

Understanding Physical Concepts using an Immersive Virtual Learning Environment

Johanna PIRKER ^a, Stefan BERGER ^a, Christian GÜTL ^{a,c}, John BELCHER ^b and Philip H. BAILEY ^b

^a*Graz University of Technology*

^b*Massachusetts Institute of Technology*

^c*Curtin University of Technology*

Abstract.

Understanding basic physical concepts is not an easy task. The Technology Enabled Active Learning Approach (TEAL) is an innovative learning approach and successfully improves the conceptual understanding in teaching freshmen physics at the Massachusetts Institute of Technology. This approach requires specially designed classrooms, hands-on experiments, different teaching methods and also virtual visualizations and simulations to enhance the student's engagement and learning success. The Java-based open-source framework TEALsim was especially designed to support the students understanding of different physical procedures using visualizations and simulations of physical concepts such as Faraday's Law. But not every institution or university is able to use the TEAL scenario because of the high expense in terms of required equipment. Also the distance learning idea is lost. Existing learning spaces are limited regarding time and space. Depending on the learning scope and application domain conventional E-learning tools are not always the best choice. Especially such abstract domains as physics are hard to teach without advanced tools. Drawbacks such as the lack of immersion and the lack of communication and collaboration possibilities suggest the introduction of a new e-learning tool, the Virtual 3D World. This paper focuses on the technical aspects of the implementation of TEALsim in the Virtual 3D World Environment Open Wonderland. This collaboration between the CECI at MIT and AEMT group at TU-Graz introduces a first potential scenario of in-world physics simulations. The Open Wonderland solution in particular supports collaborative learning settings, and enables students to have pedagogical valuable discussions about the material being learned.

Keywords. TEAL, TEALSIM, Open Wonderland, Virtual TEAL World, Physical Simulations, E-Learning

Introduction

The Massachusetts Institute of Technology (MIT) uses the educational model known as Technology-Enabled Active Learning (TEAL) [2] to improve the conceptual understanding of students in freshman physics. The learning outcomes are supported by specially designed classrooms, relatively small numbers of students, and group activities and visualizations. Not all principles of physics can be explained in using

static two-dimensional images. Therefore the TEALsim [10] approach uses a three-dimensional simulation framework to enhance the student understanding and conceptualization of the physical phenomena. But resources in common educational environments are often limited and many of the needs of the students cannot be met as they are in the TEAL framework. We propose a virtual three-dimensional environment where students can meet in the form of avatars, can work together and discuss problems as they could in the real world, so as to extend the TEAL learning scenario to situations with fewer physical resources, and at a distance. This environment, the Virtual TEAL World, provides students the possibility to visit online learning courses and uses the TEAL learning approach to improve student understanding. This solution is a result of collaborative research between the Center for Educational Computer Initiatives (CECI) at MIT and the AEMT group at Graz University of technology. The results reported here are a continuation of the proof of concept work in 2009 [9].

Section 1 introduces the TEAL approach and states the advantages of Virtual 3D environments. Section 2 focuses on an overview of the integration of the TEALsim framework in the Virtual 3D World environment Open Wonderland [8] and introduces the implementation of the TEALsim Module. Section 3 introduces a potential scenario which uses the developed TEALsim Module. The TEAL learning approach is used to design the Virtual 3D environment Virtual TEAL World.

1. Background

This section will address challenges of science education and introduces in this context the TEAL learning approach. Due to different drawbacks of conventional e-learning tools regarding this teaching approach, the e-learning tools Virtual 3D Worlds will be introduced.

1.1. Science Education

Teaching science, especially conceptual domains such as physics have always been challenging. Students have to face challenges such as the imagination of invisible phenomena or the relation between the physical concepts and the corresponding equations. Research shows that hands-on experiments and experiences improve the student's understanding of the concepts, and also helps the student to retain the acquired knowledge for a longer period. Visualization and simulations of physical principles which are sometimes impossible to see, enhances the student's understanding. [3][9]

The Technology-Enabled Active Learning (TEAL) approach at MIT addresses these issues in that it provides a learning environment which includes not only hands-on experiments, but also visual representations and three-dimensional simulations of the physical concepts, especially in electromagnetism. TEAL combines oral explanation in class, technology enhanced experiences such as desktop experiments, two- and three-dimensional visualizations, web-based home assignments and conceptual questions using electronic polling devices, written problems such as home assignments or class workshops, and also traditional textbooks. The approach focuses on active learning in a collaborative setting; therefore a specially designed classroom (see Figure 1) is used. [3][10]

