

# Evaluation Results of a 3D Virtual Environment for Internet-accessible Physics Experiments

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## Abstract:

*In the science of physics the interrelation of physical theory, model and experiment is hard to comprehend, therefore group learning becomes more important. This fact, combined with the opportunity to work on practical experiences over distance in a collaboratively way, has raised worldwide the interest of creating new learning environments based on 3D virtual worlds.*

*This paper outlines an evaluation that was performed to determine whether the addition of collaborative virtual learning environment (CVLE) to an internet-accessible physics experiment (iLab) would improve learning experience. We wanted to assess if the developed CLVE helps participants to achieve a better understanding of physics phenomena. Within this CLVE avatars represent learners and they are able to communicate and collaborate in a way similar to real life in order to perform physics experiments using the TEAL simulation toolkit.*

*One of the major findings of this evaluation indicates that reconsideration of design and additional items at the 3D visualization could further improve the learning process in the CLVE in a more effective way.*

## 1 Introduction

Modern eLearning technologies offer the possibility to make learning environments for physics education available anytime and from anywhere. Students are allowed to access real or virtual experiments remotely either by campus-wide WLAN access, or from outside the university. These technologies not only provide the advantages of location-independent access but also enable institutions to share experiment setups of expensive hardware. In addition, captured data is electronically available for further analysis [10]. Some other technologies are developed to illustrate abstract physics concepts visualized by means of a 3D model. Such 3D visualizations and simulations can give learners a better understanding of physical phenomena, which are typically not visible in real hardware settings, such as electromagnetic fields [7].

These technologies mentioned above have been mainly used in learning settings to complement face-to-face teaching in classrooms or to make experiments accessible for single students remotely. However, the majority of existing applications does not support

collaborative learning experiences. 3D environments, a technology becoming increasingly powerful and interesting, might overcome this issue [1, 6]. Unlike other ICT-based solutions for distance learning, 3D collaborative virtual learning environments (CVLEs) may benefit from features such as the use of multiple communication channels, the 3D environment (eg. the awareness of other avatars), and the decrease in barriers between students and tutors [11]. CVLEs provide the participants with a compelling experience and a high sense of presence in the virtual environment, that is, they have a feeling of “being there”[13]. In addition, learners may also get the feeling that other participants actually exist and are really present in the environment. That means learners get the feeling of collaborating with real people and being a part of a group and process [2, 3]. Consequently, 3D CVLEs can support interactive group learning.

A CVLE for internet-accessible physics experiments was developed in cooperation between Massachusetts Institute of Technology (MIT) and Graz University of Technology (TUG) [14]. This learning environment was built using Project Wonderland [15], developed by Sun Microsystems Inc. [17] that provides a multi-user architecture and advanced interactive user interfaces. These features create a shared sense of space where learners can work and learn together. The integration of specific technologies and projects in Sun's Wonderland had resulted in a learning space for physics education. In this CVLE learners are able to interact with a 3D simulation to visualize the real behaviour of an remote physics experiment in a collaborative way. More precisely, the learners act as avatars and can control the real hardware settings by a two dimensional (2D) GUI front panel. As soon as avatars change input values on the panel, the 3D simulation behaves synchronously according to the physics parameters being set. Parallel to this, users can compare the virtual experiment with the real video streaming of the real physical experiment, which also responds to the same input values.

In this paper we focus on the evaluation results of the applicability in learning settings of our 3D CVLE for internet-accessible physics experiments in Project Wonderland. As well whether the objectives of supporting learning and teaching by means of better collaboration in the CVLE were achieved. To this end, we will outline in section 2 a brief overview of the related software and technologies, which were integrated in Wonderland. In section 3 we will describe the 3D CVLE in Project Wonderland itself. The findings of the processed study, evaluation results as well as conclusions and future directions will be discussed in the last two sections.

