

Game-based Strategy to Teaching Electronic & Electrical Engineering in Virtual Worlds

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Abstract — In recent years there has been significant growth in the use of virtual worlds for e-learning. These immersive environments offer the capability to create complex, highly interactive simulations. Video games have entered the mainstream as an increasingly popular entertainment format. Virtual learning environments support teaching and learning in an educational context, offering the functionality to manage the presentation, administration and assessment of coursework activities. This paper will demonstrate how immersive virtual worlds can be used for a game based strategy to teaching electronic and electrical engineering using a collaborative team based competitive format. It will describe the linking and integration of a virtual world with an existing virtual learning environment and show how this approach was extended to include external hardware. The inclusion of real test instrumentation and circuits allows the students to understand the unpredictability of physical circuit behaviour, providing a more authentic and deeper learning experience. A demonstrative example of this approach is introduced and discussed.

Keywords; *Virtual worlds, engineering education, virtual learning environments, game based learning, hardware integration*

I. INTRODUCTION

The constant emergence of disruptive technologies continues to offer new and exciting opportunities for educators [1]. Developments in recent years have seen web-based Virtual Learning Environments/Course Management Systems rapidly become an integral part of teaching and learning provision in further and higher education [2]. This evolution progresses unabated as educators strive to adopt and adapt web 2.0 technologies in the provision of more interactive teaching materials and learning environments which allow students the ability not only to view content but to interact and organize it to suit their personal needs [3]. Video games and virtual worlds are moving into the mainstream as traditional media industries struggle to keep with up digital natives and their desire for information, technology and connectivity [4-7].

This paper discusses the suitability of one popular virtual world for educational and teaching purposes [8-10]. It shows how 'Second Life' (SL) can be used to teach advanced electronic/electrical circuit theory through a game based learning experience in a 3D immersive world, where teams of students work together collaboratively and competitively to

bias or configure electronic circuits. It demonstrates how external hardware devices can be integrated into virtual worlds, facilitating two way communications/control/manipulation of real and virtual artifacts between the real and virtual world. Engineering Education Island is discussed and approaches to integrating Virtual Learning Environments and Virtual Worlds shown.

Section 2 of the paper discusses the Second Life virtual world and its functionality. Section 3 describes recent research at the University of Ulster in virtual worlds. Section 4 provides an overview of how virtual learning environments can be integrated with virtual worlds and section 5 demonstrates how complex learning experiences can be created in virtual worlds. Section 6 examines how external hardware devices can be integrated into virtual worlds and section 7 shows how these elements can be combined together to create team based learning experiences. Section 8 concludes the paper.

II. VIRTUAL WORLDS AS TEACHING TOOLS

Second Life is an Internet-based 3D virtual world launched in 2003 and developed by Linden Labs. Second Life facilitates an advanced level of social networking where residents can explore and socialize by participating in individual and group activities [11]. Second Life contains basic tools that allow users to create and script interactive 3d content. The ownership and rights to this content remains with the creator. This flexibility and intellectual property ownership has led to the establishment of very active educator community in Second Life [12]. Fig. 1 shows a class being taught in real time Second Life.



Figure 1 Teaching in Second Life

III. UNIVERSITY OF ULSTER IN SECOND LIFE

The Second Life project at the University of Ulster, Magee campus, began in September 2006 were initial research focused on the potential of virtual worlds for remote collaborative working and undergraduate/postgraduate teaching [13]. Engineering Education Island was created in Second Life to investigate if virtual worlds could be used effectively for teaching and learning in this context. When residents first arrive on Engineering Education Island they land at the welcome center, a large futuristic building which includes general information on the project and teleport links to the demonstrations and exhibits. Each floor of the virtual laboratory contains a range of interactive engineering demonstrations and simulations (Fig.2).

