adoption of educational games:

- *Barriers to adoption* include standardized curriculum requirements, parents and educators' attitudes, the lack of class logistics and models to integrate games into the curriculum and the lack of support for teachers, lack of assessment possibilities, evidence of the effectivity of learning games, social and cultural structures

- *Barriers to design and development*, which include development costs and development processes, the playtesting possibilities and limited sources of funding
- *Barriers to sustainability* such as maintenance, update and support issues
- *Barriers to innovation* such as the limitation of data, pedagogical paradigms, research, and ambition.

One example of a successful gamified project is Foldit (see Figure 12). A tool to three-dimensionally restructure proteins was designed as an online puzzle game with the purpose of attracting not only researchers, but also more than 50,000 volunteering 'gamers'. The users try to get a high score by restructuring the design of proteins and trying to crack different protein-folding problems (Howard Hughes Medical Institute, 2010). Researchers evaluate the predicted design of the users with the highest score and can use these results for solving real-world problems such as fighting disease or cleaning up the environment (Foldit Website, 2012).

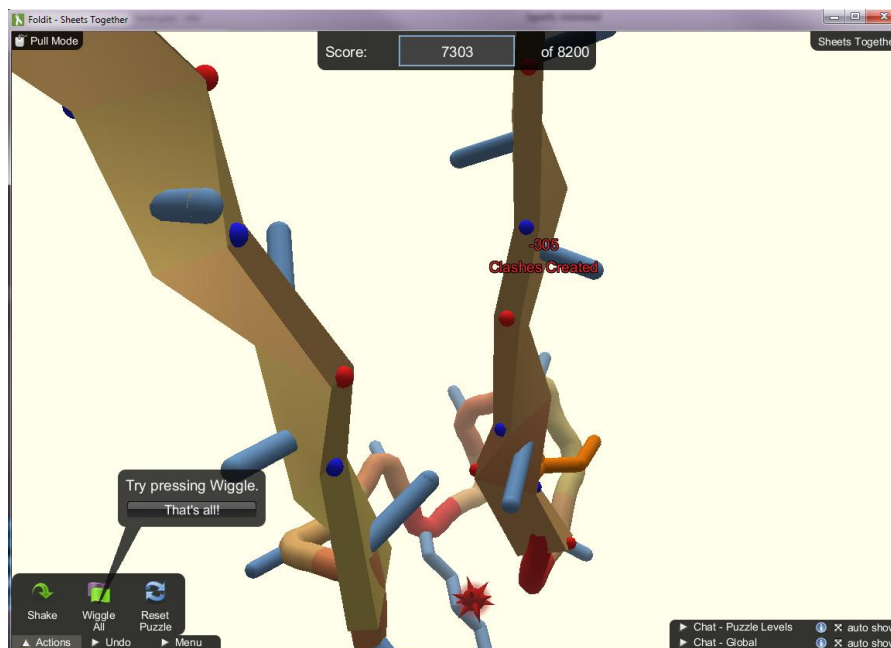


Figure 12: Playing puzzle games to solve real problems in Foldit (Foldit Website, 2012)

Revisiting the introduced tools such as remote laboratories, animations, games, and collaborative environments, many issues of conventional e-learning tools can be covered. However, a solution combining the three requirements interactivity, motivation, and social collaboration is still missing. Referring to collaborative immersive environments Gütl (2011) also points out potential obstacles such as “*limited transmission of interpersonal and social information, limitedly shared activity awareness and absence of co-location*”. The next chapter will introduce the immersive collaborative learning environment tool ‘3d virtual worlds’, which should help overcome this issues and can give the possibility of integrating the three defined main requirements (interactivity, motivation, and social collaboration) in one single solution.

## 2.3 3d Virtual Worlds

In literature, many definitions of *Virtual worlds* (VW) do exist. They are defined by using the following characteristics:

- **Persistence:** A VW keeps running and sustained, even if the user is logged out (Bartle, 2003; Holmström & Jakobsson, 2001; Reis, Escudeiro, & Escudeiro, 2010; Bell M. W., 2008)
- **Shared space:** VWs are designed as multi-user environments (Bartle, 2003; Holmström & Jakobsson, 2001; Reis, Escudeiro, & Escudeiro, 2010; Bell M. W., 2008)
- **Socialization:** Interaction with other users (Holmström & Jakobsson, 2001; Reis, Escudeiro, & Escudeiro, 2010)
- **Feeling of presence:** Related to the representation as an avatar, the user experience the presence of themselves, other users, the environment and other objects, and feel part of this environment (Gütl, 2011; Holmström & Jakobsson, 2001)
- **Representation of individuals and objects** (Bartle, 2003; Holmström & Jakobsson, 2001; Bell M. W., 2008)
- **Immersion:** Users develop a feeling of immersion in the virtual environment. (Reis, Escudeiro, & Escudeiro, 2010)
- **Interactivity:** Users have the possibility to interact with other users, objects, and the environment (Holmström & Jakobsson, 2001; Reis, Escudeiro, & Escudeiro, 2010; Bell M. W., 2008)
- **Synchronous (Immediacy)** refers to real time interaction and activities in the VW (Bell M. W., 2008; Bartle, 2003; Reis, Escudeiro, & Escudeiro, 2010)

Bell M. W. (2008) refers to the necessity of adding networked computers to the definition in order to focus on the data management and communication to avoid confusions between real immersive role-playing scenarios such as Dungeons and Dragons (D&D Homepage, 2001). Using these keywords, we can obtain the following definition: A Virtual world is an immersive, persistent multi-user environment representing individuals as avatars, which are able to interact with other users, objects, and the environment in real-time by using a network. Famous social virtual world environments include Second Life, Open Wonderland or OpenSimulator, but now names such as World of Warcraft or Guild Wars are more familiar to many people. The next chapter focuses on VWs with entertaining purpose to analyze current trends and filter potential concepts which could be integrated and applied to educational scenarios.

### 2.3.1 Virtual Worlds with Gaming Purpose

Virtual worlds with a focus on entertainment and gaming are also known as massively multiplayer online games (MMOG). MMOGs with a focus on role-playing games such as World of Warcraft (WoW) are also called massively multiplayer online role-playing games (MMORPG). Although WoW is sharing the market with actual titles such as Diablo 3 and Guild Wars 2, it

remarks 9.1 Million paying subscribers (Forbes, 2012). James et al. (2004) point out concepts of this kind of games that single-player offline games do not provide: *Social systems* (communication, groups, organizations, rituals, events), *Political systems* (politics of community relations, political game design), *Economic Systems* (Trading, Fashion, Utilities, Faucets and Drains). Therefore, researchers from different fields such as psychology, sociology, or economy are interested in this trend. Users are playing these games for different reasons. Bartle (2003) developed a model to define the player type with on the basis of his in-world actions or interactions. He distinguishes between (1) killers, “people who want to dominate others”, (2) explorers that are motivated by increase of “knowledge about the way the virtual world works”, (3) socializers, who want to “interact [...] with other people, trough the medium of the virtual world”, and (4) achievers, focusing on fulfilling the game-defined goals (see Figure 13).

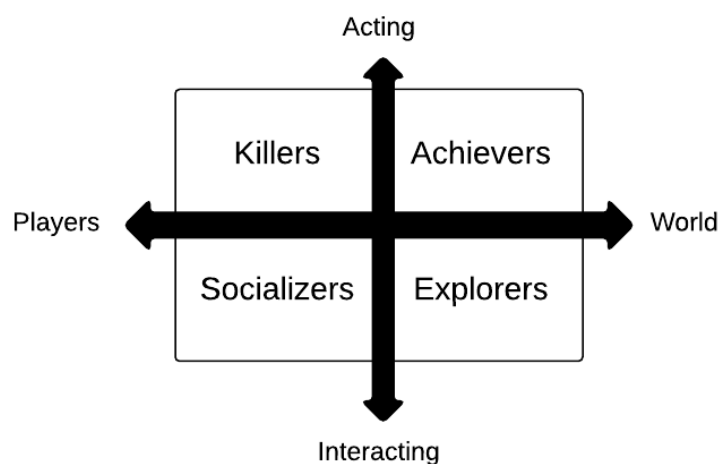


Figure 13: Player types defined by Bartle (2003): “Achievers have fun acting on the virtual world; explorers have fun interacting with the virtual world; socializers have fun interacting with other players; killers have fun acting on other players”

Breau (2002) distinguishes between player types motivated and attracted by different in-world activities: *Warfare and Combat, Business, Social, Mastery, Exploration, Adventuring*. Figure 14 shows different activities in different MMOGs.

In particular, those interactive, collaborative, social experiences seem fascinating also for educational purposes. The next section identifies scenarios and advantages of using VWs in educational contexts.

### 2.3.2 Virtual Worlds for Educational Purposes

As for application domains grounded on a constructivist education theory, a VW seems to be a valuable platform. Moschini (2010) states, “virtual worlds are constructed, designed and shaped by their uses. Communication and social interaction are at the centre of virtual world social experience. Virtual worlds therefore present an ideal platform for the engagement of learners in constructivist-focused educational practice.” Ibáñez et al. (2011) set emphasis on learning strategies based on constructivism, such as situated learning, role-playing, cooperative and

collaborative learning, problem-based learning, and creative learning. Virtual worlds support different medial activities based on image, action, and sound that supports different kinds of learner activities and learning styles and enables students to use observational skills related to their senses (Trotta & Glenn, 2012).



(1)



(2)



(3)



(4)

Figure 14: Virtual Environments (1) a fighting scene in Diablo 3 (Diablo 3 Website, 2012), (2) a trading market in Guild Wars (Guild Wars Website, 2011), (3) World of Warcraft (WOW website, 2004) demonstrating socializing, and (4) exploration activities in Guild Wars 2 (Guild Wars 2 website, 2012)

The definition of Virtual worlds already implies different advantages such as the presence feeling, which can affect suspension of disbelief and increase motivation and productivity in comparison to traditional e-learning tools. Following advantages can be defined in comparison to conventional e-learning activities:

- Provision of different communication channels (both verbal and non-verbal) for improved understanding (De Lucia, Francese, Passero, & Genoveffa Tortora, 2008)
- Activity-based interactions support the motivation and autonomy of the users (Gütl & Pirker, 2011)
- Increased social awareness (Gütl, 2011; De Lucia, Francese, Passero, & Genoveffa Tortora, 2008)



- Feeling of presence in the virtual environment (Gütl, 2011)
- Awareness of other avatars and the environment (Gütl, 2011)
- Belonging to a social community that creates a virtual social space and can positively impact learning outcomes (Gütl, 2011; De Lucia, Francese, Passero, & Genoveffa Tortora, 2008)
- Facilitated collaboration through different tools (Gütl & Pirker, 2011)
- Visualizations and simulations of learning content via 2d and 3d artifacts (Gütl & Pirker, 2011)
- Personal motivation through active participation and co-creation of the world (De Lucia, Francese, Passero, & Genoveffa Tortora, 2008; Gütl & Pirker, 2011)

Bartle (2003) emphasizes in particular features such as the VWs' collaborative and motivational nature and their potential for use at a distance, for language use, for usability, and easy teachability. He also mentions the change from classroom learning, what also engages children to express themselves.

Drawbacks, challenges, and boundaries of the use of social virtual world environments include:

- *High technical demands* such as a good internet connection and bandwidth constraints, a correct firewall configuration, and a modern PC supporting 3d graphics are required to enable 3d visualizations and synchronous remote activities such as a voice-over-IP chat (Gütl & Pirker, 2011).
- Students and teachers require *technical know-how* to interact with the world and to build new artifacts (Gütl & Pirker, 2011). New users need teaching aids and tutorial sessions in the beginning. Otherwise, this can reduce the learning curve and can be a demotivating factor (Thackray, Good, & Howland, 2010).
- Another challenge to face is the *acceptance issue*, which can be counteracted by a design focusing on advantages in comparison to traditional e-learning tools and raising the motivation by including motivators such as a game-based approach (Gütl & Pirker, 2011). Users have to be aware of the purpose and strengths of this environment. Instead of storing lots of documents in-world the purpose should focus more on the collaborative and communicative aspects.

Combinations between traditional e-learning tools such as CMSs and the VW can connect asynchronously with synchronous learning activities. Improved usability should also help raise the users' acceptance. Nielson (1995) refers to five quality components to define usability: *learnability* so that the use of the system is fast and easy to learn; *efficiency* measures how quickly users can perform single tasks; *memorability* of the usage heuristics; *errors* of users and *satisfaction* of the usage. During a hybrid review-case study in the field Second Life for medical and health education, Boulos, Hetherington and Wheeler (2007) also referred to different implications for practice, (1) "enable educators and learners to be more creative and to develop new effective ways of teaching and learning, rather than to purely replicate real life and classrooms

in *Secon Life*", (2) "Identify and focus/capitalise on what 3-D virtual worlds are best at; those useful things and scenarios that can only be effectively carried out in virtual worlds", (3) "make 3-D virtual worlds more accessible and user friendly".

It is also crucial to find an appropriate scenario to use a VW. Potential scenarios appropriate for educational purposes that can be grouped into the categories referring to interactive activities as stated in Figure 15.

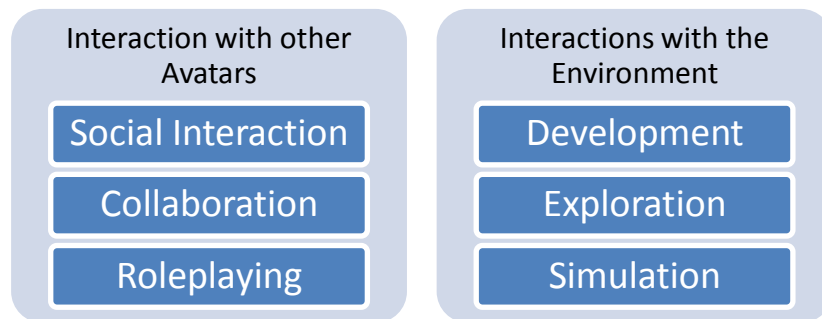


Figure 15: Simplified categorized interactions in the VW

Potential scenarios (Clifford, 2012) and in-world interactions can be classified using this model into scenarios using user interactions with other avatars and using interactions with the environment.

- **Interaction with other avatars**

Collaborative and interactive activities enable users to work together and cooperate together with other in-world avatars to conduct different learning scenarios. Scenarios using interactions with other avatars are for instance language learning, communication scenarios, role-playing scenarios, collaborative activities, conferences, social groups, and communities.

- **Interactions with the environment**

The environment can be used for development, exploration, or simulation activities. Potential scenarios are cultural immersion, development of models and tools, a virtual campus and classrooms, virtual exhibitions, virtual (archaeological) history tours, virtual facilities, a virtual museum, technical training, virtual field trips, simulated experiences, safety-focused lessons or virtual laboratories.

As one illustrative example, Figure 16, shows a language learning scenario to develop and improve together with other avatars reading skills, listening skills, writing skills and speaking skills. Cultural sights of Madrid help experience a visual, auditory, and cultural immersion (Ibáñez et al., 2011).

Different VWs are suitable for educational purpose. In the next section, different extensible environments will be introduced and compared.



Figure 16: Learning Spanish at the virtual Gran Via in Madrid (OWL Blog, 2012)

### 2.3.3 Extensible Virtual World Environments

In this section, three VW environments, Second Life, Open Wonderland and Open Simulator are compared. All three VWs have a high educational potential with regard to their extensibility and were already used for several educational research studies and application scenarios.

#### Second Life

The Second Life (SL) website (2009) describes the environment as “3d world where everyone you see is a real person and every place you visit is built by people just like you”. Second Life is probably the most common VW environment and mainly emphasis on social interactions. It is free to use, but creating an own environment, what is also called island, is about \$295 USD a month in maintenance costs (Second Life Education, 2011). It has a broad educational community and many institutions and universities already acquired spaces for different learning activities (Boulos, Hetherington, & Wheeler, 2007).



Figure 17: Screenshots of the virtual world environments Second Life

## Open Simulator

The Open Simulator (OpenSim) Website (2010) describes the environment as “*open source multi-platform, multi-user 3d application server. It can be used to create a virtual environment (or world) which can be accessed through a variety of clients, on multiple protocols. OpenSimulator allows virtual world developers to customize their worlds using the technologies they feel work best - we’ve designed the framework to be easily extensible*”. OpenSim is based on the SL system, but is open source, and it is free to use and develop. Also, the server is separated from the SL servers, which is open for the entire community. OpenSim requires an own running server instance to.



Figure 18: Screenshot of OpenSimulator retrieved from OpenSim Website (2010)

## Open Wonderland

Open Wonderland (OWL) is described as “*an open source toolkit for creating collaborative 3d virtual worlds. Within those worlds, users can communicate with high-fidelity, immersive audio, share live desktop applications, and collaborate in an education, business, or government context. [...] The vision for Open Wonderland is to provide an environment that is robust enough in terms of security, scalability, reliability, and functionality that organizations can rely on it as a place to conduct real business or education*” (OWL Website, 2007). OWL is a free, open source and Java-based environment with an emphasis on extensibility and collaborative activities. Because of the possibility of sharing desktop applications, users can for instance easily work together on Open Office documents, or use Netbeans together. OWL runs on an own server instance.



Figure 19: Screenshot of Open Wonderland

According to their descriptions they all have a different purpose and provide different features. While Second Life sets the emphasis on social activities and hosts different social milieus, OpenSimulator focuses on extensibility and present itself as a playground for developers. Open Wonderland is introduced as an extensible, collaborative toolkit for educational and business context. Table 1 shows a comparison of the three VW environments based on the results of Allison, Miller, Sturgeon, Nicoll, & Perera (2010), who compared Second Life and OpenSimulator from an educators' perspective.

	<b>Second Life</b>	<b>OpenSimulator</b>	<b>Open Wonderland</b>
<b>Commercial cost</b>	Rental fee	Free, open source (own server required)	Free, open source (own server required)
<b>Available space</b>	based on land rental fee	limited by own server capability	limited by own server capability
<b>Programming language</b>	Linden Scripting Language (LSL)	LSL and C#	Java
<b>Age restrictions</b>	different restrictions	None	None
<b>Adult content and other distractions</b>	extensive social milieus	Can be configured solely for educational use	Can be configured solely for educational use
<b>Avatar name</b>	Linden Labs name	any	any
<b>Privacy of personal work</b>	Protection options	No protection options	Security group management
<b>Quality of Latency</b>	Can be poor due to network latency	Local server results in lower latency	Local server results in lower latency
<b>Firewall problems</b>	Many institutions refuse to open all the required ports	Server can be located within the institution, outside: same as Second Life	Server can be located within the institution; outside: same as Second Life
<b>Content copy and backup outside of the virtual world</b>	only available as restrictive 3rd party commercial product	Supported; an entire Island can be archived as a single file	Supported; the entire world can be exported and saved

Table 1: Comparison of conventional the VW environments OpenSimulator and Second Life based on Allison, Miller, Sturgeon, Nicoll, & Perera (2010) with an Open Wonderland complement

The next section introduces some of these scenarios used in showcases with a focus on STEM education.

### 2.3.4 Future Trend of Virtual worlds

Considering the issues and drawbacks of VW environments mentioned in the previous section, the lack of acceptances as well as technical resources are the main problems. Gartner's Hype Cycle is a research tool providing a graphical representation with the purpose of delivering prognoses on potential future trends. The cycle is divided into five phases. The cycle starts with the (1) market introduction of the product (Technology Trigger Phase). It continues with a first (2) phase of success related to some success stories (Peak of inflated expectations). This is followed by a (3) phase of disillusionment related to major failure reports (Through of disillusionment). The fourth phase is another (4) visibility raise related to successful third-generation products (Slope of enlightenment) until the product finally is ready for (5) the mainstream adaption (Plateau of productivity). According to Gartner's Hype Cycle, VW systems were in the peak of inflated expectations phase in 2007 (see Figure 20). In 2012 (see Figure 21), they already moved onto the phase of through-of-disillusionment-phase and are about to enter main stream in 5 to 10 years as described in Figure 22 (Gartner Hype Cycle, 2012).

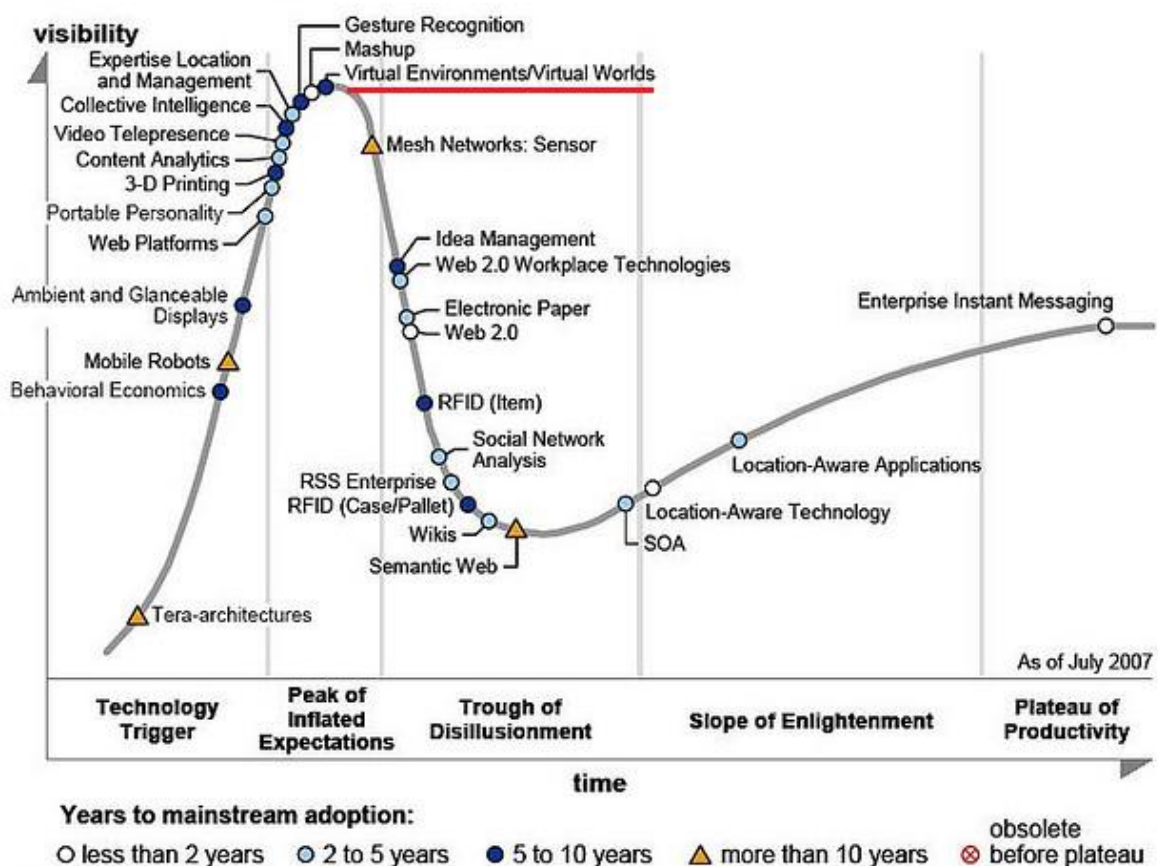


Figure 20: Gartner's Hype Cycle for Emerging Technologies 2007 (Gartner Hype Cycle, 2007)

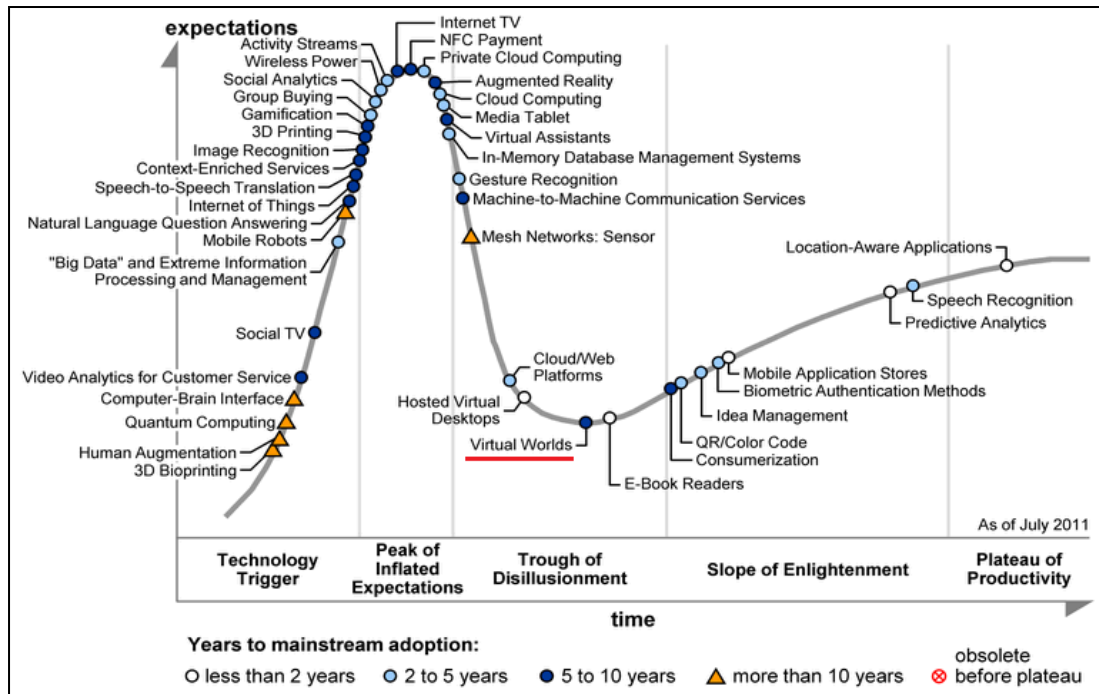


Figure 21: Gartner's Hype Cycle for Emerging Technologies 2012 (Gartner Hype Cycle, 2012)

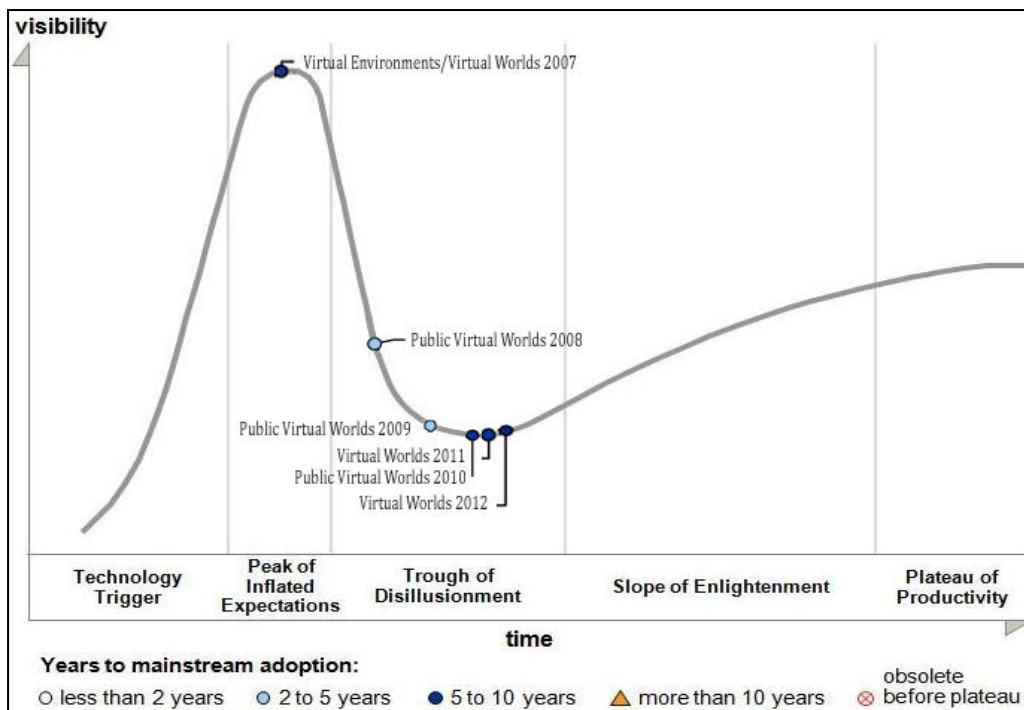


Figure 22: Gartner's Hype Cycle (Gartner Hype Cycle, 2012) showing the development of Virtual worlds form 2007 to 2012

The next section introduces some successfully implemented projects in the domain of interactive virtual STEM education.