## **2 Electromagnetic Experiment and related Technologies**

The experiment, which is integrated in the CLVE, is based on a combination of two separately pre-existing projects. It embodies virtual technologies developed at the Center of Educational Computing Initiative (CECI) at MIT. One of them is called the iLab project, which provides infrastructure for sharing Internet accessible lab experiments. This project envisions students and educators having remote access to actual equipment in real laboratories from anywhere at any time. The other technology is the Technology Enabled Active Learning (TEAL) Studio project [18] that started in 2002. TEAL's major goal was to help students conceptualize phenomena and develop better intuition about electromagnetism. Electromagnetic fields are typically not visible in real settings, but by using such a simulation engine, students can nevertheless view a synchronized visualization. The simulation renders an accurate representation of the invisible field lines. The approach of TEAL is to provide a combination of lectures, lab experiments and a

range of simulations in a specially designed physical classroom in order to facilitate group interaction.

According to recent user studies of the TEAL Studio project [7] students, who studied within the TEAL setting and make use of 3D simulations, significantly improved their conceptual understanding of the various complex electromagnetic concepts. As a matter of fact, the idea was born to offer remote lab experiments together with the proper 3D simulation.

### ***2.1 The Force On A Dipole Application***

The application combines an iLab interactive lab of the „Force on a Dipole“, where the actual hardware is located at CECI, with a correspondent TEAL simulation. The actual hardware consists of a magnet, which is suspended by a spring between two current-carrying coils. An electrical current may be directed through the top coil, at the same time the current in the other coil flows in the opposite direction. Or the current is directed into both coils and flows in the same direction. A video camera is stationed in front of the experiment to observe clearly the position of the magnet. The LabVIEW [12] application allows user interaction to configure the current amplitude and frequency of the current. It also specifies through which coils it may be directed. Students are able to watch the working experiment via webcam as well as examine the behaviour of the electromagnetic field lines generated by the 3D Simulation.

The combination of these projects provides a powerful tool to enhance understanding of abstract physics concepts using active and passive visualizations, especially in areas where we can make the "unseen seen", as in electromagnetism. TEAL's original did not consider using remote laboratories because the iLabs infrastructure was designed for one student in particular. Based on the fact that collaboration plays a major part in the learning process, a way has to be found to consider a collaborative learning environment. In cooperation between the CECI/MIT and the Graz University of Technology (TUG) the idea was born to create a CVLE.

## **3 3D CLVE for Physics Education**

Many compelling reasons exist for choosing technologies like virtual worlds to realize a CLVE for physics education. As a matter of fact simulations take place in a manner that closely resembles real-world situations and requires the active participation and engagement of the student. Students simply cannot be passive while participating in a simulation. Moreover the provided multi-user architecture in virtual worlds enables deep collaboration between teams of users. Project Wonderland was the dedicated toolkit to undertake our experiment work because it consists of 100 % Java open source. Besides that, Wonderland is based on Java3D [9], a scenegraph-based 3D application programming interface (API) for Java, which is also used by the TEALsim toolkit.

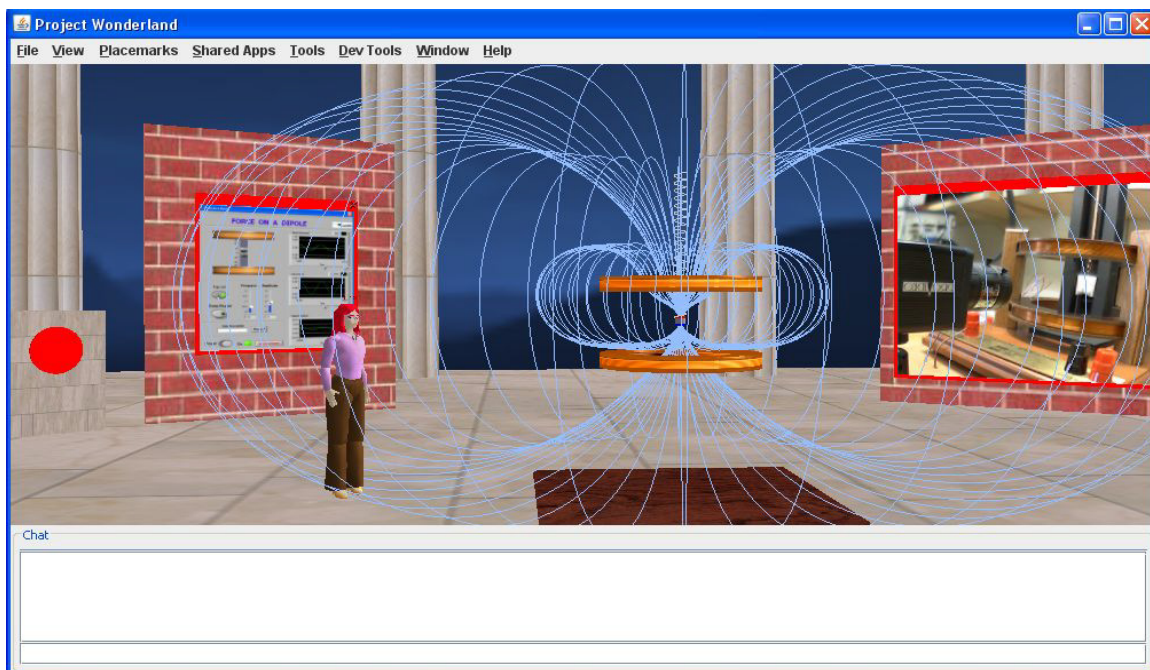
### ***3.1 Interactive 3D Simulation in Project Wonderland***