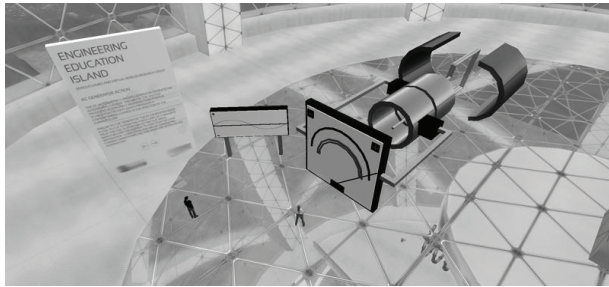


Figure 2 AC generator demo inside the virtual engineering laboratory

Fig.3 shows a typical interactive simulation on the Island which demonstrates the main functions/components of a direct current electric motor. It allows the user to start and stop the motor and to view the magnetic fields. Scripting was used to turn on and the off magnetic fields and to create the particle system showing current flow.

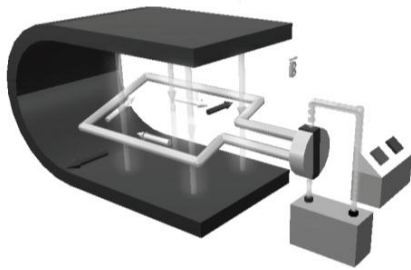


Figure. 3 Direct Current Electric Motor (Interactive)

IV. INTEGRATING VLE'S AND VIRTUAL WORLDS

Moodle (Modular Object Oriented Dynamic Learning System) is a free, open source e-learning software platform which allows users to create/manage teaching materials [14]. The extensive course management tools available in Moodle do not currently exist in most virtual worlds whose main strength in this context is the provision of immersive spaces for social interaction and experiential based learning [15+16]. The SLOODLE open source e-learning software project (Simulation Linked Object Oriented Dynamic Learning

Environment) offers the functionality to link Second Life and Moodle and to exchange and synchronize data flow between the two environments [17]. Interaction with external applications is facilitated by the Linden Scripting Language which can communicate with the PHP driven Moodle database, using XML-RPC, and outbound HTTP requests. Initially the interactive demonstrations and simulations created on Engineering Education Island did not have any explicit user objectives, formal structure or learning outcomes and had no means of recording user actions/interactions. To remedy this, several projects were designed where the interactive web based resource aspect was augmented with a virtual world. A Moodle website with SLOODLE functionality was setup which was subsequently modified and extended for this project. The approach taken uses the following structure, a registered student logs on to Moodle to access and review the learning/course material. The practical aspect of the taught material requires the student to enter the virtual world and carry out a range of task based activities, either individually or as part of a group related to a single learning objective (Fig 4).

PRACTICAL 1	Become familiar with the theory and operation of DC generators	
STUDENT NAME	Kerri Macchi	
TASKS		
LEVEL OF COMPLETION		
Enter virtual world and go to interactive simulation	Completed	Not Completed
View video in world about learning outcomes	Video viewed	Video not viewed
View slide show showing tasks	Slides viewed	Slides not viewed
Press button 1 to turn on power	Interaction 1 Completed	Interaction 1 not completed
Press button 2 to observe magnetic fields	Interaction 1 Completed	Interaction 1 not completed
Overall percentage of tasks completed	XX% Completed	
Total time student spend on assignment	XX Hours XX Minutes	

Figure 4 In-world learner centered activities

Completion of practical outcomes in this context is based on the student's presence and interaction with the in-world demonstrations in the virtual world. These actions are automatically recorded in Moodle for later retrieval and review by the student and the lecturer. The functionality required to track and record user actions/interactions is this way was not available in Sloodle at the time. Two simple extensions were required, (1) a proximity sensor was needed which would record a registered avatar's visit to the demonstrations in Second Life and (2), a tracker component which would write to a database each time individual avatars interacted with the demonstrations e.g. press buttons to start animations. When the functionality was completed three initial exemplar projects were created based on augmenting and enhancing existing in-world demonstrations to validate and test the approach shown. In the practical now discussed the student is required to understand the operation of a DC electric motor (Figure 3), its individual components, their interaction and the effects of the magnetic fields. When the student logs into Moodle they are presented with the list of practical assignments for this course. The student selects a practical assignment and is then given the details of tasks they need to complete inside the virtual world (Fig 5).

Object Name	Task De
Task 1	Enter virtual world and go to interactive simulation.
Task 2	View video in world about learning outcomes
Task 3	View slide show showing tasks
Task 4	Press button 1 to turn on power
Task 5	Press button 2 to observe magnetic fields

Figure 5 List of tasks for practical assignment 1

They logon to Second Life and teleport to the required location to carry out the individual tasks. Each stage in this process is recorded inside Moodle. As the avatar approaches the interactive demonstration shown in fig. 6 the sensor shown detects their presence, transmits this data back to the database and displays this information back to the student.