## 2.4 Showcases of Interactive Virtual STEM Education

Many educational and research institutions already take advantage of the different interactive possibilities, such as virtual world environments or interactive gaming scenarios. To give an overview of potential scenarios already implemented, this chapter introduces different interactive environments with the purpose of supporting STEM education scenarios.

### 2.4.1 Project Wonderland for Remote Physics experiments

Figure 23 shows the implementation of a prototype of an immersive collaborative learning environment solution that integrates a remote laboratory, a collaborative learning environment and simulations (Gütl et al., 2012). The project was first introduced in Scheucher (2010) and shows a proof of concept of the integration of remote internet-accessible laboratories (iLabs) in combination with the three-dimensional simulation framework TEALsim into the virtual world environment Project Wonderland.

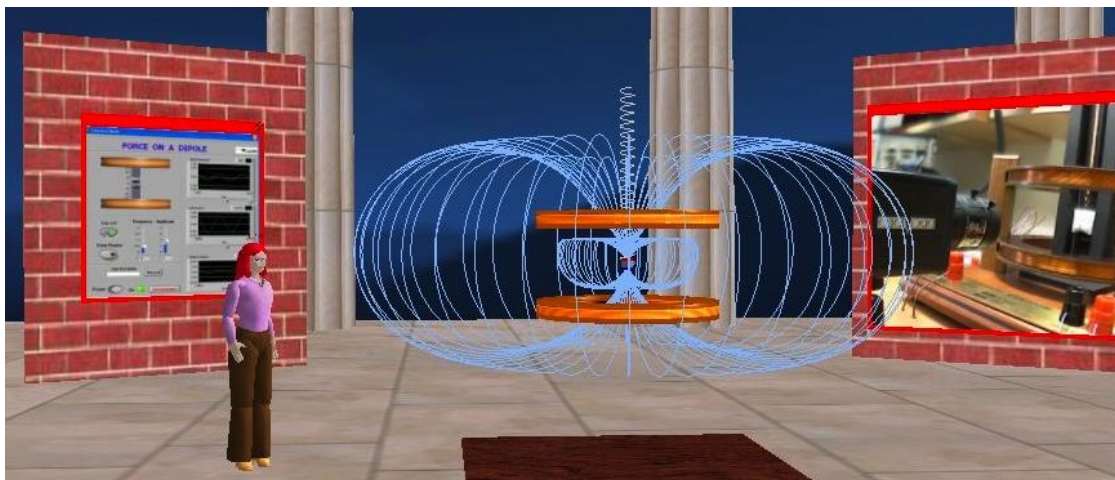


Figure 23: “Force on a dipole” experiment in Project Wonderland (Gütl et al., 2012)

### 2.4.2 Genome Island

Genome Island is a virtual learning laboratory environment in Second Life, where students can experience more than 60 interactive experiments and different exhibits in the domains genetics and bioinformatics. It is not only designed for virtual learners, but also as an addition for face-to-face students. Figure 24 demonstrates the design of a tower, which focuses on molecular and genetic experiments. The right image shows the chromosome café, which represents a gallery of human chromosomes and is part of the tower (Clark, 2012).



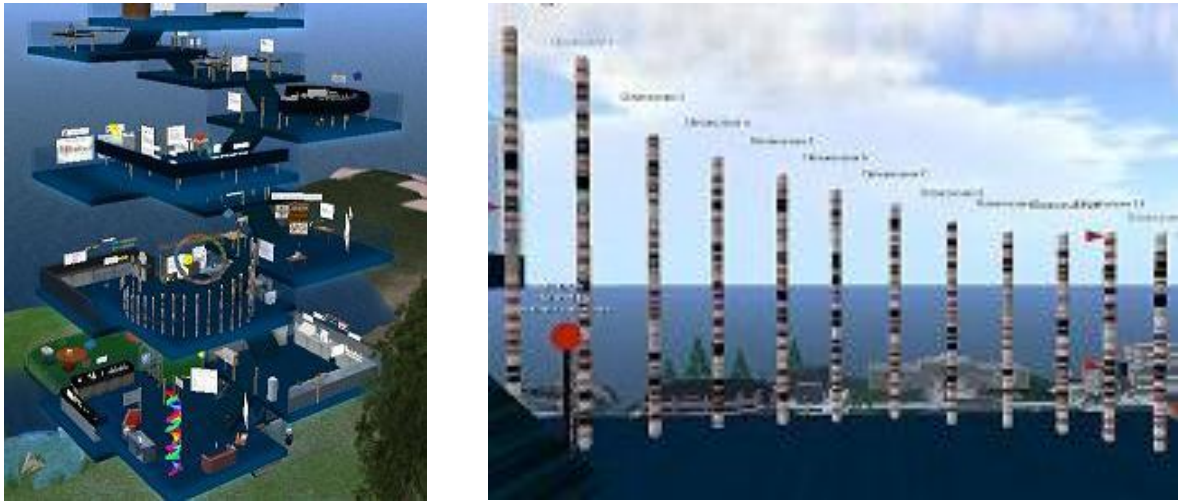


Figure 24: Genome Island and Chromosome café in Second Life (Genome Guide, 2012)

### 2.4.3 NASA initiatives

NASA is focusing their educational research also on virtual education projects such as interactive learning games and virtual world environment. They use MMOGs to enhance the development and to exercise the required skills such as strategic thinking, interpretative analysis, problem solving, team-building, and adaption to rapid change (Laughlin, Roper, & Howell, 2007). Moonbase Alpha (see Figure 25) is a 3d immersive single and multiplayer online game, where user can step into the role of a NASA crewmember to explore different missions and try to solve realistic mission challenges.



Figure 25: Screenshots from the Moonbase Alphas game (NASA Learning Technologies, 2012)



Figure 26: NASA eEducation Island in Second Life (NASA Learning Technologies, 2012)

NASA also hosts different educational projects in the virtual world environment Second Life and Teen Second Life. Their main focus is the development of the NASA eEducation Island (see Figure 26) where users for instance can explore the surface of the moon or visit an interactive planetarium showing real-time constellations (NASA Website, 2009).

## 2.5 Summary

STEM education is a challenging task. Educational principles based on constructivism can help improve the students' understanding. In particular, learning theories such as TEAL, based on interactive engagement activities are proven to improve the students' conceptual understanding of abstract domains such as physics. The TEAL approach uses especially designed studio classrooms, hands-on experiments, simulations, concept questions and communicative, collaborative tasks to teach freshmen physics. However, not every institution or university can apply this method due to the high implementation costs. In addition, the TEAL approach is not designed to enhance distance education scenarios. Traditional e-learning approaches do not seem to fulfill TEAL's requirements because of a lack of interactivity, motivational aspects and communicative and collaborative potential.

Different technology-enhanced tools and activities can help overcome those issues. As a result of their interactivity, particular remote laboratories and simulations can enhance the conceptual understanding of students. Discussions and collaborative activities raise the students' motivation and can reduce the dropout rate (Gütl, 2011). Also, game-based approaches and gamified systems can enhance the students' motivation. Especially games in 3d virtual worlds such as World of Warcraft are receiving increased interest. In comparison to many traditional games, users develop in so called MMOGs entire political, economical and social systems. These virtual worlds also engage educators to develop interactive, social and collaborative massively online learning scenarios. Virtual worlds as *immersive, persistent multi-user environments representing individuals as avatars, which are able to interact with other users, objects and the environment in real-time by using a network*, are introduced as social, collaborative environments. Extensible virtual world environments such as Second Life, Open Simulator or Open Wonderland are attracting the attention of educational communities. In the next chapter, TEAL's requirements are identified to design and adapt the corresponding concepts in a 3d virtual environment.

### 3 Design and Conceptual Model of the Virtual TEAL World

The main objective of this work is to implement the success factors of the TEAL model in an affordable environment that enhances distance-learning activities. This chapter points out the single requirements for the 3d virtual environment defined by the TEAL approach and previous findings in a literature study and gives an overview of the used methods and models to implement a 3d virtual world representation of the TEAL approach. While this chapter focuses on introducing a model that can be integrated into different virtual environments, the next chapter will introduce the implementation into the VW environment Open Wonderland.

#### 3.1 Iterative Development

The Virtual TEAL World (VTW) was implemented using an iterative virtualization model approach (IVA) as shown in Figure 27 (Gütl & Pirker, 2011). Because of the lack of usability guidelines for virtual world environments and also in-world tools, Nielsen's usability heuristics were used as a basis and adapted according to the individual needs and issues of virtual world environments. These usability heuristics serve as a basis for further requirement definitions and developments. After that, the requirements with a focus on the pedagogical objectives of the TEAL approach are defined. After the establishment of a combined requirement list (RL), the world is designed and implemented on the basis of this RL. In the third and fourth step of the IVA, the world is tested and evaluated by the main stakeholders and domain experts, such as physicists, physics instructors, and students. Their feedback is used to redefine and adapt the RL. This chapter already points out the RL that was the final delivery of several cycle steps. Insights and findings that were discovered during this iterative process will be outlined in chapter six.

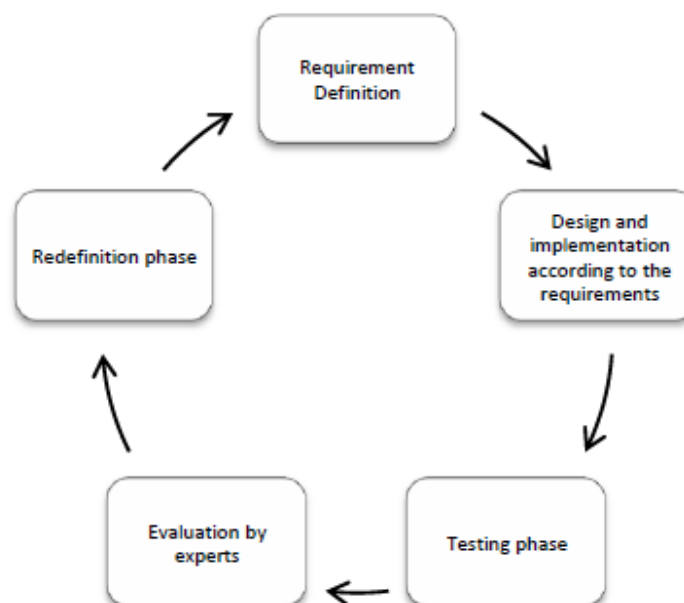


Figure 27: Iterative Virtualization Model Approach (Gütl & Pirker, 2011)

## 3.2 Usability Heuristics for Virtual Worlds

Nielson (2000) points out five key qualitative attributes to assess the usability of a system: (1) the ease of learning how to use the system, (2) the ability to remember how to interact with the system, (3) the efficiency and speed of the performed tasks, (4) the users' satisfaction with the system interactions, and (5) the users' errors making and resolving. In particular, designing a 3d virtual environment is a challenging process that addresses not only technical issues such as the rendering performance. User studies show that disorienting navigation, complex user action, and annoying occlusions can slow down the performance in the real world as well as in a three-dimensional environment and interface (Schneidermand & Plaisant, 2010; Cockburn & McKenzie, 2002). Based on Nielson's (1995) usability heuristics, different guidelines from literature for designing three-dimensional interfaces and environments can be adapted:

- **(H1) Feedback and visibility of system status**

The VW environment and the in-world tools should give users appropriate feedback within a reasonable time about what is going on at the moment. Users should be aware of potential in-world activities and interactions with other objects (Muñoz & Thiago Barcelos, 2012).

- **(H2) Match between system and the real world**

A common language, familiar and easy understandable to the user, should be chosen. Real-world conventions should be followed and the VW should be adapted to familiar systems and environments (Gütl & Pirker, 2011) to help the users understand the environment. Asynchronous and synchronous remote collaboration should be enabled (Schneidermand and Plaisant, 2010) and should be similar to real world interactions (Muñoz & Thiago Barcelos, 2012).

- **(H3) User control and freedom**

User actions and interactions should be intuitive and reversible. A history should be provided to enable users recording, undoing, and replaying actions. Tools for selecting, marking, and measuring should be offered. Different actions on objects (such as saving, copying, annotating, sharing or sending) should be possible (Schneidermand and Plaisant, 2010). The navigation must be intuitive and memorable (Muñoz & Thiago Barcelos, 2012). In particular, three-dimensional objects require adapted manipulations. X-ray vision should be provided to see into or beyond objects. Semantic zooming and moving should be supported by enabling a focus on the objects' front and center (Schneidermand and Plaisant, 2010).

- **(H4) Consistency and standards**

The VW environment and in-world situations and interactions must be consistent regarding language and behavior (Muñoz & Thiago Barcelos, 2012). Different tools should be consistent in the way they are designed and working.

- **(H5) Error prevention**  
A careful design with a focus on error prevention and potential wrong user behavior should prevent users from making mistakes in the first place (Muñoz & Thiago Barcelos, 2012).
- **(H6) Recognition rather than recall**  
The user's memory load should be minimized by making places, objects, actions, and options visible. Explanatory text should be controllable on demand by users, what can be realized by adding for instance pop-ups or floating elements. Places inside the VW should be easily accessible using landmark indexes. An overview, such as a map, should be provided to the users (Schneidermand and Plaisant, 2010; Muñoz & Thiago Barcelos, 2012).
- **(H7) Flexibility and efficiency of use**  
Accelerators and editable interfaces should be provided or definable to enhance the efficiency of the interactions for advanced users (Muñoz & Thiago Barcelos, 2012). Novel 3d icons to represent concepts that are more recognizable and memorable should be developed. Users should be able to shift the context rapidly. Hence teleportation should be possible (Schneidermand and Plaisant, 2010).
- **(H8) Aesthetic and minimalist design**  
Dialogues should not contain irrelevant information. The VW should not contain objects or actions that are not or rarely needed. Control panels should be well-arranged and not overloaded (Muñoz & Thiago Barcelos, 2012).
- **(H9) Help users recognize, diagnose, and recover from errors**  
Error messages must provide the user relevant information about the problem and how to solve it in plain language (Muñoz & Thiago Barcelos, 2012).
- **(H10) Help and documentation**  
Help and documentation must be easily accessible, not only online, but also inside the VW (Muñoz & Thiago Barcelos, 2012). Explanatory pop-ups or floating elements can give such information about tools, objects or actions (Schneidermand and Plaisant, 2010).

To make use of different psychological stimulators as well, the impact of different colors should be considered in the design phase. Engelbrecht (2003) refers to different goals by using specialized color schemes. The colors should emphasize the function of the virtual environment, and the corresponding tasks. Over-stimulations, as well as under-stimulations, should be avoided. Positive emotional and physiological effects should be created. He especially recommends cool colors for upper grade classrooms for their ability to enhance concentration.

### 3.3 TEAL Concepts

The VTW should provide a stand-alone solution and a combined solution as an extension to the existing TEAL courses. For that reason, the implementation focuses on integrating the majority of the TEAL concepts in-world. Figure 28 gives an overview of the single components of the TEAL framework sorted by their categories. In-class activities are marked in bold.

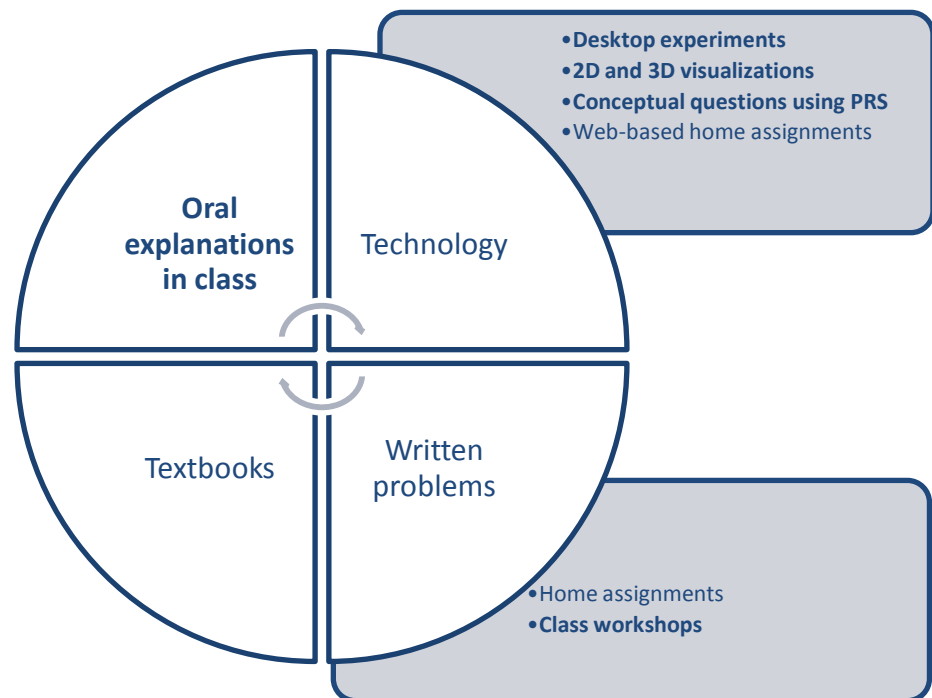


Figure 28: Overview of the single components of the TEAL framework (TEAL Casestudies, 2005)

For the implementation of the VTW in particular the following class-based TEAL concepts are considered:

- Instruction: Oral explanation in class
- Experiments: Hands-on desktop experiments
- Simulations and Visualizations: 2D and 3d visualizations
- Quizzes: Conceptual questions using personal response systems (PRS)
- Assignments: Class workshops

Strengths of TEAL are in particular motivating, collaborative, and interactive activities to enhance the students' understanding for physical phenomena. The TEAL approach focuses on the following pedagogical objects (Belcher et al., 2004):

- **Collaborative learning (Collaboration)**  
Students work together in groups between 3 and 9 and sit on round tables what enables them to discuss and collaborate.

- **Networked laptops (Hands-on experiments)**  
Students work together in groups of 3 on a laptop that is linked to a desktop experiment, what enables corresponding live data acquisition.
- **Media-rich software (Simulations)**  
Simulation software or web-based applications are used to visualize physics phenomena via the classroom laptops. Most of the simulations are provided by the simulation framework TEALsim.
- **Course notes (Information)**  
Extensive course notes are provided with links to the corresponding visualizations.

To simplify in-world implementation of these concepts in line with the according requirements of TEAL, the concepts are classified into three key concepts: (1) basic knowledge acquisition, (2) enhancement of the conceptual understanding and (3) measurement of the learning progress. They can be applied using a cyclic teaching approach to transfer single contents. Table 2 summarizes the TEAL concepts and pedagogical objects and links it to the corresponding cycle step.

	<b>Cycle step</b>	<b>Concepts</b>	<b>Pedagogical Object</b>
<b>Prior class</b>	Preparation	Textbook reading	
<b>1</b>	<b><i>Basic knowledge acquisition</i></b>	Instructions	Oral explanation Course notes
<b>2</b>	<b><i>Enhancement of the conceptual understanding</i></b>	Experiments, simulations and visualizations, discussion about concept questions, and assignments	Collaborative learning (Collaboration) Networked laptops (Hands-on experiments) Media-rich software – TEALsim (Simulations) Concept questions
<b>3</b>	<b><i>Measurement of learning progress</i></b>	Quizzes, assignments	Concept questions (PRS) Assessment
<b>After class</b>	Consolidation	Home assignments	

Table 2: Overview of the single TEAL components, concepts and the simplified cycle steps

Considering the required activities and characteristics of the single cycle steps and using the defined concepts, objects and the cyclic teaching method different requirements can be identified. The next section introduces these requirements imposed on the VTW.

### 3.4 Requirement analysis

Considering the requirements of implementing the TEAL approach in a virtual world environment two main stakeholders have to be considered: (1) Instructors and (2) students. Instructors require a user-friendly environment, where they can easily add, edit and delete learning content, create new quizzes and can see the users' answers to the concept questions. Students need an environment that is easy to use and supports collaborative and communicative activities. The VW environment should support visualizations and simulations. To avoid the acceptance issue mentioned in the previous chapter, the design of the world also focuses on advantages of VW environments in comparison to conventional e-learning tools and motivational and collaborative activities. The strengths of Virtual world environments in comparison to traditional e-learning system are potential communicative, interactive and collaborative activities. Hence the design of the VTW concentrates on emphasizing these activities to raise the students' motivation to engage them not only to learn the concepts, but also to use this modern and unfamiliar environment. Interactivity and collaborative activities should be a main issue of the design.

- **Interactivity**

In particular interactive elements should raise the students' interests and motivation. Simulations of physical phenomena can enhance their conceptual understanding.

- **Collaboration**

Collaborative in-world tasks, such as brainstorming or joint discussions of concept questions raise the students' understanding and their motivation. Different tools such as collaborative whiteboards should enhance the collaboration possibilities.

- **Assessability**

Instructors should be able to follow and assess the students' activities and question answers to measure the actual learning progress.

Summarizing the demands of the stakeholders the main functional requirements can be listed by means of the single cycle steps of TEAL listed in Table 2.

#### 1. Basic knowledge acquisition

To impart the basic knowledge different documents, videos, and animations are shown to demonstrate the phenomena in an attractive and motivating way. Using videos and animations, the different design aspects for videos such as the modality effect, the redundancy principle, the personalization, and the contiguity of commentaries have to be considered (Niegemann, 2008). Students should be able to gain this basic knowledge either alone or in a collaborative way. The following simplified functional requirements for the cycle step basic knowledge acquisition can be identified:



- 1.1. Usage of documents
  - 1.1.1. Instructors should be able to insert, move and delete documents such as PDFs
  - 1.1.2. Students should be able to view the inserted documents
- 1.2. Usage of images
  - 1.2.1. Instructors should be able to insert, move and delete images with different formats such as .png, .jpg or .gif
  - 1.2.2. Students should be able to view the inserted images
- 1.3. Usage of videos and animations
  - 1.3.1. Instructors should be able to insert, move and delete videos with different formats such as .mov, .avi or .mpeg
  - 1.3.2. Students should be able to watch, start, pause, replay and stop the inserted videos
- 1.4. Usage of whiteboards
  - 1.4.1. Instructors should be able to insert, move and delete a whiteboard and add content to it

## **2. Enhancement of the conceptual understanding**

In order to add interactive features to the VTW, different simulations should be provided in-world. For this purpose, a three-dimensional open-source simulation framework such as TEAL should be used and integrated into the virtual world environment. This enables the use of in-world, virtual, three-dimensional, and immersive simulations. These in-world simulations are used to visualize physical concepts, make invisible phenomena visible, activate group discussions, and engage collaborative behavior. Especially the three-dimensional representation should motivate students to interact with the tools and the environment to enhance their conceptual understanding in a motivating way. A user-friendly interface, collaborative assignments and tasks, assessment, and adaptation possibilities should help promote the TEALsim simulations in-world. The following simplified functional requirements for the cycle step enhancement of the conceptual understanding can be identified:

- 2.1. Usage of in-world simulations (TEALsim)
  - 2.1.1. Instructors should be able to insert, move, choose and delete different simulations of the simulation framework TEALsim
  - 2.1.2. Students should be able to watch, configure and interact with the simulations together
- 2.2. Brainstorming and discussion possibilities (Whiteboard)
  - 2.2.1. Instructors should be able to insert, move and delete whiteboards
  - 2.2.2. Students should be able to write and draw together on whiteboards and use brainstorming tools and activities (such as inserting images)
- 2.3. Concept questions and discussion spaces
  - 2.3.1. Instructors should be able to insert, edit, delete and add new concept questions and link it to a corresponding discussion area

- 2.3.2. Students should be able to answer concept questions and experience a corresponding system reaction

### 3. Measurement of the learning progress

In order to measure and assess the learning progress, virtual concept questions and quiz possibilities have to be implemented in the virtual world environment. This tool should focus on usability, interactivity, collaboration, and motivation. It should not only test the knowledge but also foster it by active discussions about the actual question. The following simplified functional requirements for the cycle step measurement of the learning progress can be identified:

#### 3.1. Usage of a question tool

- 3.1.1. Instructors should be able to insert, edit, delete and add different kinds of questions and link it to corresponding discussion areas

- 3.1.2. Students should be able to answer questions

#### 3.2. Usage of a web-interface

- 3.2.1. Instructors should be able to review the answers of students with a corresponding web-interface

- 3.2.2. Instructors should be able to insert, edit, delete and add different kinds of questions with a corresponding web-interface

- 3.2.3. Students should be able to review the questions and their answers at a corresponding web-interface

Summarizing the requirements of the single cycle steps of TEAL listed in Table 2 the following non-functional requirements can be outlined:

- **Usability**

The Virtual TEAL World must be a user-friendly environment that is easy to use for students and instructors. Enhanced usability can avoid user frustration and increases the efficiency. Usability should enhance the users' motivation to use the system, enhance learnability, efficiency, memorability, satisfaction, and reduce errors (Nielson, 1995).

- **Configurable**

Instructors should be able to adapt learning content without the help of an expert.

- **Flexibility**

Content should be easily movable and scalable.

- **Extensibility**

It should be easy to add new features and content, such as simulations or content to be learned.