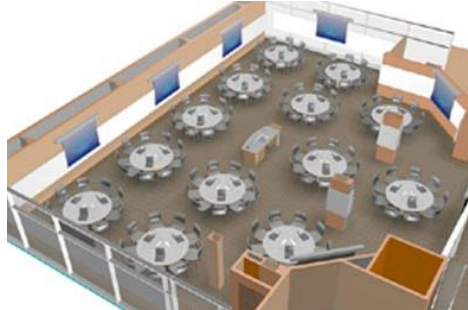


Figure 1. 3D model of the d'Arbeloff Studio classroom [10].

But not every institution or university is able to provide the required resources and funding to implement the environment required in the TEAL approach. Different E-Learning tools and systems can help in building up a similar, but much less expensive learning environment. But it is crucial that the collaborative aspects of the TEAL approach not be lost. The following section introduces Virtual 3D Environments as a means to support especially the collaborative aspects of TEAL.

1.2. Collaborative Learning in Virtual 3D Environments

Virtual 3D Worlds (VWs) such as Open Wonderland are receiving increasing interest from educational institutions. In particular the collaborative and social aspects can be seen as advantages of VWs in comparison to conventional E-Learning systems: Verbal and non-verbal communication channels provide students an optimized way to communicate, the feeling of presence in an environment increases the motivation, awareness of the environment and other users enforces the communication, three-dimensional objects such as whiteboards facilitate the collaboration, and learning content can be visualized [5][6].

The next chapter focuses on the integration of the simulation framework TEALsim into the open-source virtual world environment Open Wonderland. [8]

2. Integration of the TEALsim Framework in Open Wonderland

This section is mainly an overview of the integration of the TEALsim Framework in the Open Source toolkit for building 3D virtual world Open Wonderland (OWL) [7]. The entire section is based on Berger in 2012 where further implementation details can be found [1].

2.1. The Simulation Framework TEALsim

TEALsim is an open-source educational simulation tool, developed at the Center of Educational Computing Initiative (CECI) at MIT and focuses on the development, presentation and control of physical concepts. An example of this is the Falling Coil simulation [10], which is an example of induced currents described by Faraday's Law. As shown in Figure 2 the original TEALsim user interface consists of several parts:

1. A menu bar from which the user can choose a simulation. Additional items contain help and program control functionality.
2. A 3D window showing the spatial content of a simulation.
3. A simulation configuration window allowing the user to set simulation parameters and visualization options.
4. A simulation execution panel for starting, stopping, pausing, or reversing a simulation.

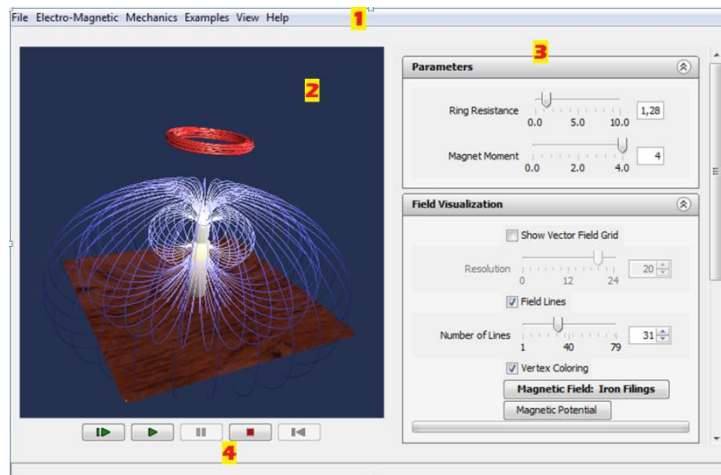


Figure 2. TEALsim desktop user interface showing the Falling Coil simulation

The simulation definition process can be performed by teachers with only moderate programming skills. This makes TEALsim easy to use for teaching personnel. The simulation definition interface consists of a tree of classes, each branch supporting a different type of simulations. To implement a new simulation one of these classes needs to be inherited. The simulations presented in this paper are inherited from the electromagnetic simulation class. In a simulation creation method TEALsim's simulation elements are assembled to a simulation. This involves setting physical values, such as the charge of the elements as well as specifying the elements in the configuration window. Additionally, the latter elements can be attached to physical values using routes. Such a connection of GUI elements to simulation elements allows the player to interactively influence the results of a simulation. A slider can, e.g., be provided to change the electric charge of an element during the course of the simulation. From the software developer's perspective, TEALsim is a desktop application written in Java.