Figure 6 Proximity sensor and feedback to student

The Moodle page displaying the practical tasks is updated. In this practical session the student is required observe the DC motor operation and bring up the magnetic fields showing how they influence circuit behavior. As the student completes each individual task they receive feedback from the Second Life client (Fig.7) and the Moodle page.

Assignment			
Object Name	Task Description	Level of Completion	Date
Task 1	Enter virtual world and go to interactive simulation.	Completed	April 11, 2009, 1:30 pm
Task 2	View video in world about learning outcomes	Completed	April 11, 2009, 1:30 pm
Task 3	View slide show showing tasks	Completed	April 11, 2009, 1:30 pm
Task 4	Press button 1 to turn on power	Not Completed	-
Task 5	Press button 2 to observe magnetic fields	Completed	April 11, 2009, 1:30 pm

Overall percentage of tasks completed:80%

[Reset Tasks\(\)](#)

Figure 7 Feedback to student on progress in practical 1

The educator can also review the student's progress and level of understanding by reviewing both the level of practical tasks carried out. This demonstrative example shows how virtual worlds and virtual learning environments can be integrated to create top down, narrative led, user learning experiences where user interactions inside the virtual world can be recorded and retrieved for analysis and assessment.

V. CPU FETCH-DECODE-EXECUTE CYCLE

It was then decided to create a more conceptually difficult demo which would help students understand and visualize, how the fetch, decode and execute cycle of a CPU functioned. Each component of the cycle was broken and replicated as a series of interacting life sized buildings in Second Life and a

demonstration created that illustrates the steps undertaken in a CPU during the execution of a single instruction [18]. This highlights the interchanging of control and operand information between the various building blocks of the CPU e.g. program counter (PC), program store (PS), instruction register (IR), operand memory (OM), data mux (DM) and arithmetic and logic unit (ALU). The example demonstration illustrates the six basic CPU steps in the multiplication of two operands. For example, step 1 highlights the role of the PC in providing the index to the PS. In this example the starting hex value of '00' is used to index the PS (Fig. 8).

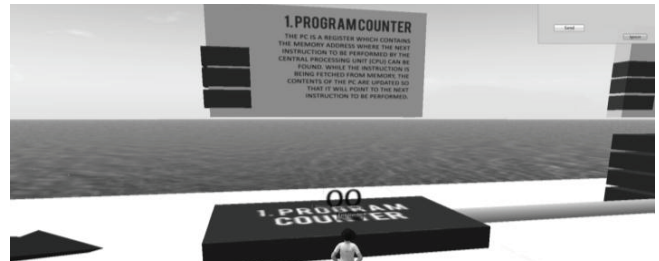


Figure 8 Program Counter with starting hex value of 00

In step 2 the PS outputs the 8-bit contents of its memory (hex value '68') as defined by the index '00' (Fig. 9).



Figure 9 Program Store with hex value 68 highlighted

This is fed to the IR in step 3 where it is partitioned into four 2-bit values; e.g. A=00, B=10, C=10 and D=01 (see Fig. 10). Each of the four 2-bit values plays an important role in the control of the CPU. For example, in step 4 the 2-bit values A and D are used to index the OM.

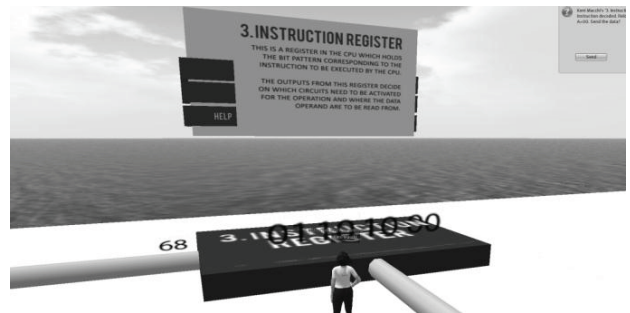


Figure 10 2 bit values displayed above the Instruction Register

In this example the decimal values '4' and '6' are output from the OM to the data mux where they will be fed into the ALU (Figures 11+12).