The generated learning space within Project Wonderland consists of the same applications that were in the original version of the Force On A Dipole application but with the difference, now they are represented in a 3D environment. Which means instead of having multiple applications working on your desktop, just the Wonderland's client application is

running and displaying the 3D learning space. Within this environment learners are acting as avatars and interacting with the technologies like in real world, which now are represented as spatial objects.

A supported graphical desktop sharing system, called Virtual Network Computing (VNC) [19], is able to show the LabVIEW application within the environment via VNC-viewer. The LabVIEW application is hosted at another computer on which a installed VNC-server allows access to the application. The interaction is provided through keyboard and mouse events, which give learners the ability to change parameters as they are used to doing. Before using LabVIEW application, the virtual representation of the experiment has to be started. For this purpose, a button is provided within the environment. After pressing the button, a socket channel is opened. The simulation engine updates its simulation objects according to the data, which are transmitted via the socket channel. Any data value changed is reported to the rendering engine, which is responsible for any visual changes to the simulation [14].

A webcam, which is primarily used by the iLab ServiceBroker, is also provided in the learning space. A video screen allows learners to see a live streaming of the working experiment via the network camera. Figures 1 and 2 show screenshots of the 3D CLVE in Project Wonderland both in first person view and third person view.



**Figure 1: Force on a Dipole Experiment in Project Wonderland - first person view**

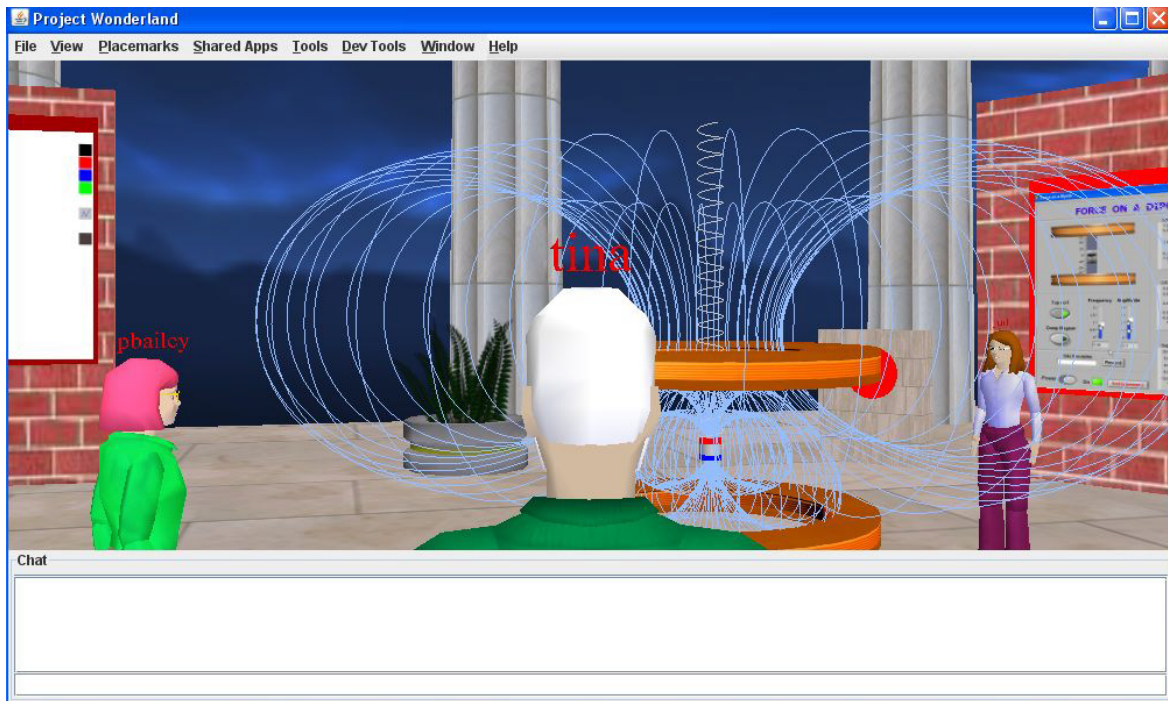


Figure 2: Force on a Dipole Experiment in Project Wonderland – third person view

## 4 Study on the Applicability of the Prototype CLVE

The 3D CLVE, described in the section above, is a prototype which was developed to confirm that the internet-accessible Force on a Dipole experiment could be visualized by means of a 3D simulation in Project Wonderland. Since this proof-of-concept was completed successfully and the created CLVE provides full functionality of the experiment ideas to improve and extend this environment. Motivated by this fact, an initial-study was designed to discover whether teaching and learning electromagnetism using 3D CLVE's is supportive. The aim of this study was to examine whether the collaborative interaction in such environments improves the learning process by means of better collaboration. Additionally, if a higher degree of immersion helps students to get a better sense of physics phenomena. From a design perspective it is an interesting point to find out how user-friendly the environment is and which modifications in the CLVE would be meaningful. Suggestions for improvements were also objectives of this evaluation and would be goal for the future development of this project.