- **Performance**  
The response times should be good enough to ensure an uninterrupted learning experience.
- **Scalability**  
Performance issues should be kept down by offering different server spaces according to the number of user groups logged into the virtual world environment.

Summarizing the requirements the VTW should be a user-friendly, collaborative environment, where students can learn and work together to enhance their conceptual understanding with the help of simulations, visualizations and material being learned inserted by an instructor in a motivational way.

### 3.5 Conceptual Architecture of the Virtual TEAL World

The entire Virtual TEAL World should be based on collaborative tasks. Student groups of 3-4 students can walk together to the single learning tasks and modules of the world to conduct and discuss activities and questions together. Oral in-class explanation can be virtually represented using descriptive videos and documents. TEAL used different multimedia visualizations of the simulations framework TEALsim. A module supporting an in-world integration of TEALsim should be implemented and integrated into the virtual learning environment. In addition, a tool providing and handling concept questions to simulate TEAL's personal response system should be integrated into the system. Table 3 lists the single pedagogical elements used by TEAL and a corresponding potential realization in the Virtual TEAL World.

	<b>TEAL environment</b>	<b>Virtual TEAL World</b>
<b>Oral explanation</b>	In class	Videos and documents in-world
<b>Collaborative learning</b>	Groups of 3, with 9 students sitting at a round table and discussing electromagnetic phenomena.	A group of 3-4 students does a 'learning round-trip' in-world
<b>Networked laptops</b>	One for each group of 3, with data acquisition links to desktop experiments.	Desktop experiments are either simulated in-world or shown via videos
<b>Multimedia visualization (TEALsim)</b>	Media-rich software delivered via class laptops and the web.	3d representation via the TEALsim module in-world
<b>Course notes</b>	Online documents with links to the visualizations.	In-world documents
<b>Conceptual questions</b>	Using Personal Response Systems	Using a specially designed learning-module with an optional interface to a conventional e-learning tool

Table 3: Overview of the single TEAL component and the corresponding in-world representation (Pirker, Berger, Gütl, Belcher, & Bailey, 2012)

Figure 28 shows a simplified version of a potential in-world scenario using a cyclic approach to impart a single learning content. An instructor adds the learning content into the Virtual TEAL World but does not necessarily attend in-world meetings. Accompanying concept questions before and after new learning content are used to assess the learning progress and ensure the achievement of the educational objectives.

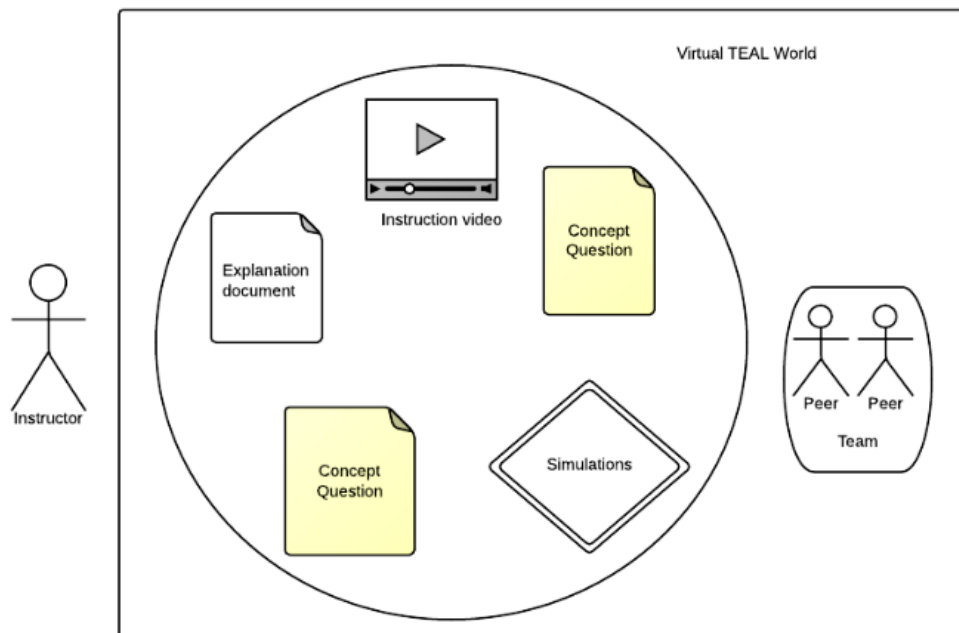


Figure 29: Overview of the single components of the VTW using a cyclic learning approach

Students meet each other at the same time in the Virtual TEAL World. The roundtrips start by reading introductions and first concept explanations. Videos of phenomena and experiments give students a first impression about the behavior of the learned concepts. A first knowledge assessment in the form of a concept question enables them, to discuss the watched concepts. After that, they can try to verify their theories within a simulation experiment to rethink their first answers.

### 3.6 Integration of the Virtual TEAL World in Open Wonderland

The initial goal of the design and implementation of the Virtual TEAL World was the integration of the introduced TEAL concepts into a virtual world environment. Different VWs, such as Second Life, Open Simulator and Open Wonderland support educational scenarios. Open Wonderland (OWL) focuses on collaboration and extensibility. It already provides several pedagogical and collaborative tools such as virtual whiteboards, video integration tools or application sharing possibilities. Thus, the VTW is developed in the open-source virtual world environment OWL. Many modules, which already exist in OWL, can be reused. In addition, a module supporting the simulation framework TEALsim is already implemented in Open Wonderland (Berger, 2012). However, this extension needs advancement regarding different identified requirements such as usability and stability. A tool providing and handling concept

questions to simulate TEAL's personal response system has to be implemented from scratch. This chapter explains the modules and components necessary for the implementation of the Virtual TEAL World. First, the simulation framework TEALsim is introduced in more detail, than the virtual world environment Open Wonderland is discussed. In order to implement the outlined requirements of the previous section, two Open Wonderland modules (OWM) and a web component are necessary:

- Adaption and improvement of the existing **TEALsim-Module**
- Creation of the **Concept Question-Module**
- Creation of a **Web-Interface** as link to the Concept Question-Module

The Concept Question-Modules should be extensible. It should be possible to link the questions and user answers to a learning management system (LMS). A demo-web interface demonstrating that ability is implemented as well. The next sections introduce the different required components to integrate a Virtual TEAL World scenario into the virtual world environment OWL.

### 3.6.1 TEALsim

The official TEALsim webpage (2004) describes the tool as „ [...] an environment for creating, presenting, and controlling simulations that represent physical and mathematical concepts. A single simulation may run as either a Java application or Applet. [...] Simulation components include a collection of rendered objects, geometric primitives, simple mechanical tools, and electromagnetic components and constructs designed to work within the simulation model and rendering system.”

#### Concepts

TEALsim was developed to provide an environment for physics students and physics instructors to (1) make abstract concepts easier understandable, (2) make invisible phenomena visible, (3) enhance the conceptual understanding, (4) allow live manipulation of parameters to make the immediate impact visible, and to (5) provide an environment that is extensible by non-programming experts. Simulations should be easily scriptable by physics instructors and students, who are not used to complex programming languages. Figure 30 gives an example on how single components can be added to the simulation using Java.

```
1 // Initialization of the MagneticDipole /
2     MagneticDipole mag = new MagneticDipole();
3     mag.setMu(1.0);
4     mag.setPosition(new Vector3d(0., 0., 0.));
5     mag.setDirection(new Vector3d(0, -1., 0));
6     mag.setMoveable(false);
7     mag.setLength(0.75);
8
```

Figure 30: Adding a magnetic dipole and setting of the initialization values such as the strength or position

To add new components, an XML-based approach that allows instructor the adaption and creation of simulations using XML files, could be considered. This would facilitate the implementation of an extension with a drag-and-drop interface to create new simulations.

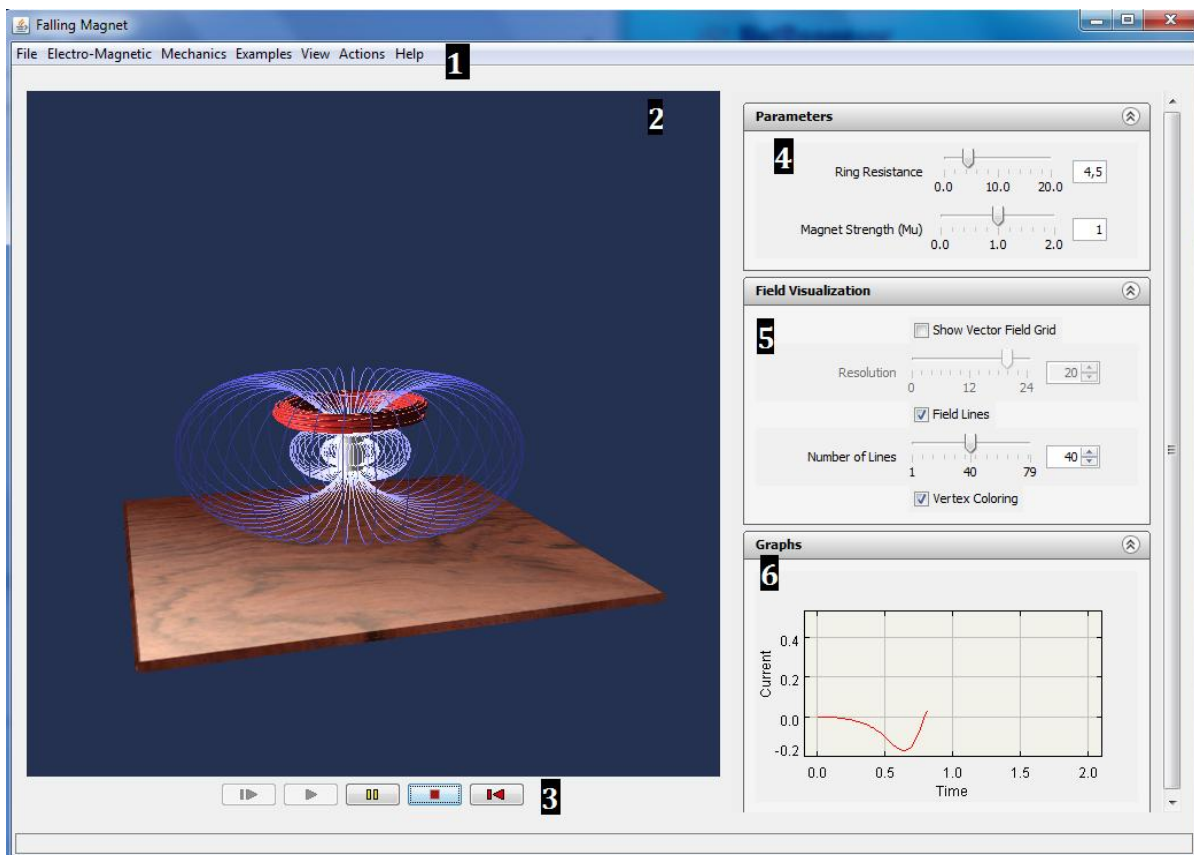


Figure 31: Desktop version of TEALsim

Figure 31 shows a screenshot of TEAL's desktop version. The user can choose different simulations based on their category (Electro-Magnetic or Mechanics) in the main menu {1}. The simulation is displayed in a Java 3d canvas {2} and can be started, paused and resumed using the control elements on the bottom {3}. Some simulations provide a 'Generator Mode' so that students do not have to interact with the simulation, but can observe their behavior by watching a predefined animation flow. Simulation specific interactivities and settings, such as components, ring resistance or numbers of different charges, can be edited in the 'Parameters' tab {4}. User interactions in this area trigger immediate feedback of the simulation, what enhances the understanding of the phenomena. Additional visualization settings can be found in different 'Visualization' tabs, such as the 'Field Visualization' tab {5}. Many simulations support active representation via graphs {6} to make actual values and the corresponding impacts visible for the students.

## Architecture

TEALsim was developed with a focus on extensibility and reusability. Figure 32 shows a simplified version of the main modules of TEALsim. Berger (2012) describes the architecture referring to the Model-View-Controller (MVC) design pattern. Created concrete simulations consisting of the different simulation elements (Model) are loaded by the SimPlayer (Controller). The player creates all the elements including the SimulationEngine, which is responsible for different mathematical and physical calculations. The Viewer component of the pattern is responsible to display the single 3d elements, represented by Java3d or JMonkeyEngine (JME). Further implementation details can be found in Berger (2012).

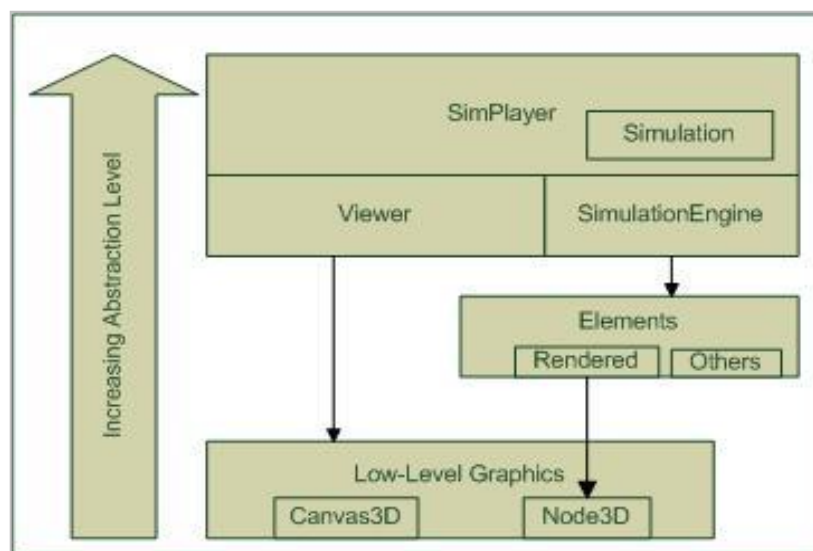


Figure 32: Simplified overview of the main components of TEALsim (Berger, 2012; Pirker, Berger, Gütl, Belcher, & Bailey, 2012)

### 3.6.2 Open Wonderland

Open Wonderland can be described as an open source virtual world environment with the purpose to facilitate the development and design of personalized VWs. Different communication channels, such as immersive audio or text chats, and tools and services such as shared desktop applications or document viewers, facilitate collaboration and communication (OWL Website, 2007).

#### Concepts

Using Open Wonderland as a development framework provides several advantages such as a vivid and aiding community, a well documented codebase, and many documentaries and tutorials. As an open-source project, the OWL project is based entirely on open standards. The project is a growing system related to its easy extensibility and regular community contributions. OWL enables developers to share not only their knowledge, but also to contribute

to the entire project. New OWL features and components can be easily added as OWL-Modules or OWL-Capabilities and shared with the community.

In addition, the content creation was designed to be easy and user-friendly. Users can easily add files and objects into the world by dragging and dropping them from the desktop or a web browser into the OWL client. The resize tools allow users to move and scale objects within the three-dimensional space. This allows also inexperienced users the creation and adaption of entire worlds.

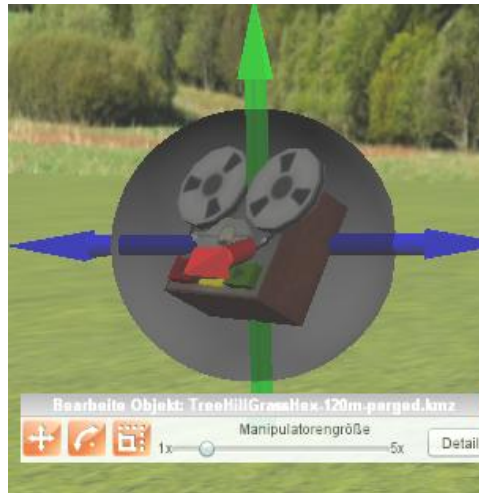


Figure 33: Modifying the object's position using the resize tool

Summarizing we can refer to the definition of Open Wonderland's main goals by Kaplan & Yankelovich (2011): (1) *enabling collaboration with a focus on synchronous interaction*, (2) *provision of an extensible toolkit based on open standards* and (3) *putting place the infrastructure for federation to enable the 3d Web*.

## Architecture

Open Wonderland is implemented using the programming language Java and uses a client-server architecture in order to separate services such as 3d rendering activities and sharing content. The different communication services require different network protocols, such as web services for authentication and content sharing possibilities, TCP (Transmission Control Protocol)-based protocols for communicating world data, and SIP (Session Initiation Protocol) / RTP (Real-Time Transport Protocol) for audio and streaming activities. Therefore, OWL combines four different server systems, which need to cooperate: (1) a web server (realized with the open-source system Glassfish) for the web-based activities and services, (2) a game server for updating the world states (Darkstar Server), (3) JVoiceBridge to enable audio communication, and a shared application server (SAS) to host desktop applications such as Open Office in-world. The client-side rendering system is based on the JMonkeyEngine (JME) and the MT game engine (Kaplan & Yankelovich, 2011). Figure 34 gives an overview of OWL's architecture and the introduced components.



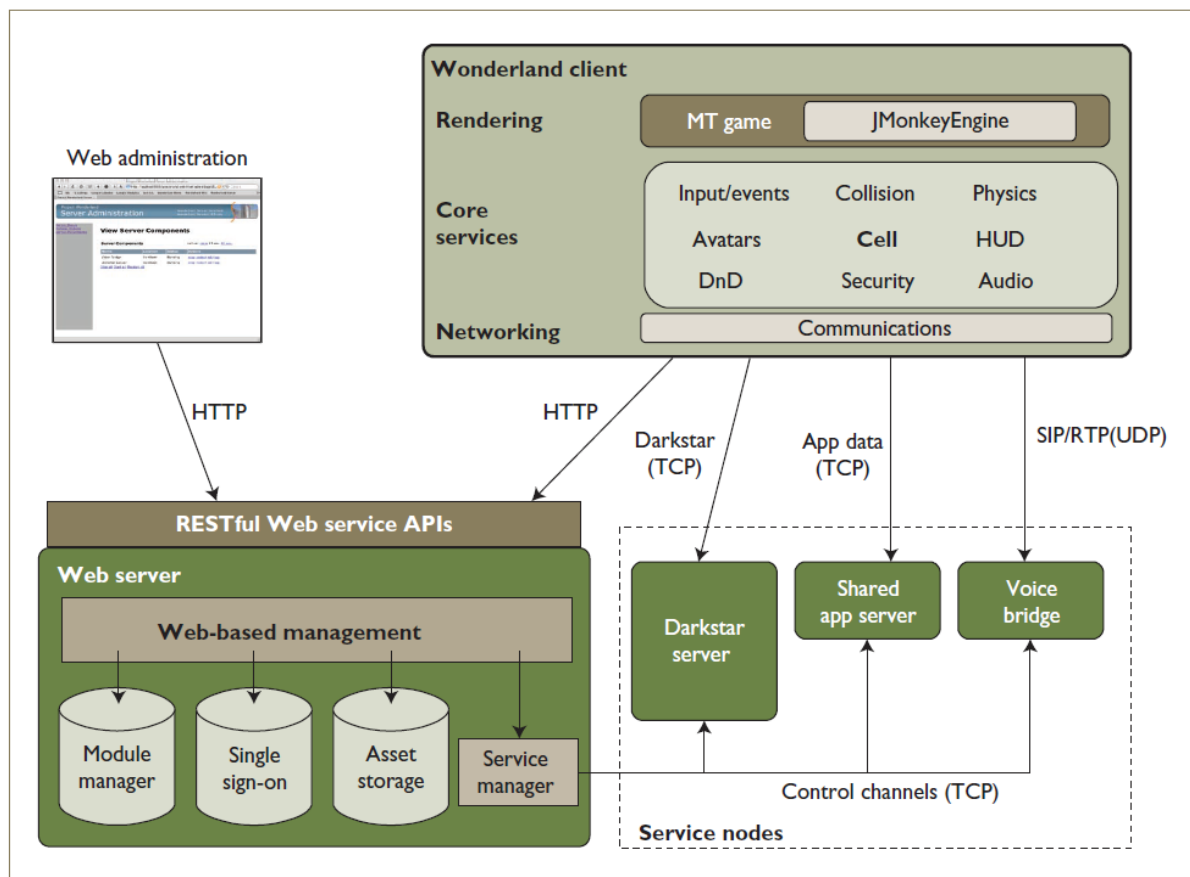


Figure 34: Open Wonderland architecture (Kaplan & Yankelovich, 2011)

Adding new objects or features to the world can be done either by adding single objects represented by a cell, or by implementing a new module or capability. The next section introduces the implemented OWL components and outlines their design and implementation details.

### 3.6.3 Open Wonderland Components

Different components are used for the Virtual TEAL World as a means to enable the different learning activities required in the TEAL approach. Table 4 extends Table 3 with an overview of the tools which are developed (marked bold) and which of them are already provided by Open Wonderland for this purpose. Modules providing the possibility of sharing documents, watching videos and writing notes together come already with the standard setup of Open Wonderland. A first realization of the TEALsim-Module was already implemented (Berger, 2012) and should be improved and adapted based on the defined requirements. In order to provide in-world concept questions and assessment possibilities, an OWL integration of TEAL's concept questions has to be implemented from scratch.

	<b>TEAL environment</b>	<b>Virtual TEAL World</b>	<b>OWL Tools</b>
<b>Oral explanation</b>	In class	Videos and documents in-world	Document Viewer Video Player
<b>Collaborative learning</b>	Groups of 3, with 9 students sitting at a round table and discussing electromagnetic phenomena.	A group of 3-4 students does a 'learning round-trip' in-world	Whiteboards Sticky Notes Document Viewer Shared Applications
<b>Networked laptops</b>	One for each group of 3; with data acquisition links to desktop experiments that students perform and analyze.	Desktop experiments are either simulated in-world or shown via videos	<b>TEALsim-Module</b> Video Player
<b>Multimedia visualization (TEALsim)</b>	Media-rich Software delivered via class laptops and the Web.	3d representation via the TEAL module in-world	<b>TEALsim-Module</b>
<b>Course notes</b>	Web documents with links to the visualizations.	In-world documents	Document Viewer
<b>Conceptual questions</b>	Using Personal Response Systems	Using a specially designed learning-module with an optional interface to conventional e-learning tools	<b>Concept Question-Module</b>

Table 4: Overview of the used tools required by the Virtual TEAL World and an overview of the corresponding toolset provided by Open Wonderland; tools marked bold do not come with the standard installation

For the development of such extensions, OWL provides possibilities through the implementation of (1) *modules*, which are independent collections of code, artwork and other resources and can work on both client and/or server-side. Extensions can also be provided via (2) *capabilities*, and are extending the modules with different attributes. The sittable-capability, for instance, enables users to sit on a module (OWL Website, 2007). The TEALsim in-world realization and also the question creator are both realized as modules.

Open Wonderland already provides a lot of modules focusing on collaborative and educational activities that are required in the TEAL approach. Most of the modules introduced in the next sections already come with the standard Open Wonderland installation.

## Document Viewer

Document Viewers such as the PDFViewer or the ImageViewer are used to display .pdf documents or image files in the virtual world environment. Users can watch PDF presentation either synchronously, so all users can see the same slide, or asynchronously so that one person can browse the slides independently, without affecting the other users. Documents can be

inserted by dragging and dropping a PDF file or an image from an external source such as the desktop or the browser into the OWL client.

## Video Player

The Video Player allows users to embed video files into OWL. The player supports different common formats such as .mov, .flow, .wmv, .mpeg4 or .avi. Like PDF files, videos can be simply inserted using the drag and drop operation.

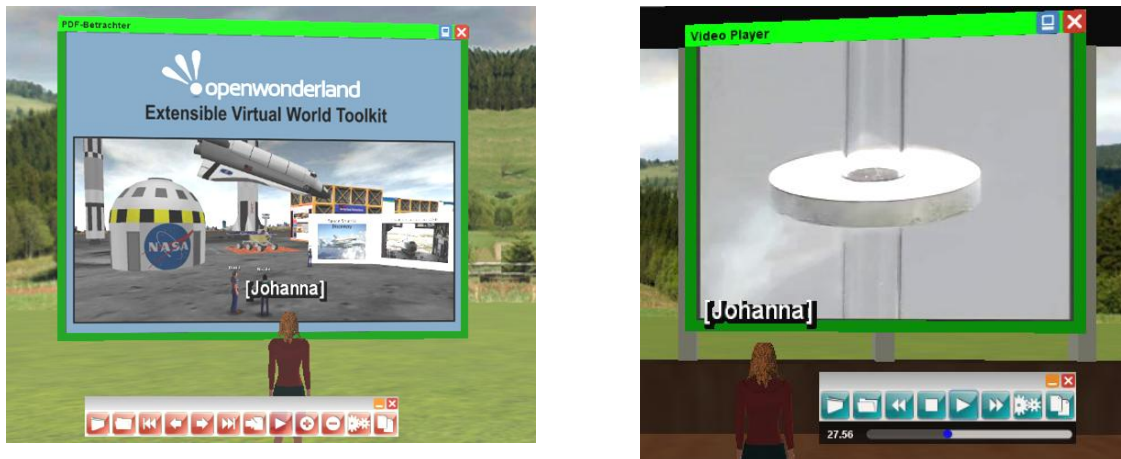


Figure 35: PDF Viewer with control on the bottom on the left; Video Player to watch videos with different formats on the right

## Whiteboard

Users can collaborate and share ideas by drawing and writing on the Whiteboard. As a multi-user application, the Whiteboard allows multiple users at the same time to control and modify it. The module can be inserted using the OWL's 'Insert Object' dialogue.



Figure 36: Whiteboard for writing and drawing in Open Wonderland on the left; Sticky Note for quick and important messages on the left

### Sticky Note

Sticky Notes are used for displaying and editing small notes and comments. In order to make other users aware of the importance of the note, the Sticky Note can be colored differently. Like Whiteboards, the object is inserted in front of the user using the 'Insert Object' command.

### Concept Question-Module

The Concept Question-Module has to be developed to provide assessment possibilities, to integrate TEAL's concept questions into OWL, and as an interface to Learning Management Systems or e-Learning tools. In order to meet the TEAL approach, the questions are divided into (1) discussion questions and (2) personal answer questions. Discussion questions focus on motivating students to collaborate and discuss potential answers, what should enhance their conceptual understanding. After reading the problem, they should discuss the answer possibilities in groups and find a consensus. Personal answer questions, on the other hand, provide assessment and tracking possibilities of the learning curve.

The following three main requirements can be defined:

- An user interface for the creation of new questions and the corresponding answers
- An XML file to allow the user to manage questions using an XML-file
- An Open Wonderland quiz cell, in which users can answer the questions; the tool will automatically log the answers with timestamp in the corresponding XML-File

### TEALsim-Module

The TEALsim-Module is the interface between Open Wonderland and the simulation framework TEALsim (see Figure 37). The first implementation of the TEALsim-Module was developed by Berger (2012) with the goals to first, integrate as many TEAL simulations as possible into OWL and second, to avoid significant changes in the TEAL framework. The main implementation steps thereby were the adaption to OWL's graphic engine JMonkeyEngine (JME) and the integration of a client-server mode (Berger, 2012; Pirker, Berger, Gütl, Belcher, & Bailey, 2012).