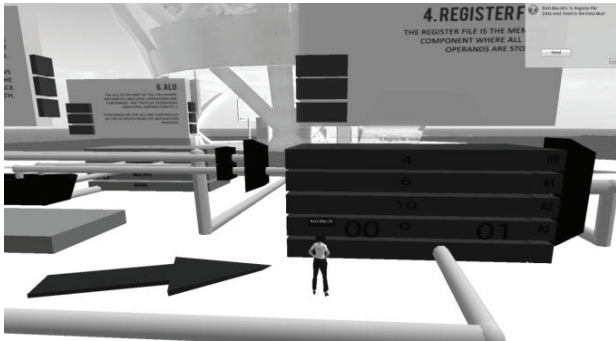


Figure 11 Decimal values 4 and 6 indicated on the register file

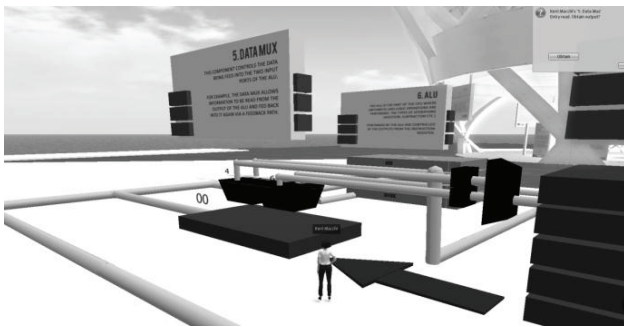


Figure 12 Decimal values 4 and 6 being transferred from Reg. to Data Mux

Step 5 outlines how the 2-bit value B (10) informs the DM that the resultant value from the ALU is to be stored back in the OM when the ALU is finished (Fig. 13). Finally, in step 6 the 2 bit value C (10) informs the ALU that a multiplication operation is to be performed on the data present at its inputs. The ALU performs the multiplication of 4 x 6 to provide the computed decimal value of 24 (Fig. 14). These six steps illustrate how the CPU performs a single multiplication operation however addition and other arithmetic operations experience the same sequence of tasks although the instruction data will be different.

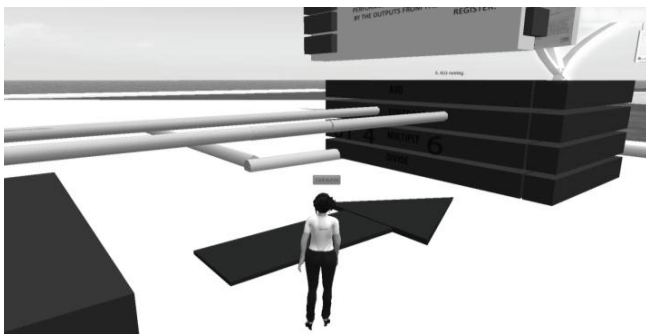


Figure 13 Decimal values 4 and 6 being transferred from Mux to the ALU

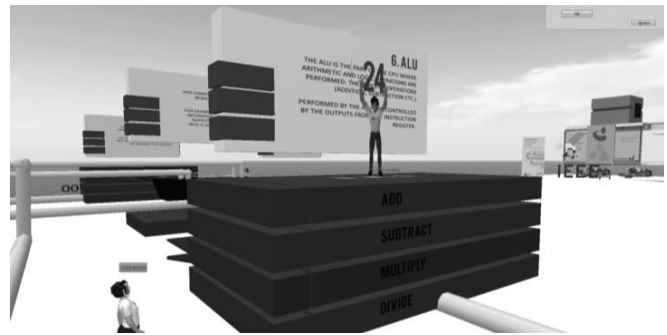


Figure 14: Result 24 displayed from the ALU

To assist in evaluating a student's understanding of the CPU operations a further demonstration was created with an error introduced in step 6 where the data value C being fed to the ALU is different from the original value stored in the IR of step 3 (Fig. 15). For example, step 1 shows the PC hex value of '01' been used to index the PS. In step 2 the PS outputs the value '40' as defined by the address value '01'. Step 4 shows the IR binary contents of '0100 0000' where A='00', B='00', C='00' and D='01'. The 2-bit values A and D are used to index the OM and read the decimal content values '6' and '4'. Step 5 outlines how the 2-bit value B (00) causes the resultant output of the ALU (i.e. when the result is computed) to be fed back into input 1 of the ALU (feedback path options is selected). A simulated fault occurs in step 6 where instead of issuing the C value of '00' (add operation) to the ALU, the C value of '01' (subtract operation) is sent which causes the ALU to perform a subtract operation and the output of the ALU subtract operation (6-4) is the value '2' (Fig.16).