### 4.1 Experiment Setup

The subjects of the study are both female and male MIT undergraduate students between the age of 18 to 24. Precondition for participating in this study was that the participants already had attended the 8.02 electricity & magnetism course. Thus we could compare have been immersed in a 3D environment is more effective in understand physics phenomena than in traditional setting. Six students fulfilled the preconditions and had participated in the survey. The participants were grouped in sets of three. The survey was conducted one per group and took place at CECI/MIT providing separate rooms, one subject per room. Each subject was provided with a notebook using version 3.5.2 of the Mozilla Firefox browser running either Mac OS X 10.5.8 or Windows XP.

From the content perspective, the evaluation environment as well as the time slot was the same for both groups. The amount of time for each process step in minutes, quoted in the

following, is constituted in parenthesis. Subjects needed to sign a document in order to give informed consent before they participated in the survey. Next they read a protocol, describing important information about the survey procedure (10).

The workflow of the evaluation was conducted as follows:

- introduction of the real 'Force on a Dipole' experiment (20),
- answering web-based pre-questionnaire before (15),
- online class interaction in Project Wonderland (35) and
- answering web-based post-questionnaire (15).

After finishing the introduction to the experiment the subjects were directed to their workplace. The web-browser on each laptop opened the predefined address to the pre-survey. The pre-survey consisted of 22 multiple choice and factual short answer items and 2 open-ended short answer problems. Subjects should be interested in playing 3D online games and have experience in 3D virtual worlds in general and as a learning environment. Having completed the pre-survey the subjects were requested to take the class in Project Wonderland. The latest version of the Project Wonderland client was launched by simply clicking on a link in the provided web browser to automatically download the application. After the client was downloaded, the subject was able to enter the learning environment and we gave the subject a few minutes to become familiar with the 3D space by moving around and learnin how to navigate through the environment before. The subjects were taught by MIT Physics Professor John W. Belcher. He is the creator of the TEAL project [18].

Following the experiment, the post-survey consisted of seven multiple choice and factual short answer items and five open-ended short answer problems. The assessment criteria therein were their perceptions of the use, benefits, and limitations of the 3D learning environment, appreciation of the collaborative value in Project Wonderland and the efficiency of being immersed in the learning process. Electronic-based surveys were used for both the pre and post-survey. Ethics clearance was reviewed and approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES) [5] for research involving human subjects that is performed under the auspices of MIT.