Figure 3 shows the main components of the TEALsim software. The architecture follows the Model-View-Controller (MVC) design pattern. In a simulation, representing the Model according to the MVC pattern, the single simulation elements, such as 3D objects, are defined and created. The corresponding simulation engine is responsible for calculating simulation steps while the simulation is running. The SimPlayer represents the Controller and creates the components and represents the GUI. The Viewer displays the single 3D simulation elements on the canvas, using Java3D. Further implementation details can be found in Berger in 2012 [1].

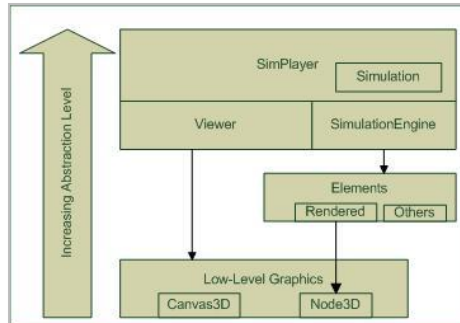


Figure 3. Main components of TEALsim [1].

2.2. The Implementation of the TEALsim Module in Open Wonderland

In order to use TEALsim within Open Wonderland (OWL), several adaptations to TEALsim were necessary. In particular, the lack of a client-server mode and the different 3D graphics library in TEALsim hinders the porting process. For the implementation several requirements on an abstract software-specific level were defined [3]:

- The integration of TEALsim into OWL should be performed in a generic way; No single simulations but most of the features of TEALsim should be ported. This way many simulations will run in OWL "out of the box".
- The simulation definition interface should be kept whenever possible. Many simulations already exist and people who define simulations often do not want to relearn the implementation process.
- The resulting software should be easily installable. OWL provides functionality to deploy modules on servers. For easy installation this functionality will be used.
- TEALsim should not entirely be converted into an OWL version. Instead, the core components will be used to build an OWL module. These improvements to the TEALsim components also affect the OWL module.

The stated requirements and the software design of the frameworks lead to three implementation steps.

Step 1: Adaption to OWL's graphics system

First, the 3D-graphics of TEALsim needs to support OWL's JMonkeyEngine(JME)/MTGame graphics system. Compared with Java3D, JME comes with more scene-graph primitives and with more support for loading 3D model formats, including those used by some TEALsim simulations. Additionally the MTGame game graphics system introduces threading support which had to be taken into account. Fortunately, TEALsim encapsulates low-level graphic elements such as scene graph objects and the 3D canvas. In order to support JME/MTGame in TEALsim, wrapper classes for these elements needed to be implemented. The Java3D support was kept and a mechanism was introduced to select the desired 3D implementation (that is, either Java3D or JME). When used with OWL the graphics output has to be set to JME/MTGame.

Step 2: Adding the client-server mode

The second implementation step is adding a client-server mode to TEALsim. How the components are split into client and server parts is influenced by many considerations. One possibility might be to keep TEALsim running on the clients only. This would require only minimal adaptations to TEALsim. However, keeping the simulations in sync between the clients is difficult with this approach. Simulation elements would have to be synchronized among the clients even without user interaction from time to time. Simulations can also include random values, which increases synchronization issues. Another possibility might be that the whole simulation is placed on the server and synchronization is only necessary on user interaction. Everything but the 3D rendering would happen on the server. This approach, however, has a major drawback. All data has to be transferred to the client. This includes the position data of the 3D elements. Some of them, e.g. field lines, are represented by hundreds of three-dimensional vectors. This is too much data to transfer over the internet.

Our approach combines the advantage of these two approaches and reduces the disadvantages. TEALsim's components are separated. Some are placed on the client, some on the server, and some are split into a client- and a server-version. This approach implies changes in some core components of TEALsim. The simulation is mostly running on the server side. This simplifies synchronization. However, visualization elements, such as field lines, which do not directly influence the simulation, are computed on the client side. This increases bandwidth utilization.

TEALsim's main components (see Figure 3) need to be split into client-side and server-side components. For easier synchronization the simulation definition object resides on the server. The physics engine, however, must be split into a server part and a client part. As stated above, most of the calculations will happen on the server. The engine is responsible for computing the next engine step, i.e., how the simulation elements change their internal physical parameters in a certain amount of time. Every engine step consists of several iterations over the simulation elements. Most of these iterations are performed as if we were running TEALsim's desktop version. The last phase is the computation of visualization elements, such as field lines. This phase happens on the clients. This requires the server to send the internal state of the simulation elements to the clients after each simulation step. Since the visualization elements are computed on the client they do not have to be sent to the client. For simulations which use visualization elements this saves a great deal of network utilization.