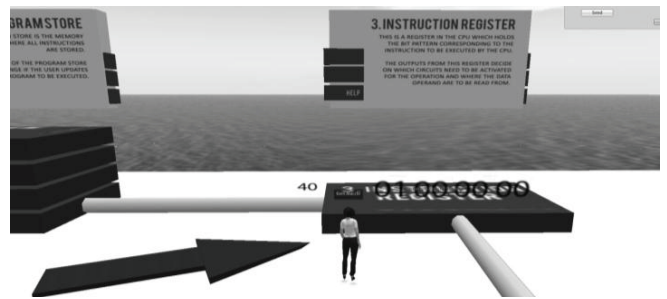


Figure 15 2 bit values displayed above the Instruction Register

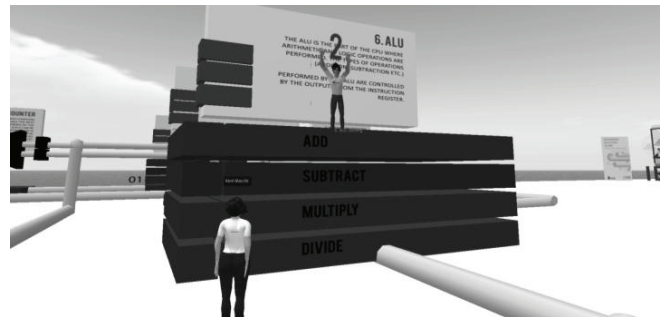


Figure 16 Incorrect result displayed on the ALU

This is incorrect as the IR told the ALU to perform an addition operation (6+4) where the resultant decimal value should be '10'. The focus of this fault is to encourage student to examine the IR where the binary instruction is divided into its four 2-bit patterns. This is often the most difficult aspect of the CPU as this is where the instruction information is used to control the OM, DM and ALU components. By tracing back through the sequence of steps and by comparison with the steps in the 'working' demos, students will be able to see the fault occurring in the output of the IR data. At the end of the "faulty demo" the student is questioned on their understanding of what went wrong in this simulation. If they answer correctly then they are congratulated. If they answer incorrectly then they are asked to re-run the simulation and take the test again. All of these interactions are recorded in Moodle for review by the student and member of academic staff at a later stage.

VI. INTEGRATING HARDWARE IN VIRTUAL WORLDS

To integrate external hardware into virtual worlds requires the use of a communication protocol that works within the constraints of what is offered by Second Life. In this instance communication and data flow is facilitated by the use of XML-RPC to send data from external hardware devices to virtual objects inside Second Life. This can be achieved by implementing a method that connects to a dedicated Second Life RPC server and then pushes the data through the channel created using PHP scripting with associated Linden Scripting Language. External hardware devices are controlled and accessed using a C++ program in conjunction with PHP scripting to allow the hardware to transmit data directly to Second Life utilizing winsock2 to send XML-RPC requests to the Second Life RPC handler. The XML-RPC method relies on a RPC server for communication and additionally an internal mechanism that passes messages to appropriate objects using a unique random channel allocated on initialization. The sequence diagram shown in Fig.16 describes the 3 main steps in sending data to virtual objects.

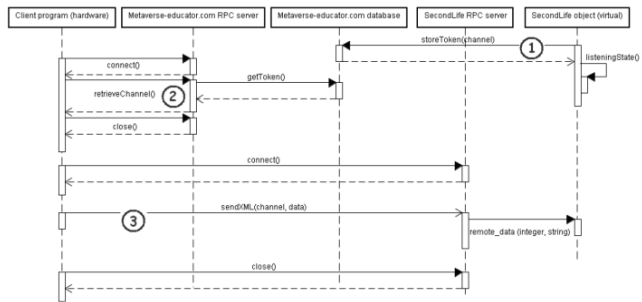


Figure 16 Sending data into Second Life

To retrieve data send from a virtual object it is necessary to use an immediate server. This is required as the Second Life "Server" has to reach the "Client", in this case the PC controlling the external hardware (Fig. 17). To do this a HTTP request must be made to the immediate server and the resultant data stored in server database until retrieved.