## **4.2 Experiment Results and Discussion**

The pre-survey declared that all subjects fulfill the preconditions and 66.7 % of the subjects have used the Force on a Dipole experiment remotely as well in its previous form. This certainty allowed us a comparison with the current use of the experiment in our 3D CLVE. Figure 3 shows the first results of the pre-survey.

Familiarity with electromagnetism & 3D Simulations

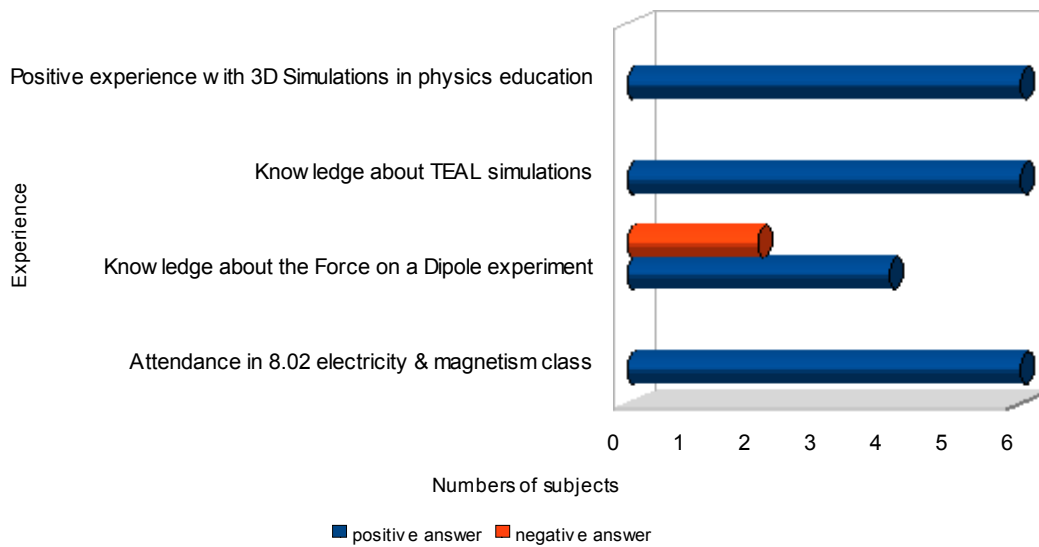


Figure 3: Experiences of subjects

The pre-survey also confirmed that the subjects knew about 3D computer games and online 3D games in general. But having them asked how often they were playing online 3D games the responses were more likely to show a moderate frequency. Figure 4 the corresponding chart.

How often do you play online 3D games?



Figure 4: Frequency of playing online 3D games

Having asked them if they ever used an e-learning framework before, four of the six subjects answered in the negative. After inquiring more in detail, two of the subjects didn't even know what an e-learning frameworks was. The others had known about it found that tools like the unit outline, discussion board and collaboration with peers were useful in their course of study. One of the subjects, if there were any features lacking in the e-learning framework, said video conferencing.

In terms of learning preferences, results revealed that the subjects prefer to learn individually as well as in groups of 2 or more. When they are studying at home and a problem occurred in understanding a particular topic, more than half preferred to ask peers for help (Yes 66.7 %, No 33.3 % ). Having asked them which means of communication they prefer, all answered peer to peer, except one subject,. Regarding whether they used a web-based medium to communicate with peers for learning purposes 66.67 % answered in the negative, 33.3 % answered in the affirmative. For instance, the voice over IP application Skype [16] and high-speed Internet provider Comcast [4] were named.

In terms of familiarity with 3D virtual worlds like Project Wonderland or Second Life, 50 % of the subjects had known these environments previously. Regarding the question had they ever used a 3D virtual world, 66.7 % answered in the negative.

#### 4.2.1 Class Scenario and Observations

Subjects entered the learning environment shortly after they completed the pre-survey. We give them few minutes to make familiar with the 3D space by moving around and learning how to navigate through the environment. Then, Professor Belcher took over and began the session with an explanation of what the student had seen in Project Wonderland. He explained in detail the visualization of the experiment, the control panel of the LabVIEW Application and how to interact with it. The intention was to show the students how the visualization works in general by adjusting the amplitude and frequency in the front panel. After that, the professor wanted each student to turn it back on and answer them a couple of phenomena related questions.