The engine is the component which is most affected by the additional client-server support. The implementation supports various engine types. In addition to the previously supported different engines for different fields of physics there is now an interface for different engine modes. The desktop mode is implemented in TEALsim whereas the client mode and the server mode are implemented in the OWL module. In order to support extending engine types for both, different fields of physics and different modes, the bridge design pattern described in [4] was utilized.

For obvious reasons the Viewer needs to reside on the clients only. While it holds a canvas in the desktop version, it will use OWL's canvas in the module version. Simulation elements representing the GUI of TEALsim are stored on the server. This is necessary to be able to send them to new clients after they log on. User interactions

mostly happen on such GUI elements. They are synchronized among the clients by serializing user events and sending them via the server to all other clients. This requires each element to have a unique identifier. Overall, TEALsim has been refactored to provide for extensions which will later be used in the OWL module. The desktop version does not suffer from a loss of features and uses the same simulation definition interface as before.

Step 3: Building of the TEALsim OWL module

The last implementation step is packing TEALsim into an OWL module and implementing the OWL-specific client-side and server-side components. The TEALsim-specific components are made using the newly defined interfaces of the TEALsim software. On the client side a specific Viewer is implemented by inheriting the general Viewer in TEALsim. Similarly, a SimPlayer is implemented for both, the client and the server components. OWL provides functionality to add module properties. We use this functionality to add support for switching between simulations. The user can simply right-click on the module, select the "Properties" entry in the menu, and select the desired simulation in the provided submenu.

3. Introduction of the Scenario ‘Virtual TEAL World’

The main objective of the Virtual TEAL World (VTW) is to provide a virtual learning environment that achieves learning outcomes as good as the TEAL environment. VTW is the attempt to design a Virtual 3D 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. E-Learning Tools, Videos and the 3D-Simulations provided by TEALsim were adapted for the collaborative Virtual World Environment Open Wonderland to assimilate the original TEAL environment. The VTW focuses on enabling discussions, active participation and collaboration. The TEALsim-Module is used to visualize the simulations in the 3D space (see Figure 4).

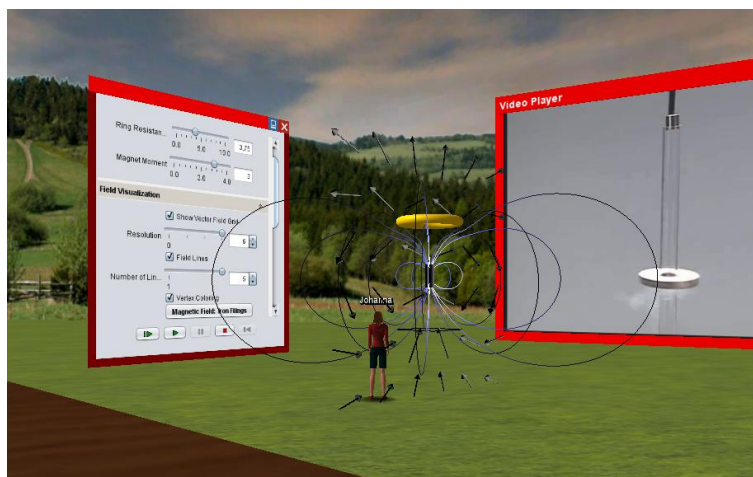


Figure 4. The TEALsim-Module showing the Falling Coil Simulation in the VTW.

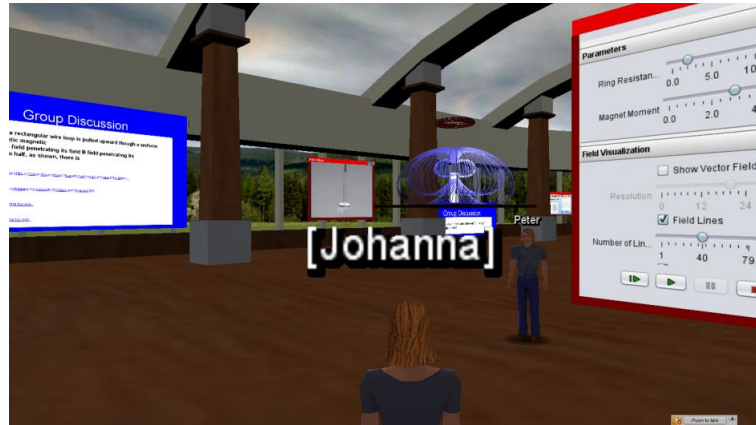


Figure 5. Overview of the Virtual TEAL World for Faraday's Law.