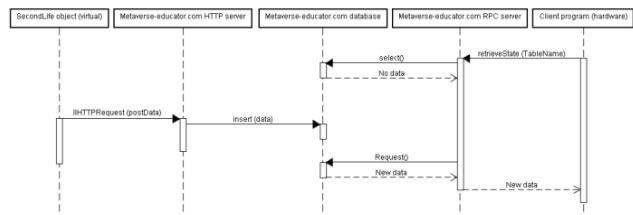


Figure 17 Retrieving data from Second Life

This architecture allows the creation of some highly interactive demonstrations. Fig.18 shows a hardware washing machine simulator with its virtual representation recreated inside a virtual world.

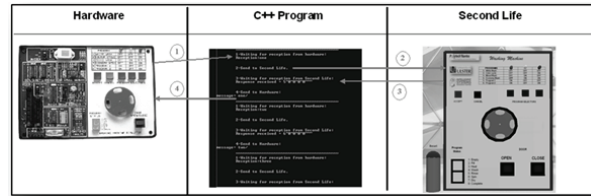


Figure 18 Integrating a machine simulator in a virtual world

The hardware simulator allows students to create control algorithms to program different aspects of a washing machine operation e.g. selection of wash and spin cycles and control of motor speed. Fig. 19 shows the synchronization of the real and virtual simulators where spin cycles selection and button operations are replicated in both the virtual and real worlds. A two way control mechanism is facilitated here; e.g. resetting the device in the real world will result in a change in the virtual world while pressing the virtual buttons in the virtual world will cause changes in the external hardware.



Figure 19 Synchronized virtual and real washing machine simulator

Extending the SLOODLE tracking architecture discussed in section 4 to record these hardware interactions allows user interactions in both the real and virtual worlds to be recorded for subsequent review and assessment (Fig. 20). This functionality and the ability to record and later access user interactions will allow for the creation of more complex simulations similar to demonstration in section 5 but with the addition of external hardware and devices.

User		Avatar				
avatar one		JayLee Darwin				
Assignment						
Delete	Object Name	Task Description	Level of Completion	Date	Reset	
<input type="checkbox"/>	1-Open the door	Student has opened the door	Completed	August 26, 2009, 10:38 am	<input type="checkbox"/>	
<input type="checkbox"/>	2-Close the door	Student has closed the door	Completed	August 26, 2009, 10:39 am	<input type="checkbox"/>	
<input type="checkbox"/>	3-Green button	Student has pressed green button	Not Completed	August 26, 2009, 10:39 am	<input type="checkbox"/>	
<input type="checkbox"/>	3-Red button	Student has pressed red button	Not Completed	August 26, 2009, 10:39 am	<input type="checkbox"/>	
<input type="checkbox"/>	3-Yellow button	Student has pressed yellow button	Completed	August 26, 2009, 10:34 am	<input type="checkbox"/>	
<input type="checkbox"/>	4-Accept button	Student has pressed 'accept' to start the cycle	Completed	August 26, 2009, 10:35 am	<input type="checkbox"/>	
Overall percentage of tasks completed:66.6%						
<input type="button" value="Reset/Delete Task(s)"/>						

Figure 20 User interactions recorded into SLOODLE learning environment

VII. GAME BASED LEARNING IN VIRTUAL WORLD'S

The objective of the extension of the work previously described was to explore how a games based approach to learning could be implemented effectively inside in a virtual world for teaching the fundamentals of circuit theory in electronic and electrical engineering. The objective of this exercise is to create a team based game which will allow both collaborative and competitive group interactions. The topic chosen in this instance was the principles of positive feedback in operational amplifiers (Fig. 25). Oscillators are astable devices that produce an alternating or pulsing output voltage and were chosen because it is possible to get a variety of output values from the circuit using any number of resistor/capacitor combinations. The game format is time based where teams of students compete against each other to bias an oscillator to achieve a pre-defined output i.e. peak to peak voltage (V_{pp}) and period of the waveform. The winners of the competition will be the team that can successfully and practically apply circuit theory to select individual resistor and capacitor values to achieve a pre-defined circuit output.