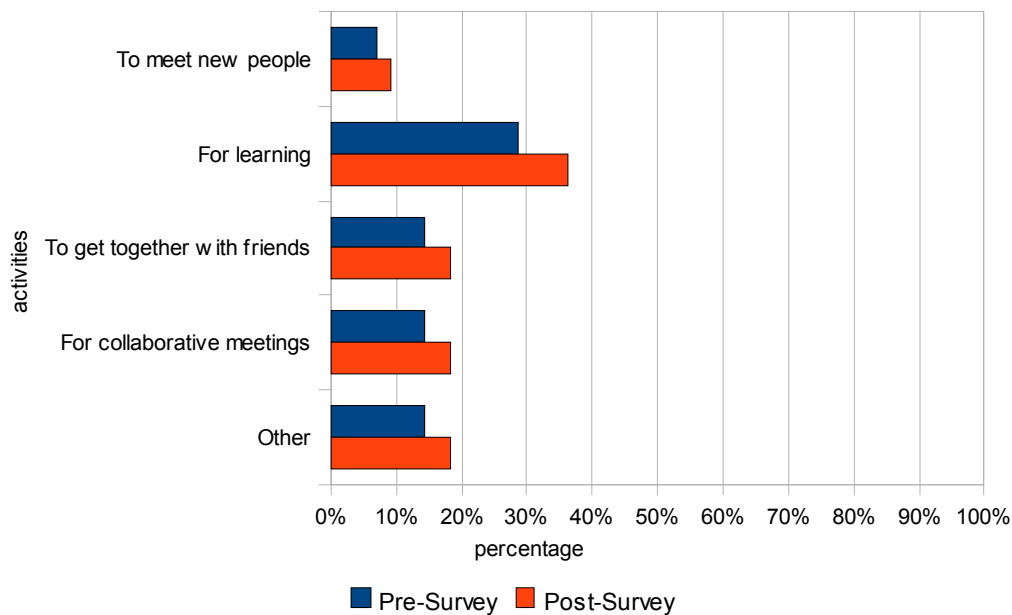
The professor was working with one student, while the other two students listened to the conversation between professor and student. During the lecture we were able to observe that some students really enjoyed the environment, and were watching the webcam to see how the magnet was moving in real time while the other student was interacting with the front panel. Some other students drew on or chatted via the whiteboard. We observe that students liked this kind of tool. Even though they didn't write something decent on the whiteboard at that time, this fact gave us the cue to integrate the whiteboard in class in future for some explanation work. Also, the gravity aspect turned out to be a powerful tool to explore the simulation from another view by flying above. They had experimented with the gravity to examine in detail electromagnetic field lines from above. Other than 2D applications, here users could explore our 3D space analyzing TEAL simulations from different locations in the room.

#### 4.2.2 Post-survey

The purpose of the first few questions in the post-questionnaire were to classify the subjects experience in Project Wonderland. Having asked them in particular if they would describe the experience in the CLVE as positive all subjects agreed. During the pre-survey, the subject was asked which activities he/she would use 3D virtual worlds for. For comparison purposes the same question was asked also in the post-survey regarding Project Wonderland. Figure 5 outlines the before and after attitudes of the subjects. Before attending the class the majority would use 3D virtual worlds for learning. After the post-survey this attitude has changed for the better.



## For which activities would you use 3D virtual worlds / Project Wonderland?



**Figure 5: User preferred activities in a 3D virtual world stated in pre-survey and post-survey regarding to Project Wonderland**

In terms of the learning experience and understanding, the post-survey outlined positive feedback. All participants indicated that the feeling of being there with other students and having the ability to communicate with them as in the real world was a pleasant experience. The students liked working at home and being able to talk to other peers or even have a professor in the environment explaining some abstract concepts. During the experiment they had the ability to walk around the visualization and get the feeling of being there in real time within a group. Having asked the participants which communication tool they preferred to use in Project Wonderland, besides whiteboard and text chat, the majority answered with the voice over IP, a participant commented this way: „I enjoyed the sound because talking is one of the best ways for me to learn through others.“ In general the avatar interaction has been much better than the standard video chat.