For the purpose to enable a first Virtual TEAL World scenario focusing on Faraday's Law phenomena the following requirements were defined:

- The Simulations regarding Faraday's Law should work in-world **fast and stable**
- All users in-world can work with the tool **synchronously**
- The TEALsim-Module should be **user-friendly** and easy to use

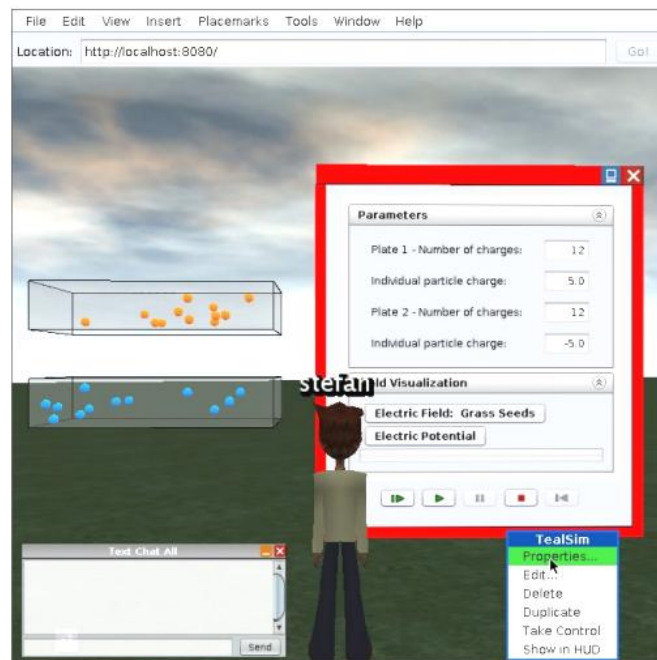


Figure 37: TEALsim simulation Capacitor in Open Wonderland (Berger, 2012)

### 3.6.4 Web Component

The Virtual TEAL World is not only designed to be a standalone learning environment, but also to be a collaborative addition to a conventional e-Learning tool. In-world actions such as the answers of the concept questions should be visible to students for self-assessment reasons and teachers to assess the students' performance. Instructors should be able to view and edit the question catalogue using the web interface. A basic showcase platform should be developed to present the possibility of a linkage to an e-learning tool or a LMS. The web interface gives students the possibility to review and answer the questions also in this 2d environment. Two main requirements can be defined.

- The username and the given answers with the corresponding timestamp should be displayed on the webpage
- Instructors should be able to view and edit the list of questions which can be displayed using the Concept Question-Module

The web component only demonstrates the adaptability of the Concept Question-module as an interface to an e-learning tool. Therefore, requirements such as security, usability, and stability can be disregarded.

### 3.6.5 Conceptual Component Architecture

Figure 38 gives an overview how the single components are integrated into the Open Wonderland environment and how they work together. Open Wonderland already comes with modules such as document viewer, video player or sticky notes. The Concept Question-Module is

implemented as an interface between an e-learning web component and the VW. XML files are used to exchange data. Students should be able to review their answers using the web component, instructors should be able to assess the answers and also edit the questions. Instructors can define new simulations using the original TEALsim framework. The simulations are integrated into the TEALsim-Module and can be used by all users of the VTW.

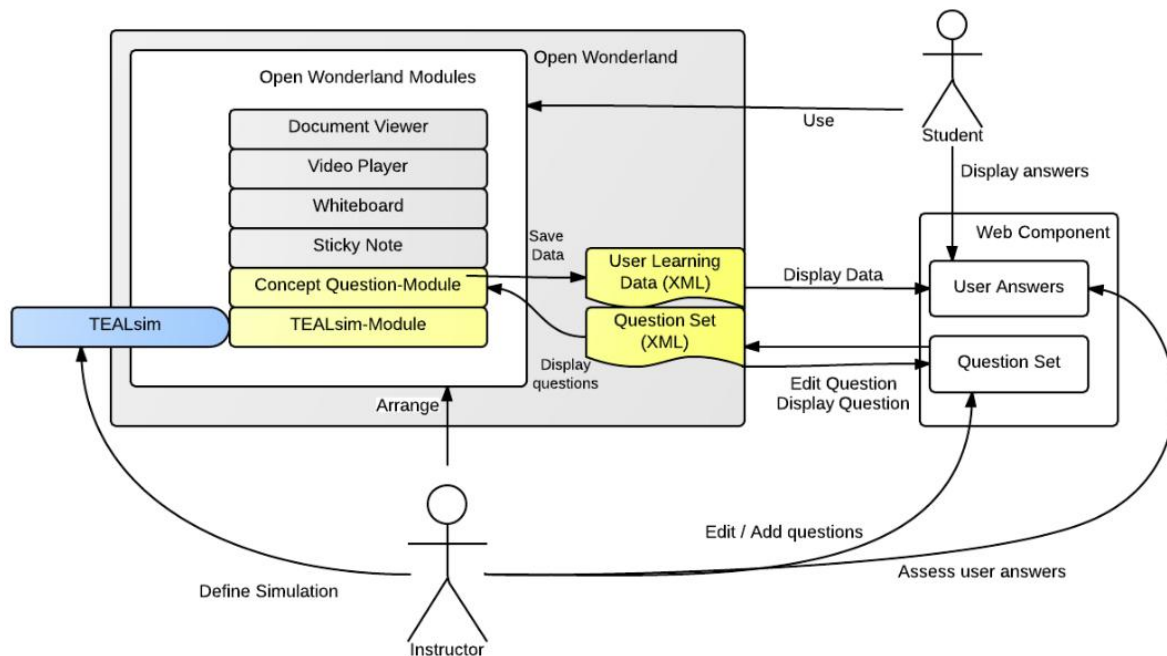


Figure 38: Conceptual architecture how the single components interact with each other

### 3.7 Summary

Before developing the first prototype of the VTW, different requirements have been defined using the single steps of the cyclic model. In the first step general design aspects have to be considered. To focus on user centric design, Nielsen's (1995) ten usability heuristics are used and adapted to the specific characteristics and problems of VWs: (1) Feedback and visibility of system status, (2) match between system and the real world, (3) user control and freedom, (4) consistency and standards, (5) error prevention, (6) recognition rather than recall, (7) flexibility and efficiency of use, (8) aesthetic and minimal design, (9) help users recognize, and (10) help and documentation. The TEAL approach uses different pedagogical activities, such as concept questions, interactive simulations, collaborative assignments, oral in-class explanations, and hands-on experiments.

The TEAL concept can be integrated into a virtual environment as cyclic model with the steps (1) basic knowledge acquisition, (2) enhancement of the conceptual understanding, and (3) measurement of the learning progress. Referring to the basic knowledge acquisition the usage of documents, images, videos, and animations has to be considered. Oral in-class explanations are substituted by documents, videos and animations considering pedagogical design issues such as the modality effect, the redundancy principle, the contiguity of commentaries, and the

personalization of commentaries (Niegemann, 2008). In order to enhance the conceptual understanding, in-world simulations, discussion area and concept questions should be provided. The VTW requires question tools and an interface to a corresponding web component, to measure the learning progress. Focusing on the user experience of students and instructors, design aspects should be in line with the non-functional requirements usability, configurability, flexibility, extensibility, performance, and scalability. The in-world integration of a virtual, interactive three-dimensional simulation toolkit such as TEALsim is used to enhance the students' conceptual understanding. Similar assessment and learning progress measurement possibilities should be integrated into the virtual learning environment, which should measure the progress before and after the single learning steps.

The virtual world toolkit Open Wonderland is used to implement a first VTW scenario because many tools and components necessary for the TEAL approach, such as whiteboards, document viewers, shared applications or video players, already come with the standard installation. Not covered by the standard environment are the interactive simulations and the concept questions. An in-world representation of concept questions enables students discussing the phenomena and provides teachers with a valuable assessment method. TEALsim's simulations can be involved by adding the TEALsim-Module to Open Wonderland. A first integration of the TEALsim simulation framework is available for Open Wonderland. The main tasks to integrate the Virtual TEAL World model in OWL are the adaption and improvement of the existing TEALsim-Module to fulfill the defined requirements, the creation of a module to integrate in-world concept questions and assessment possibilities and the creation of a corresponding web-interface as a link to the Concept Question-Module. The introduced Concept Question-module enables question and answer scenarios in-world and provides, with the help of a logging system, a potential interface to asynchronous e-learning systems like Moodle. The next section discusses the implementation details of the components.

## 4 Implementation Details and Showcase Scenario

This chapter outlines the implementation and adaptation of the components based on the requirement list and the conceptual model defined in the previous chapter. First, a short overview of the development of Open Wonderland modules is given. In the following section implementation details of the TEALsim-module, an interface between OWL and TEALsim, are discussed. After that, the Concept Question-module and the corresponding demo web-interface are introduced.

### 4.1 Open Wonderland Modules

Three-dimensional components can be added to Open Wonderland using a cell-architecture, comprising of a client, server and common part. The in-world cell is responsible for rendering objects and models in the three-dimensional space. Every cell consists of a server piece and a client piece, communicating using messages (see Figure 39). On the client-side, the Cell class is responsible for rendering and adding art assets to the objects, and for capturing user input, such as mouse clicks or property changes. Depending on the cell type, the class extends the OWLs specific Cell class. The cell must create an app by extending the App2DCell class, in order to implement a swing-based cell for instance. Each cell has a renderer object that is responsible for drawing and rendering the cell with the 3d game engine JMonkeyEngine (JME). On the server-side, a managed object (MO) class based on the Project Darkstar server is responsible for maintaining shared states.

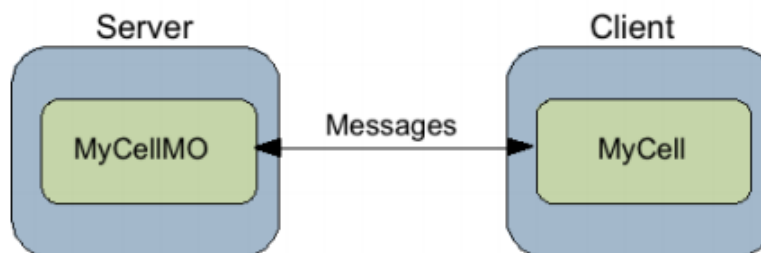


Figure 39: OWL's client-server architecture of cells (OWL Website, 2007)

As a means to support a multiuser networked environment, state changes are communicated from the client-side Cell-class to the server-side MO-class. The current state, stored by the MO-class is updated, and the server communicates the changes to the other clients to synchronize the rendered cells and the corresponding properties. The common package is used for code, which is important for both, client and server parts. Each cell can be edited by adding entries in the cell property menu or adding a HUD (Heads-up display).

### 4.2 TEALsim-Module

To display TEALsim's three-dimensional simulations in Open Wonderland, the TEALsim-module is used and adapted with respect to stability, performance, multiuser availability and



synchronization, and usability. Because of different version updates of TEALsim, Open Wonderland and in particular Java itself, the current TEALsim-module implementation had to be debugged and adapted to the new standards. Also an according adaption of TEALsim was necessary.

### 4.2.1 Conception

The TEALsim cell can be inserted using OWL's 'Insert Object' dialogue. The simulation cell and the corresponding swing menu to change the simulation properties are displayed. Figure 40 shows the simulation cell presenting a capacitor model and the corresponding properties sheet to start and stop the simulation, to change different parameters or to activate field visualizations. The right image shows the drop-down menu in the module's property sheet. Here, different simulations can be selected to be displayed in-world. In dependence of the chosen simulation name, the different visualization and corresponding control interface are rendered.



Figure 40: TEALsim simulation Capacitor in Open Wonderland on the left; TEALsim-Module properties to change the rendered simulation on the right

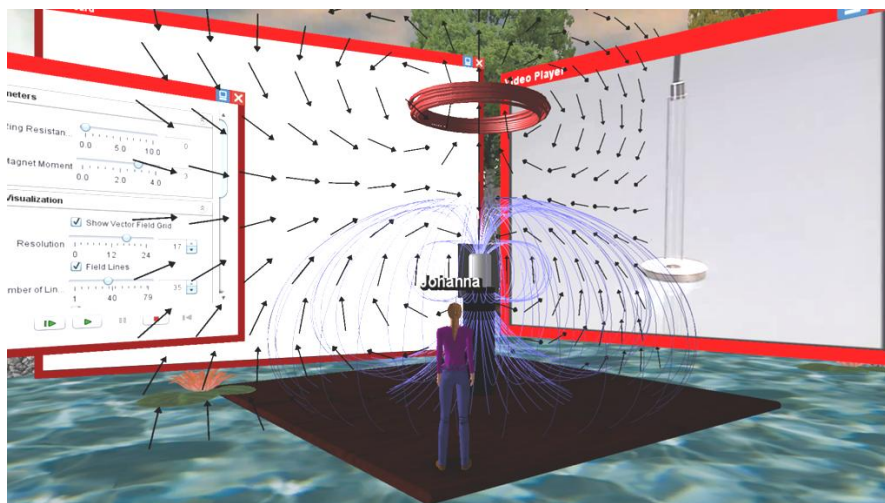


Figure 41: Immersive physics experiments

The simulation cell can be scaled and translated separately from the swing window so that not only the usability is enhanced, but users can also experience a feeling of immersion. Simulations can be scaled to complement other in-world activities (see Figure 41).

### 4.2.2 Architecture

The TEALsim-Module is based on OWL's cell client-server architecture to share the cell state such as the simulation name or state with the other clients (see Figure 42). TEALsim is imported into the entire module as a .jar file. Artwork such as .3ds files used by TEALsim and resources such as additional languages for the strings are also stored in this module.

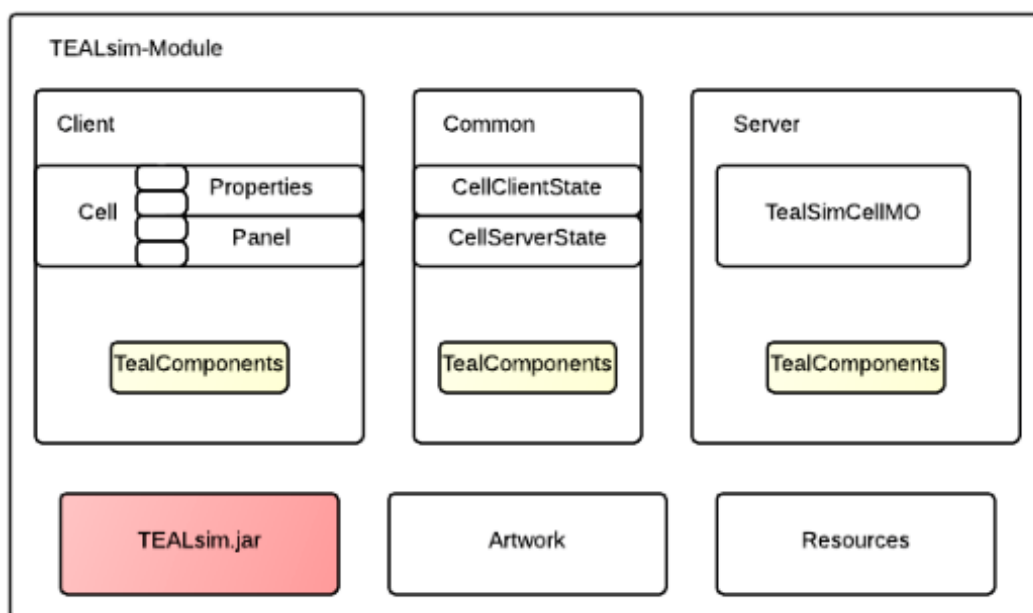


Figure 42: Conceptual model of the TEALsim-Module and the different components

As already mentioned in Berger (2012), in particular, the server-side implementation can easily lead to performance drawbacks due to the required synchronization time. Many operations of TEALsim such as the calculation of field lines require a lot of resources and should be conducted on the client side to reduce the synchronization time issues.

#### Server Side

The class TEALsimCellMO is a managed object used by the Darkstar gaming engine to administer the shared states. It is the server-side representation of the in-world cell. The initialized simulation, corresponding settings, actual scale and translation are saved in these shared objects. Information to synchronize the other clients is also managed in this class. The TEAL specific class ServerEngine is responsible for handling the changes of the different client states, paused, running, initialization or end. At this point, the four steps needed by the simulation are conducted: (1) doRecorder is used to control the objects' collisions. In the (2) doDynamic step,

integrable objects are affected by the physical calculations. The third step (3) is responsible for the updating process. In the last step, (4) doRefresh, objects like field lines, which perform calculations and need the prior step's information, are updated. In order to reduce the server effort and enhance the overall performance, objects, which are not needed by the server engine (such as spatial), can be excluded in this class. The second TEALsim specific class in the server package is the ServerPlayer, which is responsible for handling property change events of the client and the simulation. Figure 43 shows a simplified class diagram of the server-side classes.

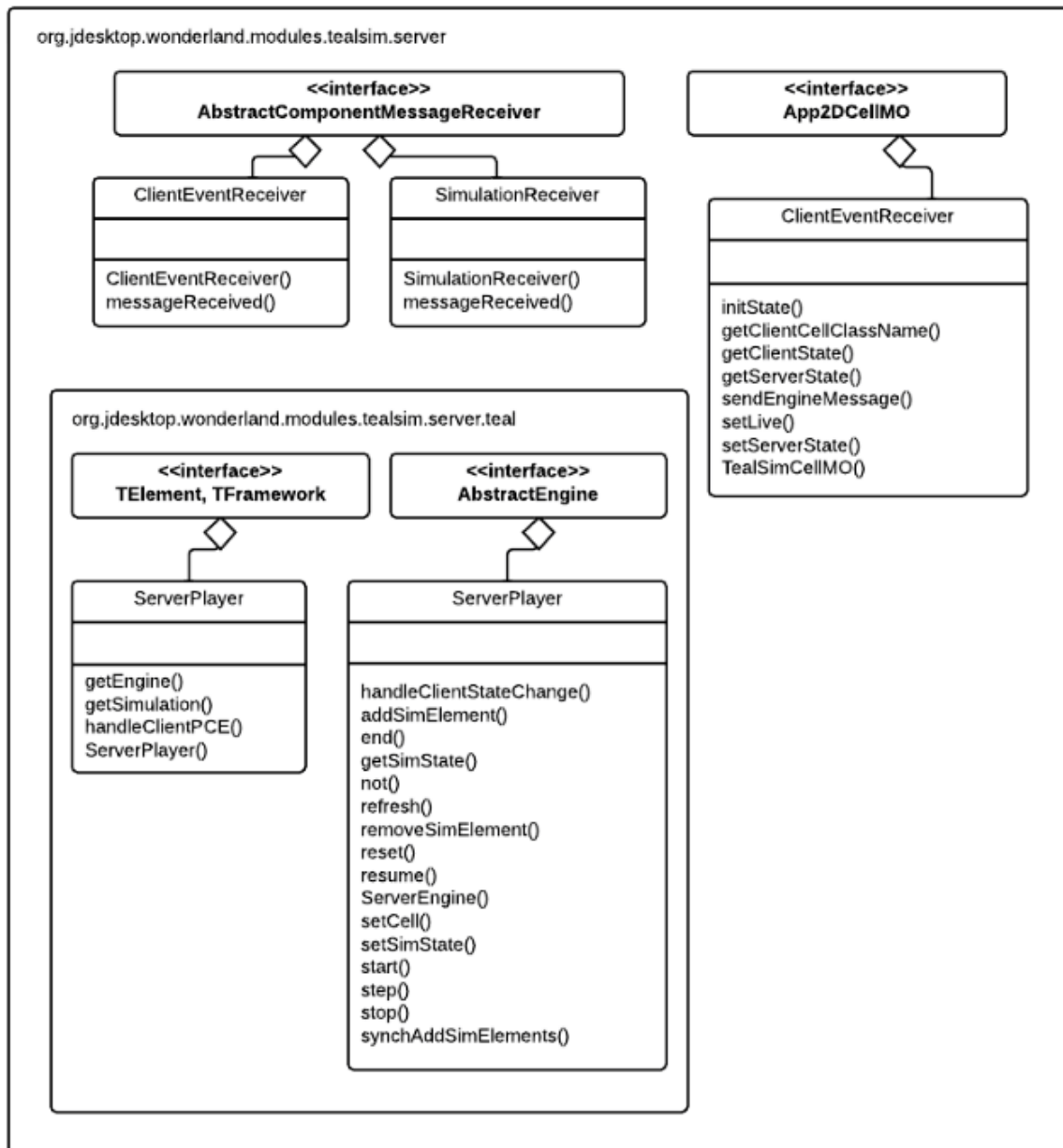


Figure 43: Simplified server-side representation of the TEALsim-module

## Common Package

The common package is needed in both, the server and client parts of the module. The class TEALsimCellClientState notifies the client if he should create a simulation or not. The class

TEALsimCellServerState represents the server-side configurations for the in-world TEALsim cell. Here information about the simulation properties such as translation or scaling are set. The class SimulationConstants contains the properties as constants. The class ClientSimulation is an extension of TEAL’s Simulation3d class and is responsible for setting simulation elements, such as the guiElements, the drawObjects or the engine type. The functions encodeToByteArray() and decodeByteArrayToSimulation() are used for the serialization process. The message package summarizes different message classes such as the EngineMessage, to handle engine states or EventMessages and SimulationMessage to handle simulation components. Figure 44 shows a simplified class diagram of the classes of the common package.

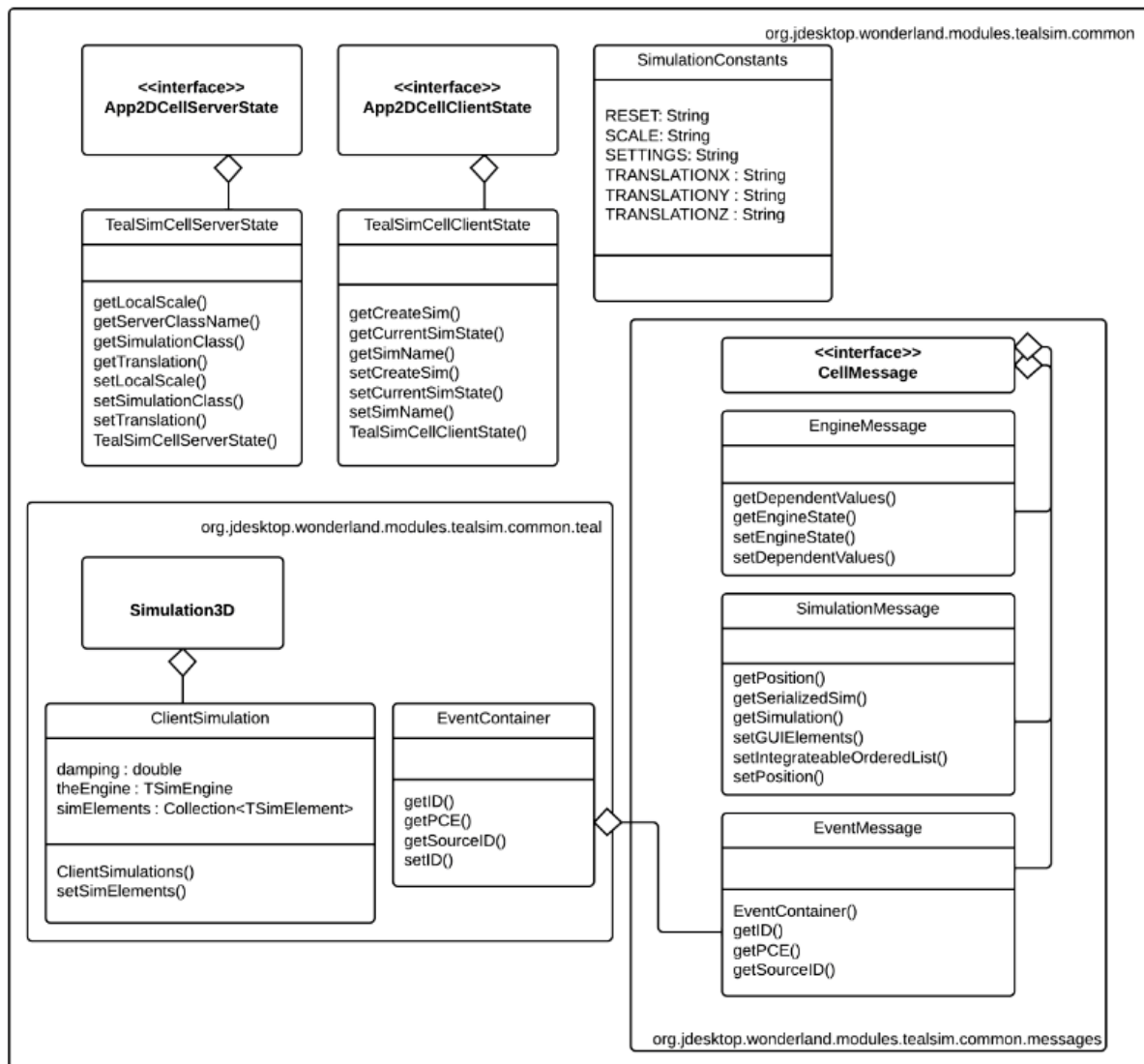


Figure 44: Simplified representation of the common package of the TEALsim-module

### Client Side

According to the shared state, the simulation and the 2d windows are created and initialized in the TEALsimCell. The simulation is created based on the simulation, which is set in the current

server state with the current scaling and translation. The class `TEALsimRender` is responsible for the cell rendering. The user can select a different simulation in the properties sheet to change the simulation. The class `TEALsimCellProperties` holds a drop-down menu containing a string array with the available simulations (see Figure 45). As soon as the simulation change is applied, the server state is updated, and communicates to the clients to update. The `SimulationSettingsPanel` is implemented as a HUD and makes position and size changes possible. The TEAL-specific class `ClientEngine` is an extension of TEALsim's `AbstractEngine`. Here, the client-side states are set and executed. The class `ClientEngineController` holds the control of the simulation states and is an extension of TEALsim's `EngineControl`. `ClientGUI` is an extension of TEALsim's `UIPanel` to represent the user controls in-world. The `ClientPlayer` handles the server property change events and adds objects, which were ignored at the server side, again to the update-list. The engine is chosen, and simulations are loaded here. The `ClientViewer` implements TEALsim's `TRenderEngine` and is responsible to set the renderer. Figure 46 shows the class diagram of the client package.