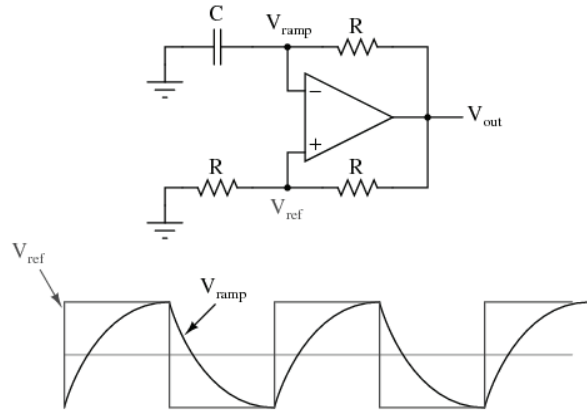


Figure 21 Oscillator circuit with positive feedback

The additional novelty of this demonstration is the fact that is it linked to real hardware and the teams are working with actual physical circuits. Fig. 22 shows an overview of the completed system functionality and Fig. 23 shows the system recreated inside the virtual world.

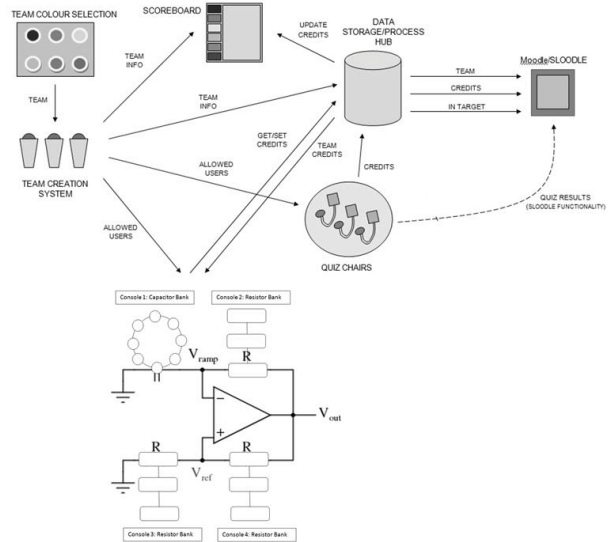


Figure 22 Overview of system functionality

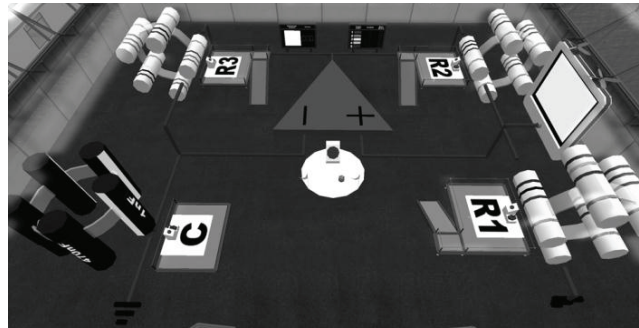


Figure 23 Virtual circuit/arena in Second Life

The team creation process was facilitated using a modified version of Moodle/SLOODLE where avatars can register and join teams (Figs. 24 and 25).

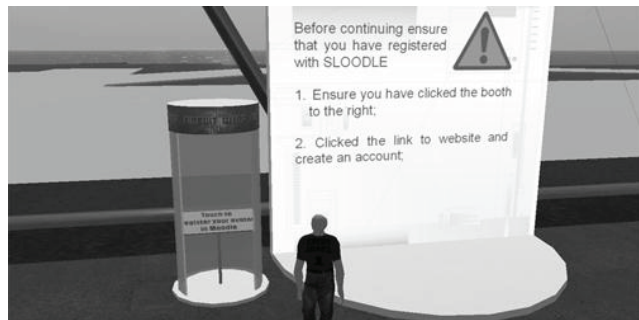


Figure 24 Avatar registration



Figure 25 Team selection and creation

After registration the teams go to the quiz chairs and answer questions on Oscillator theory. The more correct answers accumulated during the quiz stage the more attempts a team gets during the competition stage to bias the circuit (Fig 26).