Half of the participants showed some hesitation about working in groups within a virtual learning environment. They had the opinion that exploring 3D simulations of physics phenomena in a virtual world could not replace working in real. However they agreed that in situations where face-to-face communication is not possible, the CLVE offers a great opportunity.

When asking the participants for the main advantages and disadvantages they experienced, most of our assumptions have been confirmed, and we have collected useful comments. Below are examples of comments of several students, who expressed their positive and negative arguments for selecting various categories.

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

2. 3D learning space: *„All information is in one place: graphs, video, simulations.“*  
*„It's much quicker and more interactive than a traditional experiment. No time was wasted setting up the experiment, and you are effectively able to use and see the graphs, the physical experiment, and visualizations. Also, the antigravity was a lot of fun.“*  
*“I enjoyed how each user had control, and it was not dominated by one user, like some real-life labs.”*

3. Learning process and small group interactions:

*„Easier to ask for clarification of miscommunications or misunderstandings, being able to see the same data at the same time and have it explained.“*

4. Real vs. Virtual presence: *„Sometimes it's just nice to touch stuff and set up the experiment yourself. Hands on is really fun, and students will miss out on that part of the experiment.“* , *„Sometimes it's hard to know what everyone is doing/looking at unless they tell you or their avatar is clearly looking at one thing“.*

In terms of design issues we were able to confirm that contents in the virtual world should be rearranged. Subjects commented in this way: *„I really enjoyed the interaction but would like it if the experiment were arranged in a more compact view, so I could easily read all the details at once without having to move my avatar around to gain a better perspective.“* or *„ I wish the informational items could have been arranged so that users could see all of them at once, close up.“* called attention. Porting our system from Wonderland's version 0.4 to the newer version 0.5 is one of our future plans, comments like: *„Provide a more efficient means of physical communication (like gestures). Sometimes I wished I could point at an object, but instead I had to verbally identify it, which was painstaking.“* confirms this idea. The new avatar system in Project Wonderland take into account this design issue.

The fact that Professor Belcher worked together with the students turned out to be a useful experience for them, but we still recognized some design issues. Professor Belcher had the feeling that the room was larger than necessary, so it was hard to get the students together for an explanation, although wonderland provides a map showing where other avatars are. There are a number of design issues that need to be researched [8].

## 5 Conclusions and Future Work

Findings of this study indicate that the subjects enjoyed being in the CLVE in general. Subjects comments on the CLVE as a learning environment to help understanding the concept of electromagnetism. Comments like: *„I really appreciated the explanation for the magnet that Prof. Belcher provided. I never thought that you could treat the coil as another magnet.“* pointed out that teaching in a 3D CLVE enhances learners intuition of physics phenomena. The question whether the collaborative interaction in Project Wonderland improved the learning process was answered in the affirmative, a comment like: *„It kept my interest and helped me form a better mental image of the real-time dynamics of electromagnetism.“* confirmed this finding. The interaction in 3D enriches the previous 2D physics simulation, making it more interesting and intuitive. A consolidated view indicates that all participants agree with the statement that using a 3D CLVE as an additional education tool in fills the void of collaboration and communication. Adding a third dimension bring them closer to reality.

In terms of the visualization some of the participants made suggestions for additional items, which could improve the learning process. For instance, arrows placed on the field lines clarify the direction of the magnetic field. Commented: „*I really enjoyed seeing the experiment through the eyes of learning (with the field lines, and poles, etc) if more of these types of details (the type you would find in a physics textbook diagram) could be applied to the 3d simulation in real time, I think it would be a tremendous benefit to student abilities in comprehension, convention, and critical thinking.*“ Comments like this gave us to the idea of providing a screenshot of what the students are working on during the simulation and sharing this work with other participants in Wonderland.

In conclusion, these findings and suggestions will definitely be part of the future work and represent a new approach for the future development of this project. However, the question “How do we use this environment in a more effective way to foster the learning process” remains unclear and will be further analyzed. Another objective in the future will be the integration of more physics experiments like the Force on a Dipole in the CLVE. More interactivity to improve the learning process are future goals as well. Taking from this initial study, which indicates the right direction, a larger scale study is planned.

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