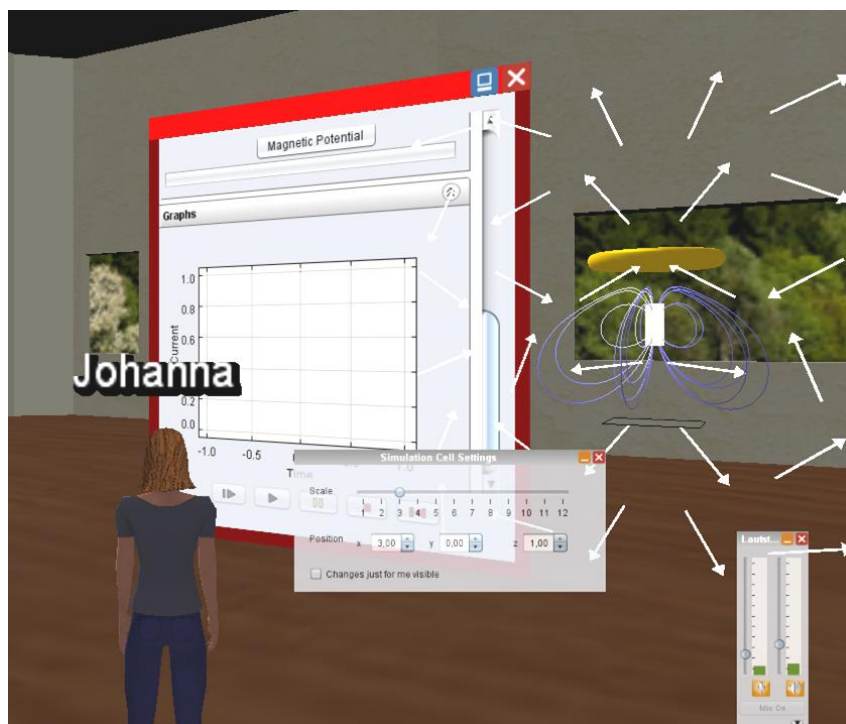


Figure 45: TEALsim simulation Falling Coil in Open Wonderland

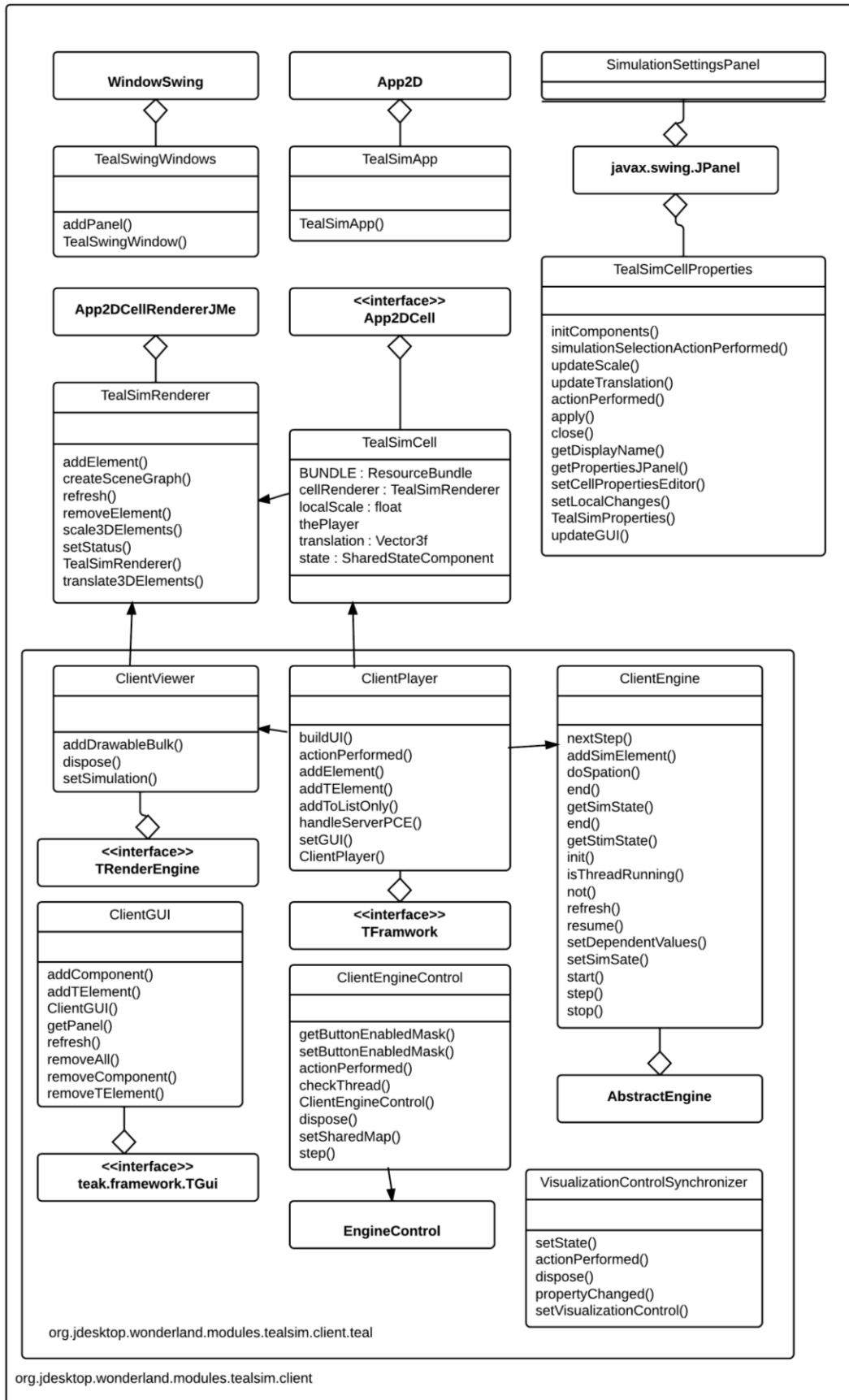


Figure 46: Simplified class diagram of the client side

### Enhancement of the Usability

In order to enable users watching the simulations even in larger groups and in a good angle, it was necessary to separate the client-simulation-cell from the client-simulation-swing-cell. This enables users to change the size and the position of the three-dimensional simulation with respect to their requirements and independent of other users. This separation focuses on being in line with the usability heuristic flexibility and efficiency. A panel (see Figure 47) was added to change the size and the position of the single simulation's objects. The according cell changes can be applied to all clients or just for the actual client session. If the checkbox 'Changes just for me visible' is checked, the simulation cell changes are only visible for the current client, otherwise the information will be sent to the server, to distribute the changes further. This should enhance, in particular, the usability and interactivity of this system for larger student groups. This made a separation between the three-dimensional simulation cell, and the two-dimensional application, responsible for the simulation settings necessary.

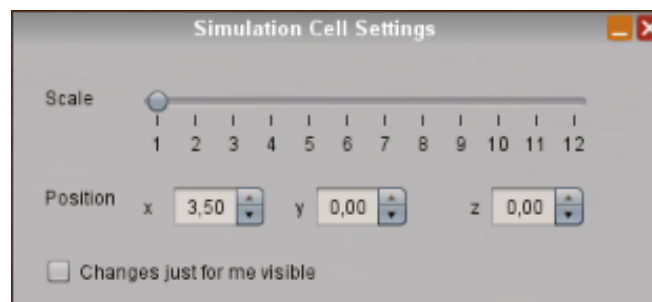


Figure 47: Simulation Cell Settings Hub

An additional color-scheme was added, which enhances in particular the visibility of spatial objects such as field lines and static visualizations in the virtual world environment. According to the heuristics of consistency and recognizably it is important that single object types, with similar properties, are also colored similarly. This gives users a first overview of the simulation.

### Enhancement of the Performance

In particular calculations, which require constant updates, need a lot of resources on the client-side. Spatial objects, such as field lines or field vectors, which are recalculated every rendering step, need simplification and also limitation to enhance the performance and enable the VW environment to a wider user group. To reduce the computing time on the client-side, the number of the spatial is limited in the Open Wonderland integration. The calculations were simplified, and redundant steps were removed. Since the JME based implementations use faster NIO buffers to store vertex and color information, and the old code used conventional Java arrays for the storage of field line information, the data were copied and saved twice in every calculation step.

## Enhancement of the Stability

The TEALsim project was developed during different Java versions, which made many features not accessible anymore, when used together with Open Wonderland. The serialization compatibility was updated to enable the client-server availability. Swing objects using the JComponent class required the same version of Java and Swing to be visible and usable. To resolve this issue, the objects are not stored in a binary representation anymore, but in an XML file, which is created by the XMLEncoder.

## 4.3 Concept Question-Module

The Concept Question-module is used to show interactive questions in-world, where users can choose answers. In dependence of the clicked answer an event like the teleportation to a discussion area will happen. Instructors can track user answers and should be able to import and add new questions easily.

### 4.3.1 Conception

Concept Question cells can be inserted using OWL's 'Insert Object' dialogue. Instructors can add and edit questions using either the cell properties or the original question file. Further design adaptations can be made in the created HTML-based cell, which is rendered. Students use this cell to view and answer questions (see Figure 48).

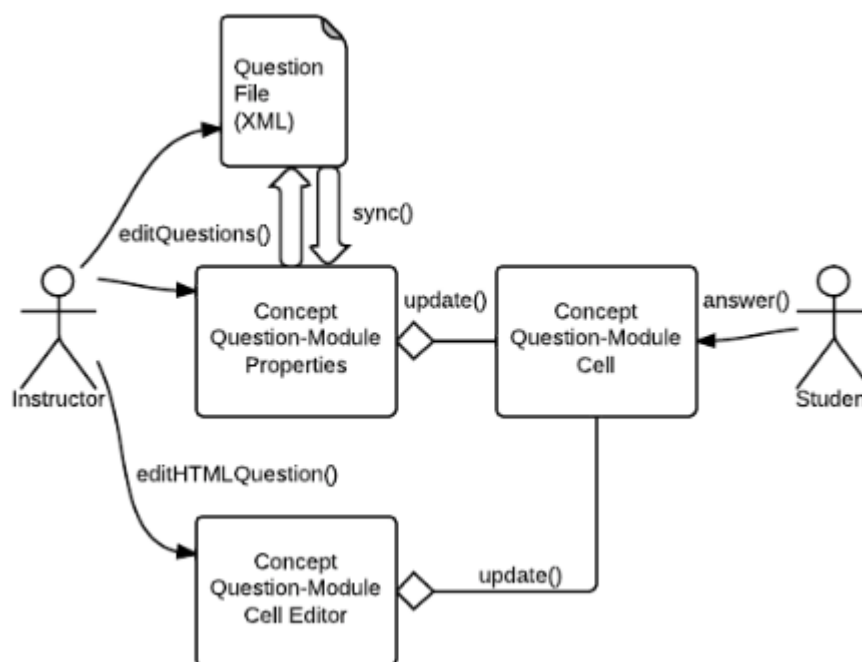


Figure 48: Instructor's and student's view of the Concept Question-Module

Each inserted question cell has its own settings. Figure 49 shows a mock-up sketch of a question setting screen. Instructors should be able to upload {1} XML-based question pools from their PC



or use existing files already imported into the world. From this question pool they can select one question {2}, which will be shown in the actual question cell. Instructors can add new questions {3} and corresponding answers {4}, which should be marked as true or false. Also, the question type can be chosen at this screen {5}.

Figure 49: Mock-Up of the Concept Question-Module's Editor Pane

When students answer the questions, they get feedback, depending on the question type. This feedback can be textual or visual, but they could also be teleported to a separated discussion or brainstorming area. The answers to the questions are logged into an XML file (see Listening 3) to provide an interface to other tools, web interfaces or e-learning systems such as a CMS. The Concept Question-Module is based on Open Wonderland's Poster Module, which allows users to add HTML content to the world. This helps provide users an easy and common way to change the appearance of their questions using HTML syntax (see Figure 50).

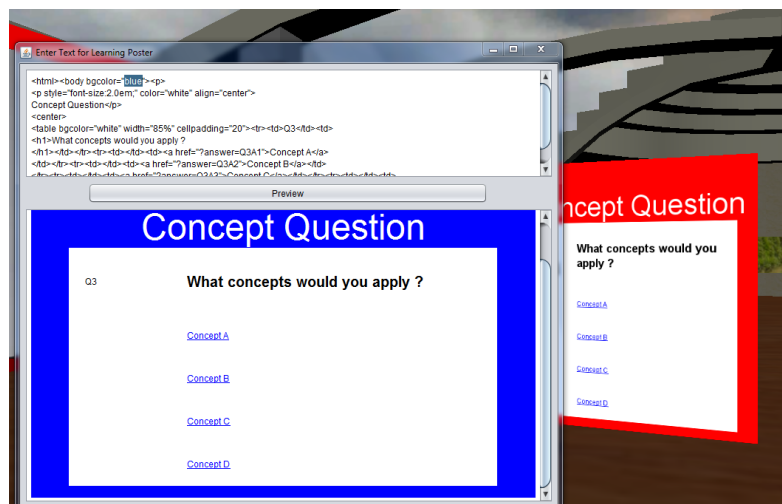


Figure 50: The standard question design can be easily edited using HTML syntax

Figure 51 shows a screenshot of the actual implementation of the question setting screen in Open Wonderland where users can select, change, add and edit questions to the question file. The left side of the figure demonstrates the properties menu, where instructors can change the questions, choose different question pools or add new questions. The left side shows the corresponding cell, where students can view the questions and click on answers.

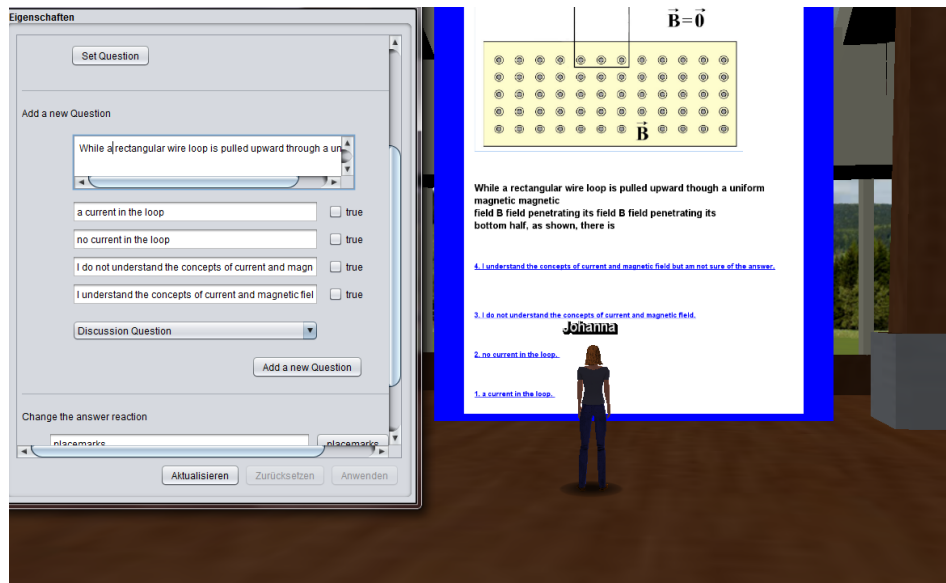


Figure 51: Concept Question-Module's settings screen to edit, change and select the question and the created cell

### 4.3.2 Architecture

On the server part, the class *ConceptQuestionCellMO* is the server-side representation of the in-world cell and is responsible for managing the shared states. This includes the text displayed in the in-world cell on the client-side and the filename of the XML-file that stores the questions. A common package realizes both the compilation into the server-side and the client-side parts. It consists of a *ConceptQuestionCellClientState* class and a *ConceptQuestionCellServerState* class. On the client-side, the class *ConceptQuestionCell* extends an *App2DCell* class and is responsible for rendering the question cell. The question is displayed using HTML syntax. If the module is initialized for the first time and the question text is still null, a string from the pre-defined resource-bundle property file is used. The property files are language dependent and used to adapt the single strings and change them to the different languages. Also, the standard-filename for the question file can be set in the property file. To display the concept question as two-dimensional window, an application is created and displayed within this cell. This app creates the singleton *ConceptQuestionWindow*, where a Swing pane for the user interface to edit and update the question, is created. The *EditorPane* enables the HTML editor toolkit and the *ConceptQuestionHyperlinkListener* so that the questions can be adapted and designed using HTML concepts.

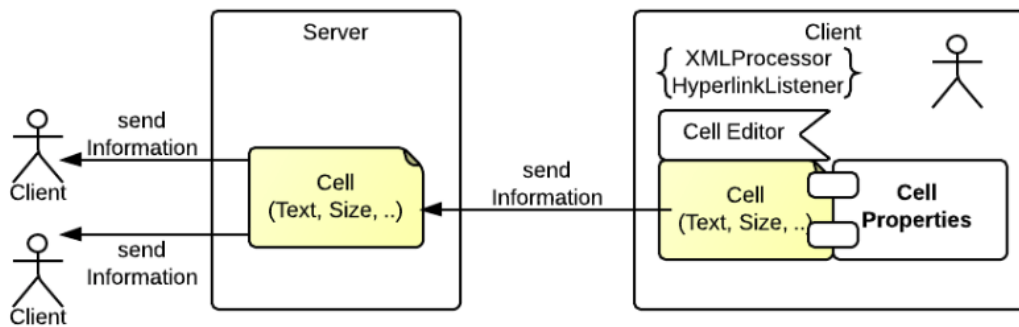


Figure 52: Client-Server structure of the Concept Question-Module

## Handling the questions

Questions are stored and retrieved using an XML file (see Listening 1), which can be edited using the cell's properties. Every cell comes with a property sheet based on JPanel, to set different properties which can be applied to the cell directly. In the LearningPosterCellProperties (see Figure 49), the ContentBrowserManger is used to save files into OWL's Content Repository, which is available to the user. This enables users to access already saved question files. Using the JFileChooser the question file can also be uploaded from the client's file system. In the case that no file exists yet, a new demo file is created. As soon as the question file is created or edited it is uploaded to OWL's Content Repository.

```

9   <Question id="Q192" type="Discussion Question">
10  <QuestionText>While a rectangular wire loop is pulled upward though a
11  uniform magnetic magnetic field B as shown, there is.. </QuestionText>
12  <answers id="Q192A1" true="true">1. a current in the loop. </answers>
13  <answers id="Q192A2" true="false">2. no current in the loop. </answers>
14  <answers id="Q192A3" true="false">3. I do not understand the concepts</answers>
15  <answers id="Q192A4" true="false">4. I am not sure of the answer.</answers>
16 </Question>

```

Listening 1: XML representation of the question and answers

A dropdown menu is used to display the different questions of the file. As soon as the setQuestionButton is pushed, the ConceptQuestionXMLProcessor parses the XML file and creates an HTML file out of the question and answers and is displayed in the in-world cell. Answers are automatically tagged as hyperlinks with the start-tag 'answer=' to enable the answer handling (see Listening 2). If the question is changed, the new data are sent to the server-side representation of the cell to cause also the other clients to update the new cell content (the new question). In this property menu, new questions and the corresponding answers can also be added to the question file. Events can be set depending on the user's answer. A user who clicked the wrong answer can be, for instance, sent to a different placemark than a user, who clicked the right answer.

```

<a href="?placemark=Gallery">Go to the Gallery</a><br>
<a href="?location=1.2 +0+13&look=15.92">Go to the Gallary</a><br>
<a href="?answer=a">I do not understand the concepts</a><br>

```

Listening 2: Advanced hyperlinks to describe locations or question answers

## Handling user answers

The Concept Question-Module was developed on the basis of OWL's HTML Poster-Module. The existing HyperlinkListener was used and extended to add additional specified hyperlink actions. The original HyperlinkListener was used to parse the HTML hyperlink text from the poster text to see if in-world placemarks using the tag "?placemark=" are specified. If the URL contains a link to an intern placemark or coordinates, the avatar's coordinates are set to this location. This class was adapted and extended with the ability to parse answer tags, so that question-answers can be specified as hyperlinks with the start tag "?answer=". As soon as an answer click is detected, the *ConceptQuestionXMLProcessor* class logs the user-name and the clicked answer and saves them together with a timestamp and a Boolean whether the answer is true or not into a pre-specified XML file (see Listening 3).

```

4 <User id="U1">
5   <userName>Johanna</userName>
6   <answers id="Q132A3" true="false">2012-06-25 14:52:39.042</answers>
7   <answers id="Q132A2" true="false">2012-06-25 14:54:12.819</answers>
8   <answers id="Q132A1" true="true">2012-06-25 14:56:15.42</answers>
9   <answers id="Q193A1" true="true">2012-06-28 00:35:13.781</answers>

```

Listening 3: XML representation of the user's answers with timestamp and validation of the answer

Figure 53 gives a simplified overview of the most important classes of the server, client and common packages and their connection to each other.

## 4.4 Web Component

The web component is a basic demo representation of the capability of the Concept Question-module and abstains from requirements such as usability or security. It focuses on the following two functional requirements to be a demonstrator of the interface ability:

- The username, the given answers and a timestamp should be displayed on the webpage
- Instructors should be able to view and edit the list of questions which can be displayed using the Concept Question-Module

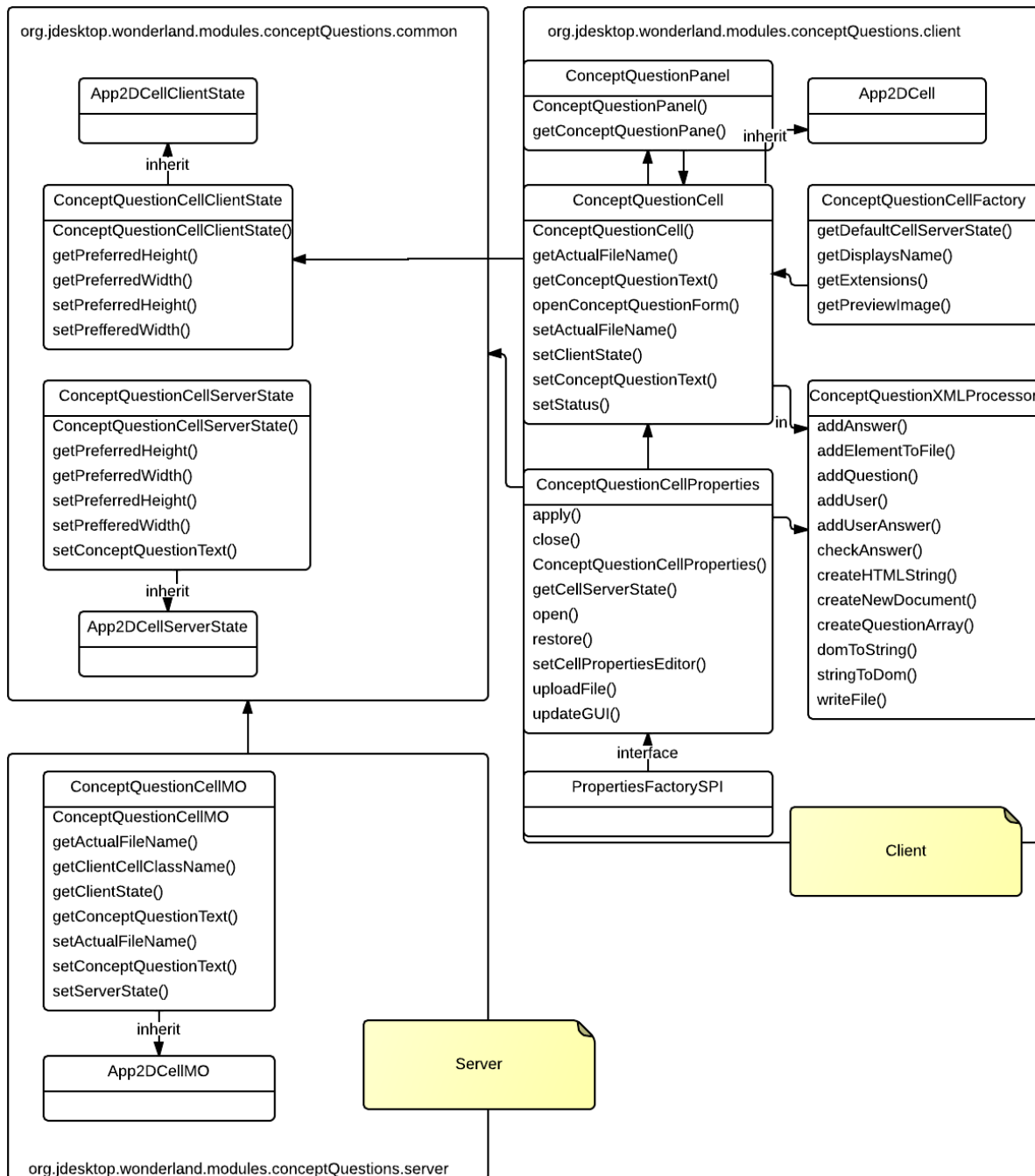


Figure 53: Simplified architecture of the Concept Question-Module

### 4.4.1 Conception

The web-component can be accessed via a web browser, and it is displayed as basic HTML page. The content is loaded dynamically from the corresponding files. The web component can be split into two main parts. The first part is a personalized website designed for students. Here, they can review their questions and past answers or can also use this tool to answer the question. The second part of the web-component is the webpage for instructors, where they can review students' answers or edit questions from the question pool file (see Figure 55).