Figure 5 gives a glance of the VTW environment representing a single module focusing on Faraday's Law. Different areas of this environment address different TEAL learning approaches. The following table aspects are adapted from the TEAL approach and converted to an in-world solution [10]:

	TEAL environment	Virtual TEAL World
Oral explanation	In class	Videos and documents in-world
Collaborative learning	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
Networked laptops	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
Multimedia visualization (TEALsim)	Media-rich Software delivered via class laptops and the Web.	3D representation via the TEAL module in-world (see Figure 4)
Course notes	With links to the visualizations.	In-world documents
Conceptual questions	Using Personal Response Systems	Using a special designed learning-module with an optional interface to a conventional e-learning tool

Table 1. Integration of the single TEAL environment components in-world.

4. Summary and Future Work

In this paper, we have focused on the advantages of using a Virtual 3D environment instead of conventional E-Learning tools in collaborative learning settings such as the TEAL approach. The Open Wonderland implementation of TEALsim gives students not only the possibility of watching and controlling the physical phenomena in a 3D space but also the ability to discuss the simulations in real-time together. The TEALsim-Module is still in development and in particular improvements regarding the performance, the usability and the client-server architecture are planned. The Virtual TEAL World tries to simulate the entire TEAL approach to provide learners not only a remote learning possibility but also a low-cost variant. The actual Virtual TEAL World is developed as a first showcase scenario and focuses on a single Faraday's Law module. Future development will include an evaluation of this scenario and also the corresponding adoption. After that, the VTW will also be introduced for other modules.

We believe that Virtual 3D Worlds such as Open Wonderland have great potential for supporting and also enhancing remote learning scenarios by adding motivational discussions and collaborative aspects.

Acknowledgement

We would like to thank the CECI at MIT for hosting this research. The authors would also like to thank the Open Wonderland team for the valuable knowledge support. This work was funded in part by the Austrian Marshall Plan Foundation and Graz University of Technology.

References

- [1] S. Berger, Virtual 3D World for Physics Experiments in Higher Education, Graz University of Technology, 2012. From: http://www.iicm.tugraz.at/thesis/Berger_Stefan_Masterarbeit.pdf
- [2] Y. J. Dori, J. Belcher, How Does Technology-Enabled Active Learning Affect Undergraduate Students' Understanding of Electromagnetism Concepts?, *The Journal of Learning Sciences*, **14.2** (2005), 243-279.
- [3] Y. J. Dori, J. Belcher, M. Bessette, M. Danzinger, A. McKinney, E. Hult, Technology for active learning, 2003. From: <http://web.mit.edu/edtech/casestudies/pdf/TEAL2.pdf>
- [4] E. Gamma, R. Helm, R. Johnson, J. Vlissides, *Design Patterns: Elements of reusable object-oriented software*, Addison-Wesley, 1994.
- [5] C. Gütl, The Support of Virtual 3D Worlds for Enhancing Collaboration in Learning Settings, Techniques for Fostering Collaboration in Online Learning Communities: Theoretical and Practical Perspectives, *IGI Global* (2011), 278–299.
- [6] C. Gütl, J. Pirker, Implementation and Evaluation of a Collaborative Learning, Training and Networking Environment for Start-Up Entrepreneurs in Virtual 3D Worlds, *International Conference on Interactive Collaborative Learning*, **14** (2011), 58-66.
- [7] J. Kaplan, N. Yankelovich, Open Wonderland: An Extensible Virtual World Architecture, *Internet Computing, IEEE* **15.5** (2011), 38-45.
- [8] Open Wonderland, retrieved from: <http://openwonderland.org/>
- [9] T. Scheucher, P. H. Bailey, C. Gütl, V. J. Harward, Collaborative Virtual 3D Environment for Internet-Accessible Physics Experiments, *iJOE* **5.1** (2009), 65-71.
- [10] TEALsim Project at MIT, retrieved from: <http://web.mit.edu/viz/soft/visualizations/TEALsim> and http://web.mit.edu/8.02t/www/802TEAL3D/TEAL_tour.htm