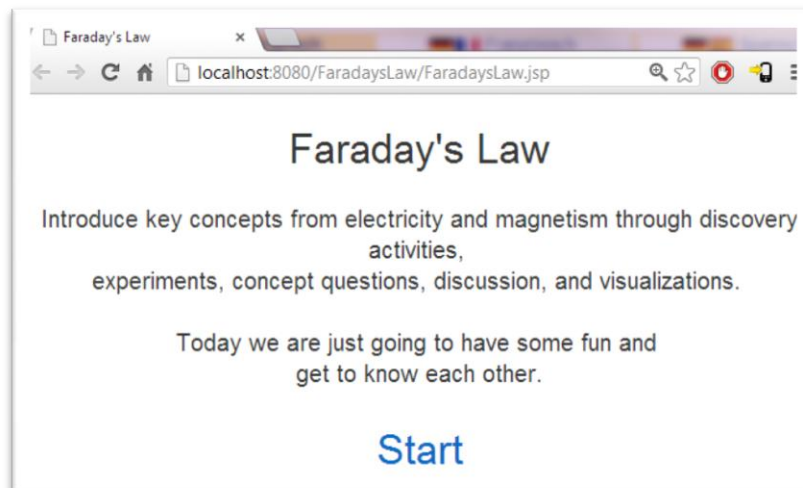


Figure 54: Start page with respect to the actual topic

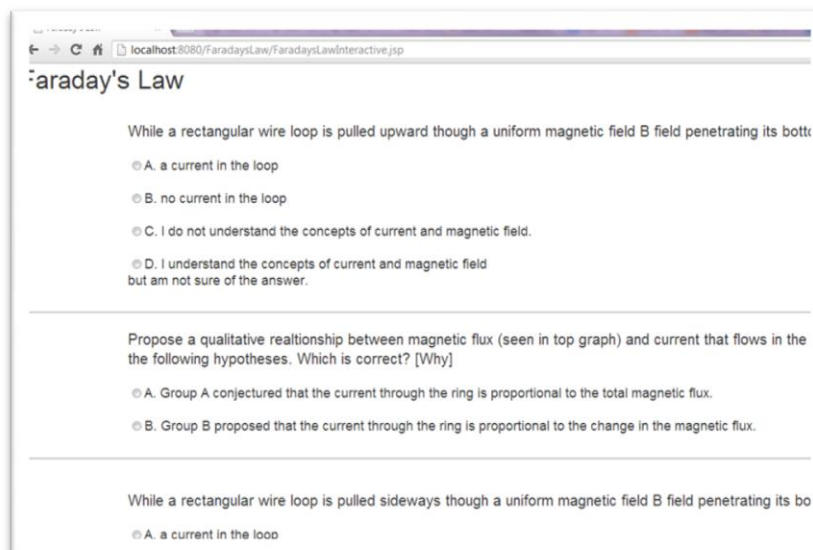


Figure 55: Question list from the question pool file

#### 4.4.2 Architecture

The single web component files are implemented using Java Server Pages (JSP) to generate HTML pages from the corresponding XML-files dynamically. Using Open Wonderland, the web component can be directly run on OWL's Apache Tomcat server. Figure 56 shows a sequence diagram of the students' and the instructors' possibilities. The files `UserData.xml` and the `Questions.xml` are parsed and relevant data are displayed at the single pages. Students can simply review their questions and answers, and answer the question again. However, they cannot change past answers or view the entire question list. Instructors can view the students' data, which include their answered questions and the timestamps. They can also edit, add or delete questions.

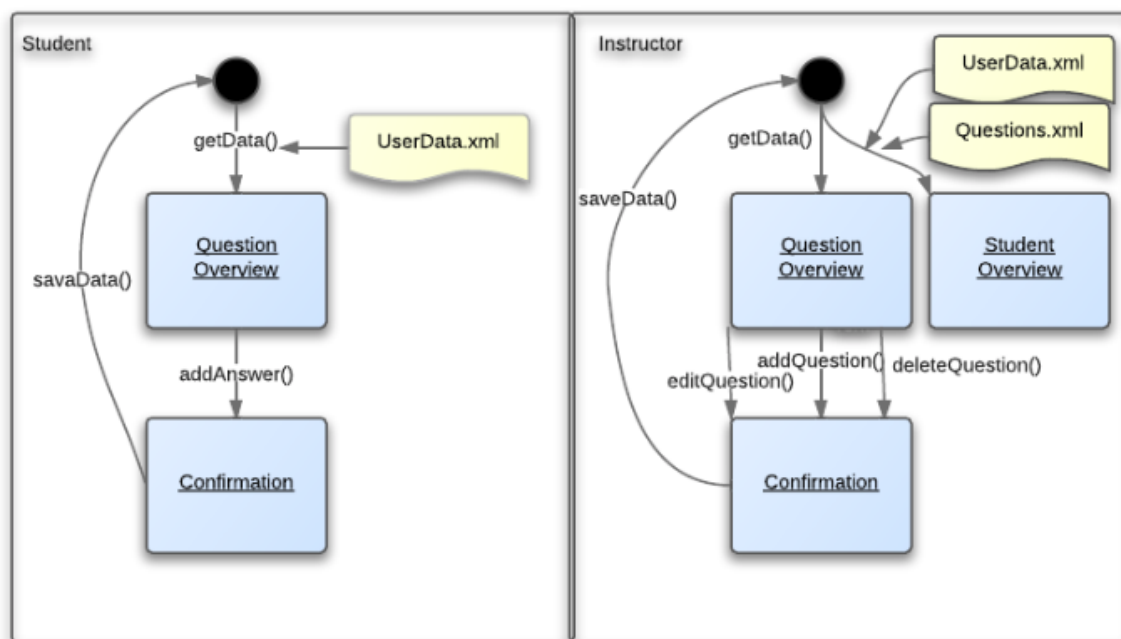


Figure 56: Input and output sequences of the single websites

#### 4.5 The Virtual TEAL World Showcase – Faraday’s Law Scenario

To provide a first showcase, a Virtual TEAL World scenario introducing the Faraday’s Law concepts was designed and implemented. Based on the corresponding TEAL lecture at MIT, this course is an introduction lecture with a focus on introducing the teachers and students to each other and to teach the first concepts of Faraday’s Law, using simulations, small experiment setups, continuous challenges, and discussions motivated by concept questions and several group assignments. The main purpose of this scenario is to provide students an entire learning roundtrip. Students should meet in-world in groups of 3-4.

Figure 57 demonstrates the conceptual overview of the cyclic approach of this scenario. Users start at a (1) instruction board where they can find information about the course content and activities. After that, a first (2) conceptual question is used to measure the level of knowledge at the beginning of the course and motivates students to a first discussion. Therefore, the learning group is teleported to a remote discussion area, where they should find a consensus and answer the question again. After having this first group discussion question, the students learn about the phenomena ‘Faraday’s Law’ by (3) watching videos and reading documents. A brainstorming should motivate the peers to think about electromagnetic terms such as ‘the flow of something’. Constant conceptual questions and discussions should enhance their understanding of the new content. After learning the first concepts, they can use (4) TEALsim’s Falling Coil simulation, which is an example of induced currents described by Faraday’s Law, to experience the phenomena and to complete appropriate tasks. Step 3 and 4 are looped with different contents and assignments. At the end of the roundtrip, they again find different questions, including the question from the beginning. Now they should answer the questions again to measure their learning progress.

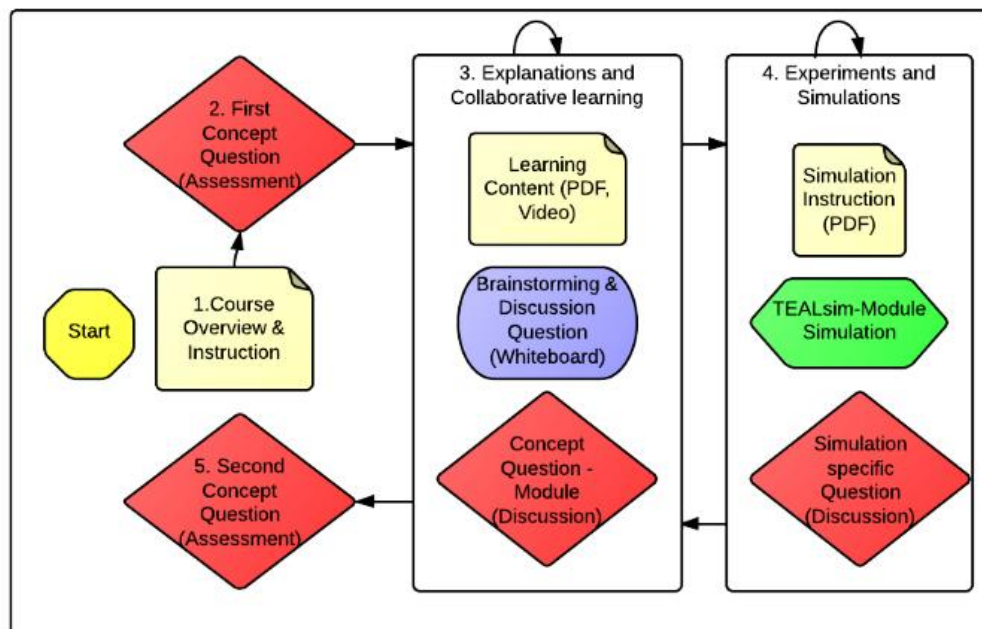


Figure 57: Conceptual overview of the single process steps of the Virtual TEAL World for Faraday's Law

Figure 58 shows a small part of the Virtual TEAL World scenario. Different knowledge concepts are taught by using videos, concept questions in the way of group discussions, and collaborative experiments with simulations that should help understand the taught concepts.

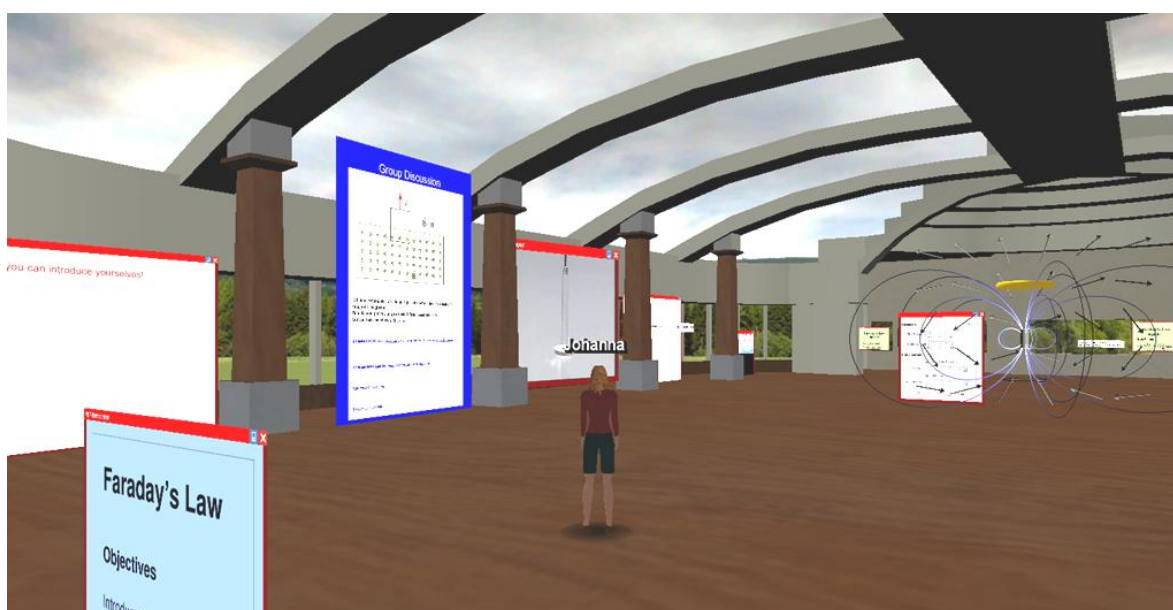


Figure 58: Overview of the Virtual TEAL World for Faraday's Law



## Collaborative learning

Students visit the Faraday's Law scenario in groups of 3-4 to conduct a learning roundtrip together and discuss new concepts and questions. This approach raises the students' motivation, reduces the dropout rate, and also enhances the conceptual understanding of the single concepts.

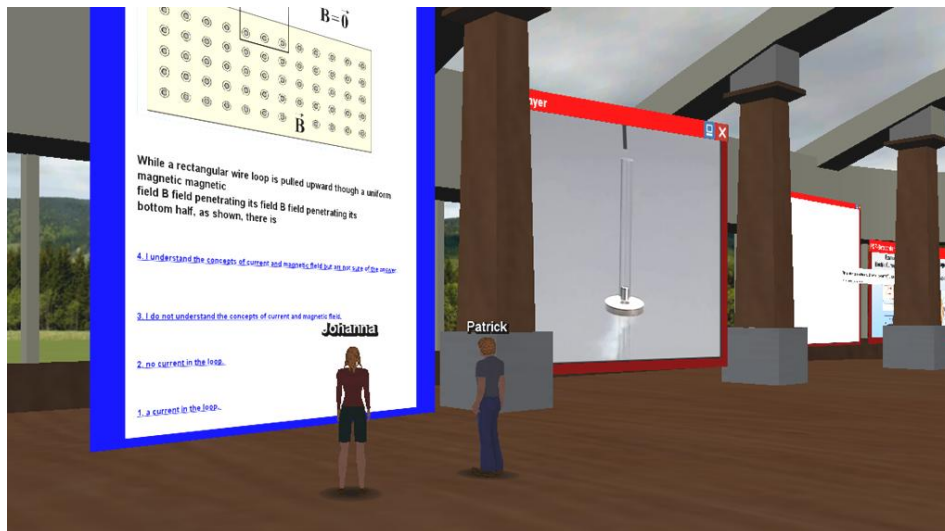


Figure 59: Student groups doing a learning round trip together

## Explanations and learning content

Videos, which show the Faraday's law phenomena, are used to replace real-life oral explanations. Auditive commentaries help students understand the phenomena. Figure 60 shows a video explaining Faraday's law using a recording, showing a magnet, which is dropped through a conducted cooper ring. Different images and documents explaining Faraday's law are used to replace traditional course notes.



Figure 60: Video showing the falling coil experiment and with an auditive explanation and course notes explaining the main concepts of Faraday's law on the right

## Multimedia visualizations and simulations

TEALsim's visualizations explaining Faraday's law are imported into the VTW. For this lecture in particular, the simulation 'Falling Coil' (see Figure 61) is relevant and important and was therefore the focus of the TEALsim's performance improvements. Figure 61 shows the original Falling Coil simulation of the TEALsim desktop application, while Figure 62 shows the in-world representation of this simulation. As in the desktop application, users can choose different input values to run the simulation. However, in comparison to the desktop application, the in-world representation is strictly limited regarding the number of field-lines due to performance limitations. When using such simulations, students are always motivated through instructions such *"Hit run and let the ring bounce several times. At the bottom of a bounce hit the "iron filings" box to see a representation of the complete field. Hit run again and increase the resistance to "10" using the slider. Watch the subsequent behavior of the ring"* (Belcher et al., 2004).

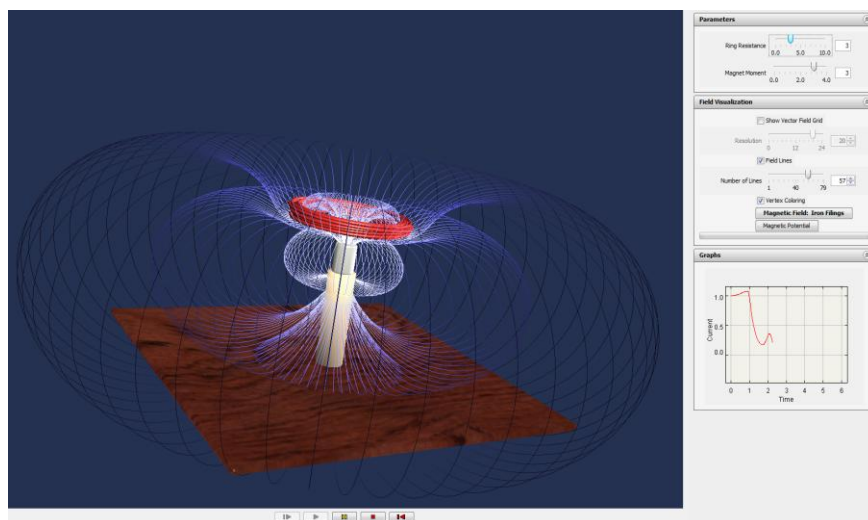


Figure 61: TEALsim's Falling Coil Simulation

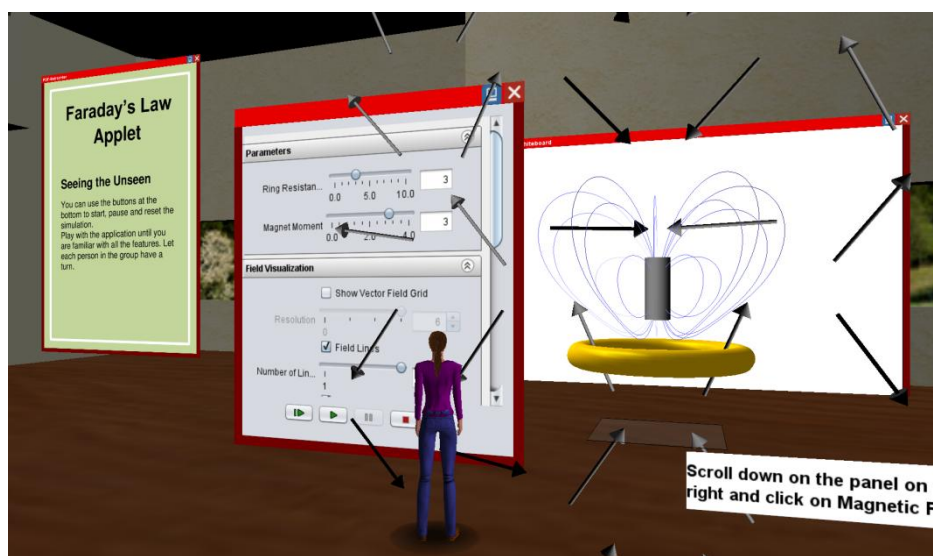


Figure 62: The TEALsim-Module showing the Falling Coil Simulation in the VTW

## Conceptual questions

The Learning-module is used to replace TEAL's concept questions. Students are motivated to discuss the question on the currents in a magnetic field before answering it (see Figure 63). The individual answers of the students are saved into a separate file together with the users' name and the timestamp. Teachers can easily edit or change the questions using the properties menu.

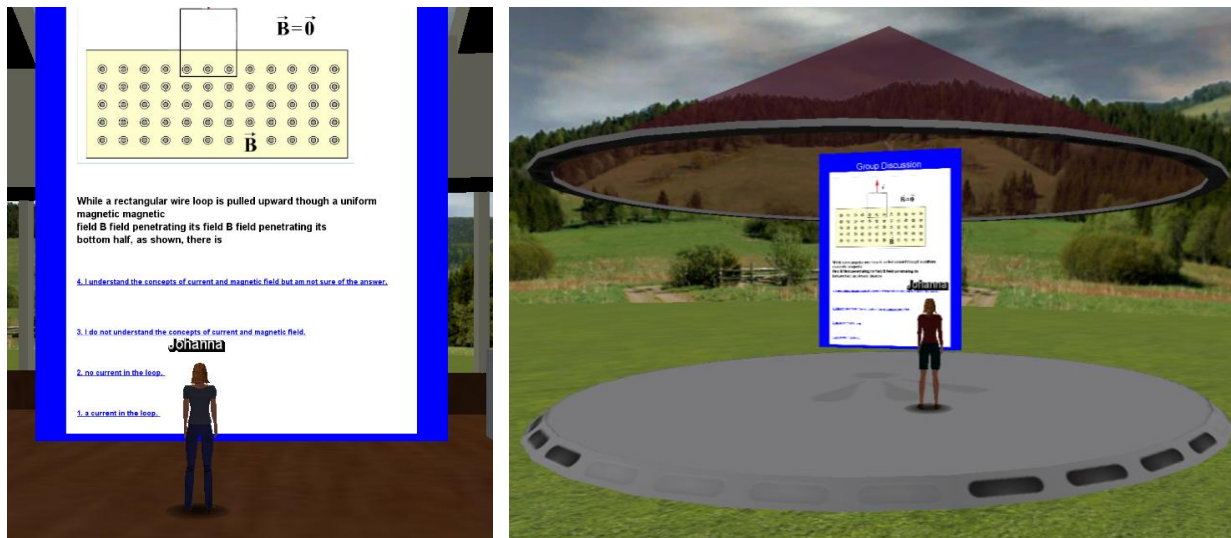


Figure 63: Concept questions about the magnetic field and a remote and quiet area for concept question discussions

To discuss concept questions or conduct brainstorming activities, links of answers use geographical links (place marks) to send users to a more remote and quiet place (see Figure 63, right). The same question is discussed at the beginning, but also at the end of the roundtrip to measure the students' learning progress.

## 4.6 Summary

To realize the Virtual TEAL World, the virtual world environment Open Wonderland was used. Different tools supporting TEAL's collaborative and interactive activities, such as a whiteboard, video player or a PDF viewer, already come along with the standard installation. Also, a first integration of TEALsim was already implemented in OWL but lacked in performance, stability and usability. The implementations and adaptations focus on meeting the pre-requirements usability, configurability, flexibility, extensibility, scalability, and performance. The TEALsim-module is used to watch TEALsim's simulation also in-world with the possibility of using three-dimensional features. It was extended to improve the usability by splitting the simulation cell from the swing property cell so that users can adapt the view with respect to their angle. The usage of spatial objects such as field lines is restricted for the OWL version to enhance the in-world performance. The implementation of the modules is based on OWL's cell server-client architecture. To use TEAL's concept question approach also in-world, the Concept Question-Module was developed. An instructor can add or edit questions that are displayed in an

interactive HTML viewer in-world. Students' answers are logged into a separate file and can be linked to an external web-interface such as a LMS. To demonstrate this feature, a simple web-interface based on JSP was implemented and linked to the tool.

A showcase scenario focusing on imparting knowledge about Faraday's law is used to demonstrate the single features in an entire environment. The world consists of a course instruction, a first concept question, to measure the students' knowledge at the beginning of the course, learning content in the form of videos and PDFs, brainstorming and discussion areas, the TEALsim integration of the falling coil experiment, and a final concept question to measure the learning progress.

## 5 Evaluation of the Virtual TEAL World

Common issues of VWs are described as low user acceptance, lack of technical know-how, and the lack of technical requirements, such as particular firewall settings, a good internet connection and a modern PC with a good graphics card. The VTW was designed with a focus on usability of the environment and the in-world tools, pedagogical aspects, and follows a learner-centric approach to enhance the acceptance and facilitate the usage. To evaluate the Virtual TEAL World three research focuses were set for the study:

- The usability of the VTW and its objects and components
- The learning progress within the Faraday's Law scenario and its assessability
- The motivational aspects of students, such as interactivity and collaboration

### 5.1 Research Methodology

The world was evaluated in two phases focusing on the two different stakeholder groups. In a first qualitative study design aspects from the point of view of physicist and instructors, further referred to stakeholder group 1 (SHG1), were evaluated. After that, the second stakeholder group (SHG2), students, evaluated the learning scenario by doing a monitored learning roundtrip.

### 5.2 Procedure

The roundtrip that was used by both stakeholder groups was setup as a simplified version of the Faraday's Law scenario. It consists of a (1) introduction of the course objectives and content presented on a PDF, (2) a place, where they can introduce their selves on a whiteboard, what also helps them train the first interaction with the system, (3) a first concept question that teleports them to a (4) discussion area, (5) learning content in the form of videos and PDFs, a (6) descriptive document how to use the TEALsim-module, (7) TEALsim's Falling Coil simulation, (8) further instructions about the tool and the same (9) concept question again.

#### Stakeholder group 1

After a first pre-questionnaire, the first stakeholder group was asked to evaluate the VTW with respect to its usability and pedagogical value. Users were given a short introduction, how to use the system and they got the chance to use the environment under the supervision of an expert. They explored the entire learning roundtrip and were asked to try out the different tools and change different settings, such as the conceptual question or the displayed simulation. The interactions with the environments and the in-world objects were noted by a supervisor. A time limit for the roundtrips was not set but calculated with 15 to 30 minutes. During the roundtrip, interactions with the avatar, the environment or the tools were noted. A post questionnaire was used to assess usability, assessability, satisfaction and pedagogical value.

## **Stakeholder group 2**

After the pre-questionnaire, students were asked to use the VTW to do a learning roundtrip in the Faraday's Law scenario in groups of two to learn the first principles of the phenomena. They were using the system from two different pre-setup PCs in different rooms. Their first task was becoming comfortable with the system and trying out different functionalities. The interactions with the environments and the in-world objects, and also collaborations were noted by a supervisor. To measure the learning progress, the in-world Concept Question-module was used. In the post-questionnaire, usability, assessability, motivation, and satisfaction were measured.

## **5.3 Participants**

All participants were between 24 and 31 and had an advanced technical background knowledge and experience with three-dimensional computer games.

### **Stakeholder group 1**

Two physicists with pedagogical background were asked to evaluate the world from a scientific and academic point of view.

### **Stakeholder group 2**

8 students (6 male) between 24 and 31 ( $M = 27.25$ ;  $SD = 2.43$ ) consented to participate in the user study. For the in-world task, students were asked to work together in groups of two.

## **5.4 Materials**

Two different test settings with pre- and post-questionnaire were used for the evaluation. The questionnaires for the two different stakeholder groups are different regarding subject specific questions and involve both, open ended questions and questions using a Likert scaling between 1 (strongly agree) and 5 (strongly disagree). The questionnaires are included in the materials appendix on the CD.

### **Stakeholder group 1**

To evaluate the instructor's and physicist's arguments, a pre-questionnaire (PREQ.1) with about 30 questions focusing on general information, pedagogical objectives and identifying the previous experience with virtual world environments was used. The post-questionnaire (POSTQ.1) involves about 30 environment specific and pedagogical questions and the standardized System Usability Scale (SUS) questionnaire.

## **Stakeholder group 2**

To evaluate the students' arguments, two questionnaires were used. The pre-questionnaire (PREQ.2) was presented to the students before the learning roundtrip and focused on demographic data and previous experiences with collaborative assignments and virtual world environments. Also, course specific questions such as their current knowledge about Faraday's law are asked. The second part of the setup was the collaborative learning roundtrip including the measurement of the learning progress. The post-questionnaire (POSTQ.2) was delivered at the end of the roundtrip and focused on usability aspects of the world and its components. To evaluate the usability, the questionnaire was based on the SUS and the pre-defined usability heuristics for VW environments (see Section 3.2). CES was used to measure the emotions of the students after the roundtrip.

## **Learning Progress**

To measure the students' learning progress and assess the influence on the answers of the peer discussions, they had to use VTW's Concept Question-module to answer a question focusing on their understanding about Faraday's law. First they were asked to answer it on their own, than they had the possibility to discuss their answers at a separated discussion area together with their peer and answer a second time. At the end of the round-trip they should have developed the ability to solve this question and were asked to answer the same question again.

## **System Usability Scale (SUS)**

SUS is an evaluation tool providing a pre-defined scale of 10 measuring, scalable items and a pre-defined score schema. It focuses on measuring usability indicators such as effectiveness, efficiency, and user satisfaction (Brooke, 1996). The results can be scored using a simple algorithm so that the values range from 0 to 100 and can be compared to letter grading.

## **Computer Emotions Scale (CES)**

CES is used to measure the different user emotions when learning how to interact with new computer software. The four emotions anger, anxiety, happiness and sadness are measured (Kay & Loverock, 2008).

## **5.5 Results**

The results are a combination of open-ended answers of the participants, answers based on the Likert scale between 1 (strongly agree) and 5 (strongly disagree), and comments and experiences during the experiments.

### 5.5.1 Pre-Questionnaire

All participants of both stakeholder groups stated to be experienced computer users and play three-dimensional computer games. Most of the participants preferred role-playing games. Only 2 out of 10 participants stated that they have less or no experience with 3d virtual worlds. They had different ideas of potential scenarios how to use a VW. Most of them would use it for games, while others would use it for social meetings, three-dimensional demonstrations, learning scenarios, communication or simulations. Many participants answered that they would expect freedom, good performance, intuitive operation, and good and realistic graphics from a VW environment. While students mentioned in particular disadvantages such as the lack of personal contact or information overload, the first stakeholder group was in particular concerned about the preparation time, the lack of expert knowledge or the difficulty to simulate the reality.

#### Stakeholder group 1

Both physics experts agreed that collaborative and interactive activities are both important teaching methods. They in particular mentioned the importance of enhancing the students' understanding and competences and the integration of lab and group oriented work.

#### Stakeholder group 2

Most of the students rated their physics abilities very low ( $M=4.25$ ;  $SD=0.83$ ) and just a few already agreed in having heard something about Faraday's law ( $M=3.25$ ;  $SD=1.4$ ). When asked about their expectation in the physics education, most of them mentioned small learning groups, many experiments and interactivity. Most students rated the importance of interactivity ( $M=2.25$ ;  $SD=0.83$ ) in physics courses moderately higher than the importance of collaborative activities ( $M=2.5$ ;  $SD=0.86$ ).

### 5.5.2 Experiment

Nearly every student needed an introduction what tools are accessible and how to use them. After the introduction, every student immediately changed their avatar. After that, they started with the roundtrip and the first concept question. They did not experience audio problems and felt immediately comfortable talking with their peer and barley used the text chat. Only one student experienced technical problems forcing him to restart the Open Wonderland system.

#### Learning Progress

Two students answered that they do not understand the concept, one student answered wrong, and five of the eight students answered the question correctly at the first time. After the discussion phase, one of these students, and the student with the wrong answer changed their opinion and also stated that they are not sure about the answer. Another student learned about the right answer by having a discussion with the peer who already knew the concept. After the



discussion phase, 5 out of 8 were sure about their answer. After the learning roundtrip all 8 students were able to answer the question correctly.

### 5.5.3 Post-Questionnaire

The majority of the participants would like to use the VTW ( $M=2.4$ ;  $SD=1.28$ ), even more would use it with the appropriate resources such as a good graphics card ( $M=2.0$ ;  $SD=1.0$ ). The participants in particular liked the integration of different tools and interactive and social activities in the world. In particular, the TEALsim simulation was very helpful but also entertaining for the participants. Many students were not satisfied with the performance and the graphics. The majority rated the importance for the experience of the simulation tool ( $M=1.2$ ;  $SD=0.6$ ) and the learning content ( $M=1.3$ ;  $SD=0.64$ ) as very high. The concept question tool was more important for the first stakeholder group than for the students (overall:  $M=1.6$ ;  $SD=0.49$ ). One student remarked that this tool was one of the most valuable tools, *"I got to know the particular learning objective and got to know what I had to look for."* However the videos were in English, and all participants were native German speakers, the majority of the participants stated that a transcript of the video would not be necessary, but a nice addition.

#### Learning Progress

After the positive measurement of the learning progress during the experiment, students also stated in the post-questionnaire that they gained knowledge about Faraday's law ( $M=1.625$ ;  $SD=0.86$ ) and 7 out of 8 students also agreed that they learned something new ( $M=2.25$ ;  $SD=1.3$ ).

#### Assessability

Both stakeholder groups were satisfied with the overall assessability of the system ( $M=2.4$ ;  $SD=0.92$ ). However, they also mentioned that it is, similar to traditional group assignments, not possible to evaluate individual contributions. One instructor remarked, *"It is similar to real life group assignments. You never know who contributed to the assignment"*.

#### Interactivity

The participants rated the interactivity of the environment with a mean of 1.6 ( $SD=0.66$ ). In particular experiences, which are not possible in real-life, were mentioned as important and interesting features. All participants were excited about the interactive TEALsim integration, to simulate a falling coil experiment. One physicist mentioned: *"Such a playful animation can motivate also students, which are not really interested in the topic."*

#### Collaborative activities

The participants especially liked the social and collaborative aspects of the world, such as

“*solving questions with other peoples*”. Based on the learning progress results, they discussed their tasks a lot, which also influenced their final decisions (3/8 students changed their answer after the discussion). Also, the first stakeholder group was surprised about the different in-world collaboration possibilities: “*In real learning spaces it would be also very nice to be able to offer students separated discussion areas*”. The majority of the participants rated the system as very collaborative (M=1.4; SD=0.49).

### Usability

8 of the 10 participants rated usability of the environment according to the SUS grading with 70 or more. The mean rating was 73.89, but with a mentionable standard deviation of 22.81. The students, agreed that in-world discussions (M=1.29; SD=0.45) and collaborations (M=1.57; SD=0.72) are easy. Most of the students said that the concept questions were very easy to answer and to use (M=1.25; SD=0.66). The mean value of the usability rating of the simulation tool was moderately higher with a mean of 2 (SD=0.5).

### Motivation

Generally, students stated that they liked the entire experience and the corresponding tools, such as the simulation application or the concept questions. During the in-world roundtrips in particular the collaborative activities and the discussions were important for the students. To measure the students’ emotions with a focus on happiness, sadness, anxiety and anger, after the roundtrip, the CES was used. The 10 different indicators where ranged between 1 (none of the time) and 4 (all the time). The students’ emotions can be described as happy after the experiment (see Figure 64).

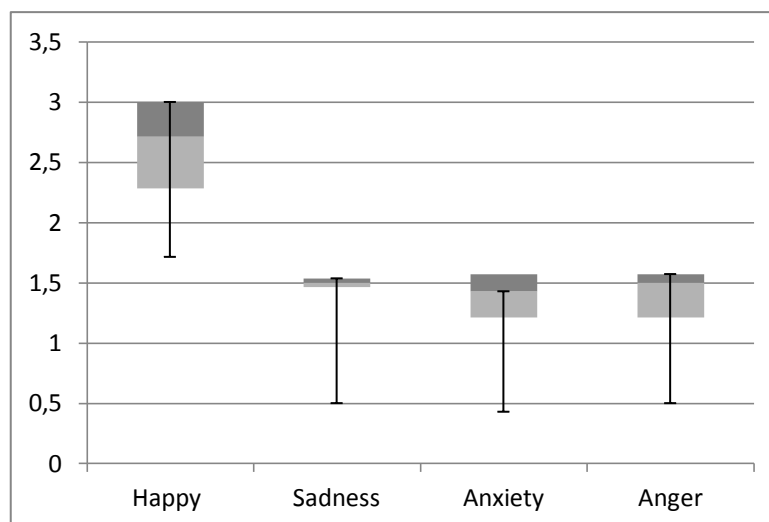


Figure 64: Computer Emotion Scale evaluation according to Kay and Loverock (2008)

Happy was identified by the feelings satisfaction, excitement and curiosity. Comparing the students' ratings regarding the different happiness indicators it should be noted that the value curiosity is very high, whereas the excitement was in comparison rather low (see Figure 65).

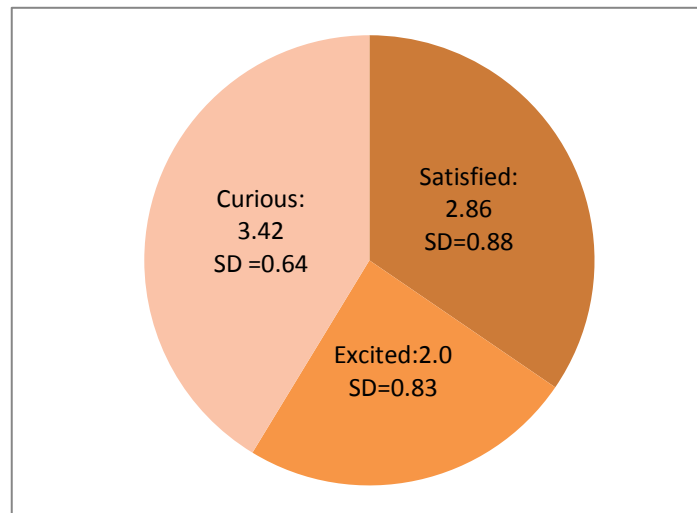


Figure 65: Distribution of the three happiness indicators

## 5.6 Discussion

Overall the evaluation was very successful. The results state that all participants experienced the environment as an interactive and also collaborative space. They were seriously interested in the different tools, in particular the simulation tool TEALsim-module. "It would be nice to have such a system also at our university." "It would be great for our physics course. The setup of experiments always takes half an hour." They even developed their own games with this tool and triggered different effects although they already finished their tasks. Also, according to the CES, students stated to be happy after the course. However, in particular the happiness indicator excitement was not high and should be included in the design decision for the next phase as a means to support the students' incentive, to stimulate in particular the intrinsic motivation. During the short roundtrip to learn the basic principles of Faraday's law, all students rated to gained new knowledge and were able to answer a basic comprehension question at the end of the course. For further studies, it would be crucial to use an extended version of the roundtrip, including more concept question to measure the learning progress in a more qualitative way. Participants rated the assessability of user interaction with 2 or less. In particular individual contributions cannot be monitored with the current setup.

According to the SUS rating of 73.9 and environment specific questions, the majority of the participants is satisfied with the usability of the environment and also its tools, such as the TEALsim-module or the concept question tool. However, they mentioned that the use of the tools is not very intuitive without an introduction and recommended an improvement of the controls. The majority of participants did not experience severe technical problems during the experiments. Only one student had significant problems with the system when logging in for the first time. This experience was reflected in his SUS score of 7.5. Nearly all participants recommend an improvement of the overall performance of the system and adapted graphics to

actual standards. Satisfying a sample of game experienced students regarding performance and optimized graphics is a challenging task. The first stakeholder group was not very satisfied with the assessment possibilities of individual contributions. The system allows a measurement of concept question answers, but the learning progress of individuals cannot be measured.

Most of the participants associated VWs with gaming environments and social platforms. Thus, a future approach should also include gaming aspects, to make the learning environment more attractive for the *World of Warcraft* generation.

## 6 Lessons Learned

This chapter discusses different experiences made during the literature study, the design and development phase and evaluation. Some of these findings will be also included in the following chapter, pointing out potential future work and improvements.

### 6.1 Theory

Reviewing the theoretical parts of this thesis, different techniques, which are still in development and not very common yet, were introduced. Technologies such as game-based learning, remote laboratories, three-dimensional simulations or virtual worlds were already introduced many years ago but still face different drawbacks, boundaries and issues. When designing or implementing a system using such technologies, it is always important to focus on the advantages and strengths in comparison to conventional tools and to keep the boundaries in mind. A well defined stakeholder analysis and requirement definition can help overcome different issues. In literature, an exhaustive guideline, how to design a 3d virtual world environment with a focus on supporting specific teaching scenarios is still missing. It is crucial to define guidelines suitable for the design scenarios and activities.

### 6.2 Development

When using Virtual worlds as a learning environment, it is really important to counteract acceptance issues and lack of motivations. This will not only ruin the learning experience but will also lead to a refusal of the virtual world environment. Playful, but in particular collaborative tasks can counteract those issues and will raise the students' motivations. Technical boundaries such as the lack of bandwidth or technical requirements can be disregarded when considering the working project as pioneer research project.

The practical work was developed within a working group of specialists at the Massachusetts Institute of Technology. Key developers of the learning approach TEAL, and the development frameworks TEALsim and Open Wonderland were supporting and facilitating the design and implementation process and offering input from their perspectives. Being able to address expert questions directly to the specialists was very helpful and time-saving. Working together with experts from different interest groups of the project was also inspiring. The Open Wonderland community is remarkably vivid and helpful and provides an up-to-date forum. When working with frameworks or open-source projects, it is always advisable to choose one with such an active community.

Since an iterative design and development approach was used, the necessary functionality of the VTW was developed and improved over time. Regular meetings with the main stakeholders were used to make important redesign decisions and to adapt the single components and activities. For instance, the necessity to use a pedagogical reviewed design framework, when inserting videos, was discovered by a main stakeholder. The first approach, supporting both, an

acoustic and written description of the video content, would have led to a cognitive overflow of the students.

Both Open Wonderland and TEALsim are frameworks, which are in continuous development for several years. Therefore, the versions are not always stable and also not always compatible with each other, what makes it necessary to keep the documentation up-to-date and be aware of the version differences. The same issue is addressed to the different libraries and frameworks used, such as MTGames or Java Monkey Engine. In particular, a major version change of the used programming language Java was necessary to monitor.

### **6.3 Evaluation**

The evaluation was based on standardized questionnaires for traditional software and complemented with pedagogical and environment specific questions, due to the lack of design guideline and evaluation forms for virtual world learning environments. For instance using only the SUS, a differentiation between the usability of the environment and the in-world tools would not be possible. In particular open-ended questions and user comments during the experiments were helpful to identify the users' emotions and deduce to further requirements to improve the environment. It was very surprising that in particular the standardized questionnaire CES pointed out the lack of a motivator, which can be included during the next iteration step. It was also helpful to use for both stakeholder groups questions, which were to some extent similar, to compare the results from the different points of view.

The in-world experiments were setup in a controlled environment. This enabled an easy supervision of the experiments and prevented difficulties with the technical requirements or the setup. Because of this setup, participants were not distracted by known technical issues of VWs, such as firewall problems, but were able to focus on the evaluation of the design requirements. An interesting outcome of the evaluation was the high gamer rate of the participants and that the majority would also use VWs for gaming purpose. This confirms the idea of adding game elements to the VTW.

It was very helpful to define TEAL's factors of success and focus the implementation on these aspects. The evaluation shows that students liked the VTW in particular because of these factors and would use it again. Experiences such as stepping into a three-dimensional falling coil experiment, discussing with peers different questions, and trying to solve different assignments made the entire virtual environment to a virtual learning experience.

## 7 Suggestions for Future Work

At the moment, only one VTW learning scenario representing Faraday's Law is developed. The next steps will include the implementation of further VTW learning scenarios. An introduction area could be the start position with portals linked to the different learning modules. Due to the dimension of this project there are many ideas and suggestions for future work. The main aspects of the future work will include the enhancement, extension and quality assurance of the existing components. The next section will outline suggestions for future work identified in the framework of the evaluation.

### 7.1 Evaluation results

During the evaluation, three major suggestions for improvement were recommended by the participants directly: (1) improvement of performance, (2) enhanced graphics and (3) integration of more intuitive tool controls. The first point could be achieved by enhancing the server hardware, optimizing further TEALsim calculations, and dividing large scenarios into smaller ones. Also, the graphics could be enhanced, by using more complex structures for the environment. However, such an improvement would require more calculation time and reduces as a consequence the performance. The third suggestion can be integrated immediately by installing a new module for Open Wonderland, which enables users controlling in-world tools, by simply click on it, instead of using a sub-menu. Due to the indirect evaluation results, further improvements also should include an improved assessability, the integration of exciting activities, such as games, and an improved video player, which supports subtitles on demand. Assessability and gaming activities will be discussed further in the next section.

### 7.2 Further improvements and scenarios

The following section will introduce briefly further scenarios, which are based on the introduced requirements of the designing phase:

- **Usability:** A user-friendly environment, which is easy to use for students and professors. This should also enhance the users' motivation to use the system
- **Interactivity:** In particular interactive simulations should raise the students' interests and motivation and enhance their conceptual understanding
- **Collaboration:** Collaborative in-world tasks, such as brainstorming or the joint discussion of a concept question
- **Assessability:** Instructors should be able to follow the students' activities and question answers

#### Including Remote Laboratories

The actual version of the VTW supports the possibility to include watch remote laboratories using Open Wonderland's webcam integration. An imitated remote laboratory setting reacting

on the input of the avatars could improve the interactivity, motivation and also the conceptual understanding of the students. In Gütl et al. (2012) a proof of concepts referring to an in-world realization of the interactive laboratory setting iLab is given.

### Including Game Designing Aspects

To enhance the students' motivation game-based approaches or gamified systems could be added. Already the implementation of some small game elements, such as rewards or batches associated with learning advancements, can enhance the engagement, motivation and fun. Also, the extension of simulations in order to provide the same content being learned and experience via a game would be reasonable. A game-based approach or a gamified model can be introduced to advance the peer collaboration, but it would also be useful to enhance self-motivation and self-regulation.

### World Designing Tool for Open Wonderland

To make the VTW easily extensible and changeable for instructors, a web-based designing and editing tool could be provided to create an entire world (representing a single course). Instead of adding and positioning single objects such as Whiteboards, PDFs, simulations or videos in the three-dimensional virtual world, a drag-and-drop system can quicken and simplify the creation and change processes. As a proof of concept, a similar system, the 'RoomManager' was realized for the Open Simulator platform (Haas, 2012). Figure 66 gives an overview of the original layout of the RoomManager tool, which enables the creation and design of rooms with different objects such as whiteboards, tables and benches.

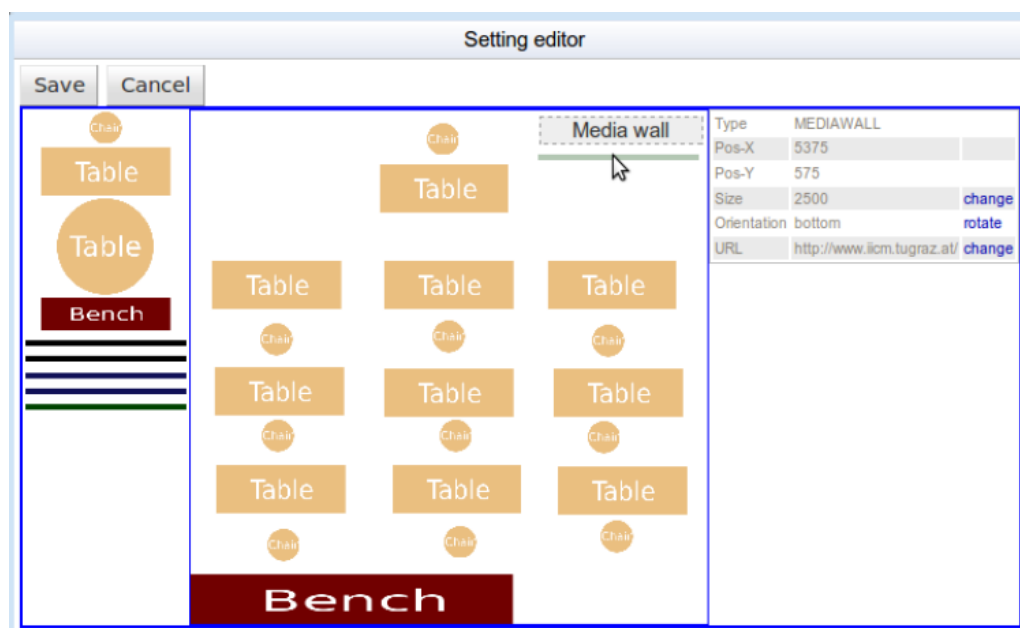


Figure 66: RoomManager tool for creating entire classrooms using a web-interface (Haas, 2012)



**Assessment possibilities**

The actual tool for creating and answering concept questions already provides the possibility to apply easily and add assessment methods. However, assessing in-world discussions, collaborative activities or also the interaction with tools such as the whiteboard or the simulation toolkit are not possible yet. Adding additional assessable information to these activities and tools would be a pedagogical enhancement from which instructors, but also students could profit.

**Further user studies**

To improve the VTW, it is necessary to conduct further user studies. In particular, a study with modified variables, such as different learning scenarios, or a comparison between collaborative learning with traditional learning should help measure the learning progress and identifying further improvement possibilities. It would be also helpful for further developments to compare the learning progress of the learning outcomes of the traditional TEAL course with the outcomes of the virtual one.

## 8 Summary and Outlook

Teaching freshmen physics is a challenging task. Teaching objectives should not only motivate students to learn, but rather to understand the phenomena. A successful model to achieve this goal was introduced at MIT. The TEAL (Technology-Enabled Active Learning) approach uses collaborative, interactive and hands-on experiences to enhance the students' conceptual understanding. However, due to the high environment expenses, the implementation of TEAL cannot be afforded by every institution or university. Also, TEAL cannot be used in distance learning scenarios, which are becoming receiving increased interest. Depending on the learning scope and application domain, conventional e-learning tools are not always the best choice. In particular abstract domains such as physics are hard to teach without advanced tools. Drawbacks of conventional e-learning tools, such as the lack of immersion, communication and collaboration possibilities require the introduction of a new e-learning tool, the 3d virtual world. Even though traditional e-learning systems bring many advantages such as flexible learning possibilities, internationalization and cost reduction, particular disadvantages such as the lack of social interactions, technical demands, required self-motivation, and the lack of hands-on experiences are common objections. Three major requirements of environments to overcome some of those issues were defined: (1) social collaboration, (2) interactivity and (3) motivation. Remote laboratories, animations and simulations, game-based learning and collaborative immersive environments were identified as adequate servers of these needs. The 3d virtual world environment was introduced as a potential environment to provide all the services at one interactive, collaborative place.

This work presented the design, implementation and evaluation of a virtual world environment for the interactive engaging pedagogical approach TEAL. The simulation tool TEALsim helps students understand different physical procedures by making the invisible visible. Therefore, some of these aspects, such as simulations and collaborative learning, were already integrated into the VTW. During this thesis, a model to integrate the pedagogical approach TEAL into a virtual world environment has been developed and a first scenario focusing on teaching the concepts of Faraday's law was introduced. To enhance the conceptual understanding of the students, the VTW design process focused on approaches meeting interactive, motivational, social, and collaborative needs.

A first user evaluation with the two main stakeholder groups shows that in particular collaborative and interactive activities are attractive features of such environments. Participants especially liked to use the interactive, three-dimensional TEALsim simulation of a falling coil experiment. However, the evaluation also outlined different needs and suggestions for enhancement, such as an improved performance or enhanced graphics. It was also shown that an improved assessment approach to control the student's individual contribution would be helpful for instructors.

A usability evaluation using the SUS outlined that the participants scaled the system's usability above the average, but they also recommend improving the intuitiveness and clarity of the use of the in-world tools. A future implementation of a 2-dimensional, web-based class room generator to easily place learning content in-world could help overcome this issue. The CES showed that

the students' mood was happy after the experiment, but experienced a lack of excitement. Integrating fun and game elements should help overcome this issue and enhance also the students' motivation. Therefore, recommendations for future work include the integration of game elements and further interactive tools, like connections to remote laboratories.

Even though users were first suspicious of the use of virtual world environment for learning purpose, the majority of the participants would like to use such a system in the future. Also considering the future prognosis according to Gartner's Hype Cycle (Gartner Hype Cycle, 2012), virtual world environments have a great potential as future e-learning and collaboration tools. In particular, the special needs of STEM education can be met in an exemplary fashion because of potential integration of different multimedia-based interactive activities.

## Bibliography

- Active Learning*. (2009). (Center for Faculty Excellence, University of North Carolina at Chapel Hill) Retrieved 9 2012, 1, from Classroom Activities for Active Learning: <http://cfe.unc.edu/pdfs/FYC2.pdf>
- Allison, C., Miller, A., Sturgeon, T., Nicoll, J. R., & Perera, I. (2010). Educationally Enhanced Virtual Worlds . In *Frontiers in Education Conference (FIE), 2010 IEEE* (pp. T4F-1 -T4F-6).
- Bartle, R. (2003). *Designing Virtual Worlds*. New Riders Games.
- Belcher, J., Dourmashkin, P., Liao, S.-b., Litster, D., Derby, N., & Olbert, S. (2004). *Visualizing Electricity and Magnetism at MIT*. Retrieved 06 22, 2012, from [http://web.mit.edu/8.02t/www/802TEAL3d/TEAL\\_tour.htm](http://web.mit.edu/8.02t/www/802TEAL3d/TEAL_tour.htm)
- Bell, M. W. (2008). Toward a Definition of "Virtual Worlds". *Virtual Worlds Research: Past, Present & Future*, 1(1), 1-5.
- Bell, R. L., & Smetana, L. K. (2008). Using Computer Simulations to Enhance Science Teaching and Learning. *National Science Teachers Association*, 23-32.
- Berger, S. (2012). *Virtual 3d World for Physics Experiments in Higher Education: Implementation of Physics Experiments in a Virtual World*. Graz: Graz University of Technology.
- Bonwell, C. C., & Eison, J. A. (1991). Active Learning: Creating Excitement in the Classroom. *ERIC Digest*.
- Boulos, M. N., Hetherington, L., & Wheeler, S. (2007). Second Life: an overview of the potential of 3-D virtual worlds in medical and health education. *Health Information and Libraries Journal*(24), pp. 233-245.
- Breau, G. (2002). *The Online World Economy*. <http://www.quantumg.net/owe.php>.
- Brooke, J. (1996). SUS: a "quick and dirty" usability scale. In B. T. P. W. Jordan, *Usability Evaluation in Industry*. London: Taylor and Francis.
- Bruning, R. H., Schraw, G. J., Norby, M. M., & Ronning, R. R. (2004). *Cognitive psychology and instruction*. Columbus: Pearson.

- Chang, V., Gütl, C., Kopeinik, S., & Williams, R. (2009, November). Evaluation of Collaborative Learning Settings in 3d virtual worlds. *International Journal of Emerging Technologies in Learning*, pp. 6-17.
- Christian, W. (2005). *Davidson College WebPhysics server*. Retrieved 9 1, 2012, from <http://webphysics.davidson.edu/Applets/Applets.html>
- Clark, M. A. (2012). Genome Island. In *Engaging the Avatar: New Frontiers in Immersive Education* (pp. 277-308). Charlotte, North Carolina: Information Age Publishing.
- Clifford, M. (2012, 9 22). *School Leadership 2.0*. Retrieved 9 20, 2012, from <http://www.schoolleadership20.com/forum/topics/top-20-uses-of-virtual-worlds-in-education>
- Cockburn, A., & McKenzie, B. (2002). Evaluating the Effectiveness of Spatial Memory in 2D and 3d Physical and Virtual Environments. In *Proc. CHI 2002 Conference: Human Factors in Computer Systems* (pp. 203-210). New York: ACM Press.
- Cooper, A. (1999). *The Inmates Are Running the Asylum*. Sams.
- Corter, J. E., Nickerson, J. V., Esche, S. K., Chassapis, C., Im, S., & Ma, J. (2007). Constructing Reality: A Study of Remote, Hands-On, and Simulated Laboratories. *ACM Transactions on Computer-Human Interaction*, 14(2), 1-26.
- Cox, A. J., Belloni, M., Dancy, M., & Christian, W. (2003). Teaching thermodynamics with Physlets® in introductory physics. *Physics Education*, 38(5), 433-440.
- D&D Homepage*. (2001). Retrieved 9 1, 2012, from Official Dungeon and Dragons Homepage: <http://www.wizards.com/dnd/>
- De Lucia, A., Francese, R., Passero, I., & Genoveffa Tortora, G. (2008). Development and evaluation of a virtual campus on Second Life: The case of SecondDMI. *Computer & Education*, 52(1), 220-233.
- Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011, September). From Game Design Elements to Gamefulness: Defining "Gamification". *MindTrek '11 Proceedings*, pp. 9-15.
- Diablo 3 Website*. (2012). Retrieved 9 1, 2012, from Official Diablo 3 Webpage: [www.diablo3.com](http://www.diablo3.com)
- Dillenbourg, P. (1999). What do you mean by 'collaborative learning'? In *Collaborative-learning: Cognitive and Computational Approaches* (pp. 1-19). Oxford: P. Dillenbourg.

- Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1996). The evolution of research on collaborative learning. In E. Spada, & P. Reiman, *Learning in Humans and Machine: Towards an interdisciplinary learning science* (pp. 189-211). Oxford, OK: Elsevier.
- Dori, Y. J., & Belcher, J. (2005). How Does Technology-Enabled Active Learning Affect Undergraduate Students' Understanding of Electromagnetism Concepts? *THE JOURNAL OF THE LEARNING SCIENCES* 14(2), pp. 243-279.
- Dori, Y. J., Belcher, J., Bessette, M., Danziger, M., McKinney, A., & Hult, E. (2003, dec). Technology for active learning. *materials today* , pp. 44-49.
- Dougiamas, M. (1998, 11). *A journey into Constructivism*. Retrieved 8 1, 2012, from <http://dougiamas.com/writing/constructivism.html>
- Duffy, A. (2000). *Interactive Lecture Demonstrations*. Retrieved 9 1, 2012, from <http://buphy.bu.edu/~duffy/ILD.html>
- Emrich, A. (2004). *The Gamer Generation And Why Baby Boomers Shouldn't Worry so Much about Them*. Retrieved 9 2012, 1, from [http://www.alanemrich.com/SGI/Week\\_10/SGI%2010%20GAMER%20GENERATION.pdf](http://www.alanemrich.com/SGI/Week_10/SGI%2010%20GAMER%20GENERATION.pdf)
- Engelbrecht, K. (2003). *The Impact of Color on Learning*. Chicago, Illinois : Perkins & Will.
- Feynman, R. P. (1969, September). What Is Science. *The Physics Teacher*, 7(6), pp. 313.
- Foldit Website*. (2012). Retrieved from <http://fold.it>
- Forbes*. (2012). Retrieved 9 1, 2012, from Forbes - World of Warcraft Drops a Million Subscribers in Three Months: <http://www.forbes.com/sites/insertcoin/2012/08/03/world-of-warcraft-drops-a-million-subscribers-in-three-months/>
- Freedman, R. A. (1996 ). Challenges in Teaching and Learning Introductory Physics. In *From High Temperature Superconductivity to Microminiature Refrigeration* (pp. 313-322).
- Gartner Hype Cycle*. (2012). Retrieved 9 1, 2012, from <http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp>
- Genome Guide*. (2012). Retrieved 9 1, 2012, from <http://faculty.txwes.edu/mclark/Genome/Guide.htm>

- Glaserfeld, E. v. (1989). Constructivism in Education. In T. Husen, & T. N. Postlethwaite, *The International Encyclopedia of Education, Supplement Vol.1* (pp. 162-163). Oxford / New York: Pergamon Press.
- Gomes, L., & Bogosyan, S. (2009). Current Trends in Remote Laboratories. *IEEE Transactions on Industrial Electronics*, 56(12), 4744-4756.
- Graham, C. R. (2006). Blended Learning Systems: Definition, current trends, and future directions. In *The Handbook of Blended Learning* (pp. 1-21). San Francisco : Pfeiffer.
- Gravier, C., Fayolle, J., Bayard, B., M. A., & Lardon, J. (2008). State of the art about remote laboratories paradigms - foundations of ongoing mutations. *International Journal of Online Engineering*, 4(1).
- Guild Wars 2 website*. (2012). Retrieved 9 1, 2012, from Official Guild Wars 2 Webpage: [www.guildwars2.com](http://www.guildwars2.com)
- Guild Wars Website*. (2011). Retrieved 9 1, 2012, from Official Guild Wars Webpage: <http://www.guildwars.com/>
- Gütl, C. (2011). The Support of Virtual 3d Worlds for Enhancing Collaboration in Learning Settings. In *Techniques for Fostering Collaboration in Online Learning Communities: Theoretical and Practical Perspectives* (pp. 278-299). Hershey, PA: IGI Global.
- Gütl, C., & Pirker, J. (2011). Implementation and evaluation of a collaborative learning, training and networking environment for start-up entrepreneurs in virtual 3d worlds. In *14th International Conference on Interactive Collaborative Learning 2011 (ICL)* (pp. 58- 66).
- Gütl, C., Scheucher, T., Bailey, P. H., Belcher, J., Santos, F. R., & Berger, S. (2012). Towards an Immersive Virtual Environment for Physics Experiments Supporting Collaborative Settings in Higher Education. In *Internet Accessible Remote Laboratories: Scalable E-Learning Tools for Engineering and Science Disciplines* (pp. 543-562). IGI Global.
- Haas, K. (2012). *Flexible Learning Environment in Virtual 3d Worlds*. Institute of Information Systems and Computer Media, Graz University of Technology.
- Hake, R. (1988). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.
- Hake, R. (2002). Lessons from the Physics Education Reform Effort. *Conservation Ecology*, 5(2). Retrieved from <http://www.consecol.org/vol5/iss2/art28/>

- Hestenes, D. (1996). Modeling Methodology for Physics Teachers. *Proceedings of the International Conference on Undergraduate Physics*.
- Hoag, A., & Baldwin, T. F. (2000). Using Case Method and Experts in Inter-University Electronic Learning Teams. *Educational Technology & Society* 3 (3), pp. 337-348.
- Holmström, H., & Jakobsson, M. (2001). Using Models in Virtual World Design. In *Proceedings of the 34th Annual Hawaii International Conference on System Sciences*. Hawaii.
- Horton, W. (2011). *e-Learning by Design*. San Francisco: John Wiley & Sons.
- Howard Hughes Medical Institute . (2010, 8 4). *Protein-folding game taps power of worldwide audience to solve difficult puzzles*. Retrieved from EurekAlert! : [http://www.eurekalert.org/pub\\_releases/2010-08/hhmi-pgt080310.php](http://www.eurekalert.org/pub_releases/2010-08/hhmi-pgt080310.php)
- Ibáñez, M. B., García, J. J., Galán, S., Maroto, D., Morillo, D., & Delgado, C. (2011). Design and Implementation of a 3d Multi-User Virtual World for Language Learning . *Journal of Educational Technology & Society*, 14(4), 2-10.
- James, D., Walton, G., Robbins, B., Dunin, E., Mills, G., Welch, J., DeBenedictis, S. (2004). *2004 Persistent Worlds Whitepaper*. IGDA Online Games SIG. Retrieved 9 1, 2012, from [http://web.archive.org/web/20080228225951/http://www.igda.org/online/IGDA\\_PS\\_W\\_Whitepaper\\_2004.pdf](http://web.archive.org/web/20080228225951/http://www.igda.org/online/IGDA_PS_W_Whitepaper_2004.pdf)
- Kaplan, J., & Yankelovich, N. (2011, sept.-oct.). Open Wonderland: An Extensible Virtual World Architecture. *Internet Computing, IEEE*, pp. 38-45.
- Kay, R. H., & Loverock, S. (2008). Assessing emotions related to learning new software: The computer emotion scale. *Computers in Human Behavior*(24), pp. 1605-1623.
- Klopfer, E., Osterweil, S., & Salen, K. (2009). *Moving Learning Games Forward*. Massachusetts Institute of Technology: The Education Arcade.
- Koumi, J. (2012). Pedagogic design guidelines for multimedia materials: a mismatch between intuitive practitioners and experimental researchers. In *Educational Media Production Training*.
- Kruse, K. (2004). *The Benefits and Drawbacks of e-Learning*. Retrieved 9 29 12, 1, from [http://www.corebiztechnology.com/software\\_article\\_elearning\\_d.htm](http://www.corebiztechnology.com/software_article_elearning_d.htm)



- Laughlin, D., Roper, M., & Howell, K. (2007). *Research Challenges in the Design of Massively Multiplayer Games for Education and Training: NASA eEducation Roadmap*. Washington, DC: NASA Learning Technologies.
- Lee, Y.-F., Guo, Y., & Ho, H.-j. (2008). Explore Effective Use of Computer Simulations for Physics Education. *Journal of Computers in Mathematics and Science Teaching*, 27(4), 443-466.
- Lunce, L. M. (2006, Spring/Summer). Simulations: Bringing the benefits of situated learning to the traditional classroom. *Journal of Applied Educational Technology*, pp. 37-45.
- Ma, J., & Nickerson, J. V. (2006). Hands-On, Simulated, and Remote Laboratories: A Comparative Literature Review. *ACM Computing Surveys*, 3(7), 38.
- MacKay, B., & College, C. (2006). *Iterative Engagement*. (Science Education Resource Center at Carleton College) Retrieved 9 2012, 1, from <http://serc.carleton.edu/introgeo/models/IntEng.html>
- Mazur, E. (1996). *Peer Interaction, A User's Manual*. Prentice Hall.
- McDermott, L. C., & Redish, E. F. (1999). Resource Letter on Physics Education Research. In *The American Journal of Physics*. American Association of Physics Teachers.
- Means, B., Toyama, Y., Murphy, R., Bakia, M., & Jones, K. (2009). *Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies*. <http://www2.ed.gov/rschstat/eval/tech/evidence-based-practices/finalreport.pdf>.
- Monke, L. (2004). *Education Next : The Human Touch*. Retrieved 9 1, 2012, from <http://educationnext.org/thehumantouch/>
- Moodle Website. (2010). Retrieved 06 20, 2012, from <http://moodle.org/>
- Moschini, E. (2010). The Second Life Researcher Toolkit - An Exploration of Inworld Tools, Methods and Approaches for Researching Educational Projects in Second Life. In *Researching Learning in Virtual Worlds* (pp. 31-51). London: Springer.
- Muñoz, R., & Thiago Barcelos, V. C. (2012). Defining Virtual Worlds Usability Heuristics. *2012 Ninth International Conference on Information Technology: New Generations (ITNG)*, (pp. 690-695).
- NASA. (2012). *NASA Moonbase Alpha - Educator Guide*. Retrieved from NASA Learning Technologies: [http://www.nasa.gov/pdf/526940main\\_Moonbase\\_Alpha\\_Educator\\_Guide\\_v1.pdf](http://www.nasa.gov/pdf/526940main_Moonbase_Alpha_Educator_Guide_v1.pdf)

- NASA Website. (2009). Retrieved from <http://www.nasa.gov/audience/foreducators/virtual-education.html>
- Niegemann, H. M. (2008). *Kompendium multimediales Lernen*. X.MEDIA.PRESS.
- Nielsen, J. (1995). *Usability 101: Introduction to Usability*. Retrieved 9 1, 2012, from <http://www.useit.com/alertbox/20030825.html>
- Nielsen, J. (2000). *Designing Web Usability: The Practice of Simplicity*. CA, USA: New Riders Publishing.
- Nielson, J. (1993). *Usability Engineering*. San Francisco: Morgan Kaufmann.
- Novak, G. (1999). *Just-In-Time-Teaching*. Retrieved 9 2012, 1, from <http://jittdl.physics.iupui.edu/jitt/what.html>
- O'Kuma, T. L., Maloney, D. P., & Hieggelke, C. J. (2000). *Ranking Task Exercises in Physics*. Upper Saddle River, New Jersey 07458: Prentice Hall.
- Online Education. (2012). Retrieved 0 2012, 1, from <http://www.onlineeducation.net/videogame>
- OpenSim Website. (2010 ). Retrieved 06 20, 2012, from Official Open Simulator Website: <http://opensimulator.org>
- OSP. (2003). Retrieved 9 1, 2012, from Open Source Physics: <http://www.compadre.org/osp/>
- OWL Blog. (2012). Retrieved 9 1, 2012, from Open Wonderland Blog: <http://blogs.openwonderland.org/>
- OWL Website. (2007). Retrieved 06 20, 2012, from Open Wonderland Website: <http://openwonderland.org/>
- Oxford Dictionaries. (2012). Retrieved 08 10, 2012, from <http://oxforddictionaries.com>
- PhET. (2011). Retrieved 09 2012, 1, from PhET Interactive Simulations: <http://phet.colorado.edu>
- Pirker, J., Berger, S., Gütl, C., Belcher, J., & Bailey, P. H. (2012). Understanding Physical Concepts using an Immersive Virtual Learning Environment. *European Immersive Education Summit*. Paris.

- Redish, E. F. (1996). New Models of Physics Instruction Based on Physics Education Research: Part 2. *Proceedings of the Deustchen Physikalischen Gesellschaft Jena Conference*.
- Reis, R., Escudeiro, P., & Escudeiro, N. (2010). Comparing Social Virtual Worlds for Educational Purposes. In *2010 IEEE 10th International Conference on Advanced Learning Technologies (ICALT)* (pp. 186 -190).
- Rong, Z., Chen, K., Zhou, M., & Xiao, J. (n.d.). Designing and Implementing the E-learning system. In *International Conference on Computer Science and Software Engineering 2008* (pp. 797 -800). 2008 .
- Ruth, S. (2010). Is E-Learning Really Working? The Trillion-Dollar Question. *Internet Computing, IEEE, 14*(2), 78 -82.
- Sanders, M. (2009, December/January). STEM, STEM Education, STEMmania. *The Technology Teacher*.
- Schell, J. (2008). *The Art of Game Design: A Book of Lenses*. Elsevier/Morgan Kaufmann.
- Scheucher, B. (2010). *Remote Physics Experiments in 3d*. Graz: Graz University of Technology.
- Schneidermand, B., & Plaisant, C. (2010). *Designing the User Interface - Strategies for effective human-computer interaction*. Boston, MA: Pearson Higher Education.
- Second Life Education*. (2011). Retrieved from [http://wiki.secondlife.com/wiki/Second\\_Life\\_Education](http://wiki.secondlife.com/wiki/Second_Life_Education)
- SL Website*. (2009). Retrieved 06 20, 2012, from Official Second Life Website: <http://secondlife.com/>
- Tabbers, H. K., Martens, R. L., & Merriënboer, J. J. (2001). The modality effect in multimedia instructions. In *Annual conference of the Cognitive Science Society*.
- Tabbers, H. K., Martens, R. L., & Merriënboer, J. J. (2001). The modality effect in multimedia instructions. *23rd Annual Conference of the Cognitive Science (Society Cogsci)*. Edinburgh, Scotland. Retrieved from <http://conferences.inf.ed.ac.uk/cogsci2001/pdf-files/1024.pdf>
- TEAL Casestudies*. (2005). Retrieved 09 01, 2012, from <http://web.mit.edu/edtech/casestudies/TEAL.html>
- TEAL-Project*. (2006). Retrieved 06 2012, 23, from Technology Enabled Active Learning: <http://icampus.mit.edu/projects/TEAL.shtml>

- TEALsim Website*. (2004). Retrieved 06 20, 2012, from <http://web.mit.edu/viz/soft/visualizations/TEALsim/index.html>
- Teed, R. (2012). *Game-Based Learning*. (Science Education Resource Center @ Carleton College) Retrieved 9 2012, 1, from <http://serc.carleton.edu/introgeo/games>
- Thackray, L., Good, J., & Howland, K. (2010). Learning and Teaching in Virtual Worlds: Boundaries, Challenges and Opportunities. In *Research Learning in Virtual Worlds* (pp. 139-158). London: Springer.
- The Active Class Webpage*. (2012). Retrieved 9 1, 2012, from <http://theactiveclass.com/category/k12/>
- Thornton, R. K. (1987). Tools for scientific thinking—microcomputer-based laboratories for teaching physics. *Physics Education*, 22(4), 230-238.
- Trotta, H., & Glenn, M. (2012). Salt Marsh Dynamics - A Problem-based Learning Scenario. In R. Hinrichs, & C. Wanekl, *Engaging the Avatar* (pp. 189-215). Charlottter, Noth Carolina: Information Age Publishing, Inc.
- Welsh, E. T., Wanberg, C. R., Brown, K. G., & Simmering, M. J. (2003, Nov 14). E-learning: emerging uses, empirical results and future directions. *International Journal of Training and Development*, pp. 245-258.
- Windschitl, M., & Andre, T. (1998). Using Computer Simulations to Enhance Conceptual Change: The Roles of Constructivist Instruction and Student Epistemological Beliefs. *Journal of Research in Science Teaching*, 35(2), 145-160.
- WOW website*. (2004). Retrieved 9 1, 2012, from Official World of Warcraft webpage: <http://www.worldofwarcraft.com/>
- Wu, B., Wang, A. I., & Zhang, Y. (2010). Experiences from implementing an educational MMORPG. In *2010 International IEEE Consumer Electronics Society's Games Innovations Conference (ICE-GIC)* (pp. 1-8).
- Zichermann, G., & Cunningham, C. (2011). *Gamification by Design*. Sebastopol, CA 95472.: O'Reilly Media.

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## List of Abbreviations

CBV	Computer-based Visualization
CES	Computer Emotions Scale
CMS	Course Management System
CSCL	Computer-supported Collaborative Learning
GBL	Game Based Learning
GUI	Graphical User Interface
ICT	Information and Communication Technology
IE	Interactive Engagement
JiTT	Just in Time Teaching
JME	JMonkeyEngine
JSP	JavaServer Pages
LMS	Learning Management System
MBL	Microcomputer-based Laboratories
MIT	Massachusetts Institute of Technology
MMOG	Massively multiplayer online game
MMORPG	Massively multiplayer online role-playing game
OSP	Open Source Physics
OpenSIM	Open Simulator
OWM	Open Wonderland Module
OWL	Open Wonderland
PI	Peer Instruction
PRS	Personal Response System
SL	Second Life
SUS	System Usability Scale
STEM	Science, Technology, Engineering, and Mathematics
TEAL	Technology-Enabled Active Learning
THA	Thinking aloud
VTW	Virtual TEAL World
VW	Virtual world
WoW	World of Warcraft
XML	Extensible Markup Language

## Appendix

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## **Appendix A: CD Content**

The attached CD contains the following resources:

### **Package ‘Development’**

- Java version 7.0.1
- The latest Open Wonderland server version used for the experiment
- Installation script to start the OWL server
- The TEALsim-Module
- The Learning module
- The Learning module web interface
- The Export file of Faraday’s Law scenario

### **Package ‘Theory’**

- PDF version of this document
- The two Evaluation forms
- A summary of the evaluation results

## Appendix B: Installation of the VTW Prototype

The entire Virtual TEAL World can be easily imported into a running Open Wonderland system. This chapter explains the standard setup of Open Wonderland, the installation of the required modules and the setup of the VTW in an empty OWL space.

In order to install the VTW in Open Wonderland the following files from the Open Wonderland Website<sup>1</sup> and the OWL's Module Warehouse<sup>2</sup> are required:

- Open Wonderland Server
- Subsnapshot Importer Exporter JAR file (SubSnapshots.jar)

In order to install the VTW in Open Wonderland the following files from the VTWpackage are required:

- LearningPoster.jar
- TEALsim.jar
- FaradaysLaw.wlexport

### Setup of Open Wonderland

To install Open Wonderland a Sun Java SE 6 JDK or later is required. Open Wonderland's server version can be installed either on Windows, Mac OS X, Linux or OpenSolaris. The server can be started either using the installation script contained at the CD or by typing:

```
Java -jar Wonderland.jar
```

In the case that Java is located in a different directory the Java command should be replaced by the entire path of the Java location. This command should trigger the server to start up in a terminal. When the message "Wonderland web server started successfully" is displayed, the Open Wonderland server is running and ready to use. The webinterface can be accessed using a browser by entering the URL "localhost:8080", where localhost can be replaced by the server's IP address. Further installation details can be found at the Open Wonderland website.

### Installation of the required Open Wonderland Modules

The Subsnapshot Importer Exporter JAR file (SubSnapshots.jar) should be downloaded from OWL's Module Warehouse.

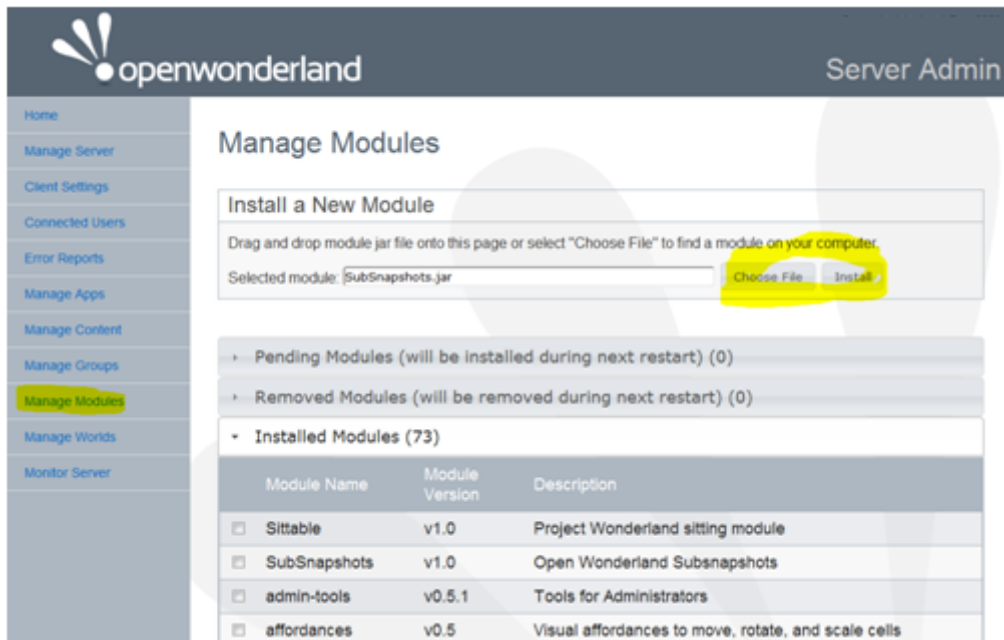
---

<sup>1</sup> <http://openwonderland.org/download>

<sup>2</sup> <http://openwonderland.org/module-warehouse>

All three JAR files, SubSnapshots.jar, LearningPoster.jar and TEALsim.jar, should be installed according to the following steps:

On the main page of your Open Wonderland environment (if you are running it locally without special configuration you should find it at localhost:8080) click on the 'Manage Modules' link (see Figure 67). There you find a listing of the actual installed modules. Add all three modules by selecting them using the file selector and install them. You should see the modules now listed as 'Pending Modules'.

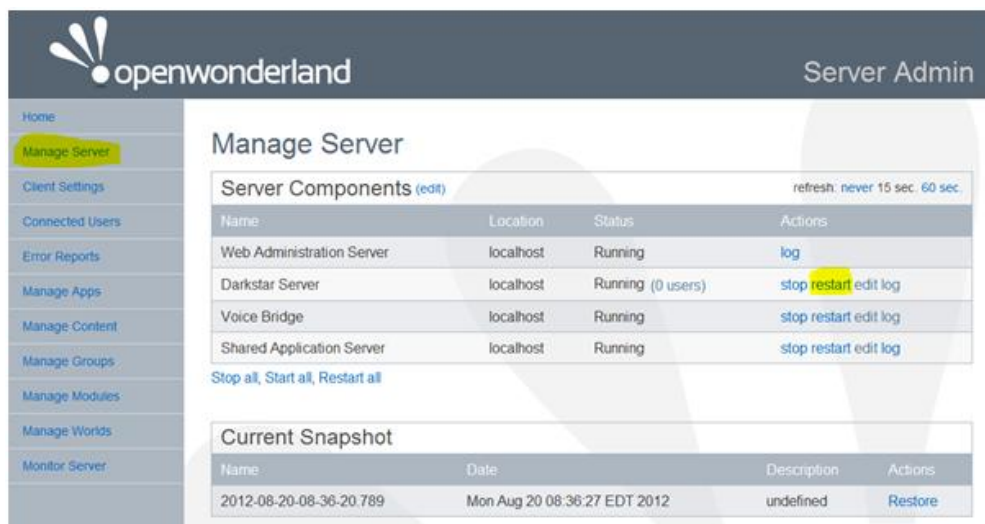


The screenshot shows the 'Manage Modules' web administration page. The page title is 'Manage Modules' and it is part of the 'Server Admin' interface. The main content area is titled 'Install a New Module' and contains instructions: 'Drag and drop module jar file onto this page or select "Choose File" to find a module on your computer.' Below this, there is a text input field for 'Selected module:' containing 'SubSnapshots.jar' and two buttons: 'Choose File' and 'Install', both highlighted in yellow. Below the input field, there are three sections: 'Pending Modules (will be installed during next restart) (0)', 'Removed Modules (will be removed during next restart) (0)', and 'Installed Modules (73)'. The 'Installed Modules' section contains a table with the following data:

Module Name	Module Version	Description
<input type="checkbox"/> Sittable	v1.0	Project Wonderland sitting module
<input type="checkbox"/> SubSnapshots	v1.0	Open Wonderland Subsnapshots
<input type="checkbox"/> admin-tools	v0.5.1	Tools for Administrators
<input type="checkbox"/> affordances	v0.5	Visual affordances to move, rotate, and scale cells

Figure 67: Manage Modules web administration page

Are all modules installed, it is necessary to restart the Darkstark Server. This can be done on the 'Manage Server' page (see Figure 68).



The screenshot shows the 'Manage Server' web administration page. The page title is 'Manage Server' and it is part of the 'Server Admin' interface. The main content area is titled 'Server Components (edit)' and contains a table with the following data:

Name	Location	Status	Actions
Web Administration Server	localhost	Running	log
Darkstar Server	localhost	Running (0 users)	stop restart edit log
Voice Bridge	localhost	Running	stop restart edit log
Shared Application Server	localhost	Running	stop restart edit log

Below the table, there is a link: 'Stop all, Start all, Restart all'. Below this, there is a 'Current Snapshot' section with a table showing the current snapshot details:

Name	Date	Description	Actions
2012-08-20-08-36-20-789	Mon Aug 20 08:36:27 EDT 2012	undefined	Restore

Figure 68: Manage Server web administration page

## **Import of the Virtual TEAL World Snapshot**

Open Wonderland provides the possibility to easily export and import entire worlds. The exported files are saved as '.wlexport' files. In order to import the entire VTW scenario 'Faradays Law', just drag and drop the FaradaysLaw.wlexport file into an empty space.