Figure 26 Quiz section

When the teams enter the game arena, the game starts. Teams are called to the podium individually and given pre-determined values of peak to peak voltage and period of the waveform to achieve (Fig. 27).



Figure 27 Game play arena

R1 (Ω)	R2 (Ω)	R3 (Ω)	C (nF)	Vpp (V)	Freq. (Hz)
1000	2200	3300	47	5.5	4695
1000	2200	3300	100	5.5	2353
1000	3300	3300	47	4.125	6390
4700	3300	3300	470	10.5	218
3300	1500	3300	22	12.312	3731

Figure 28 Possible resistor/capacitor combinations and output values.

Each team is given 3 minutes to calculate the values of resistance and capacitance and to set the resistors and capacitor to the correct values (Figs 28 and 29).

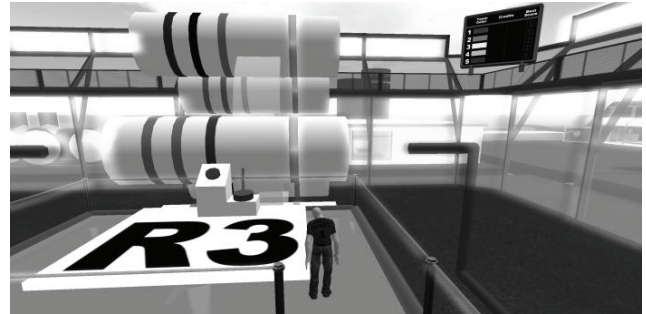


Figure 29 Resistor value selection

When the virtual circuit is biased they hit the red button in the center of the arena (Figure 30).



Figure 30 Circuit completion and scoreboards

The physical circuit is then completed (Fig.31) and the actual values achieved by the team is read back into the system and compared to the target values and a score given

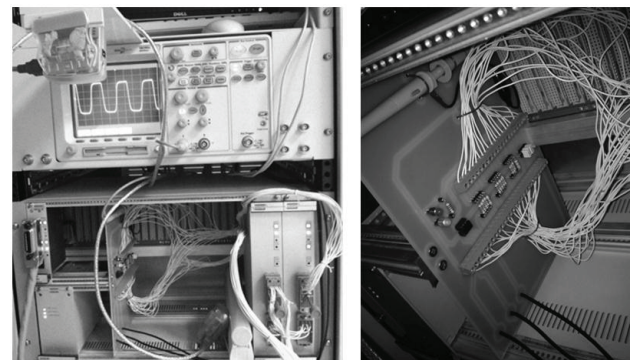


Figure 31 Physical circuit completion

The scoring system is based on the formula given in Fig 32.

$$\text{Score} = 100 \times (\alpha \times \text{Frequency_percentage} + (1 - \alpha) \times \text{Vpp_percentage})$$

$$\text{Frequency_percentage} = \frac{\text{Min}(\text{Target_frequency}, \text{Achieved_frequency})}{\text{Max}(\text{Target_frequency}, \text{Achieved_frequency})}$$

$$\text{Vpp_percentage} = \frac{\text{Min}(\text{Target_Vpp}, \text{Achieved_Vpp})}{\text{Max}(\text{Target_Vpp}, \text{Achieved_Vpp})}$$

Figure 32 Scoring mechanism

The team with the highest overall score wins. All student interactions in the virtual world are recorded back into Moodle/SLOODLE for future assessment and review (Fig 33).

r (Avatar)	Third Member (Avatar)	Fourth Member (Avatar)	Created in	Quiz mark (/20)	Score (/100)
	Alexi Marville (Alexi Marville)	Florent ARLINGTON (Florent Arlington)	August 27, 2010, 11:45 am	8	97
o (Fabian in)	sy20 rocket (Sylvain Swords)	Demil Mares (Demilmars Overland)	August 27, 2010, 11:49 am	7	75

Figure 33 Team interactions recorded in Moodle/SLOODLE

VIII. CONCLUSION

This paper provided an overview on ongoing research at the Intelligent Systems Research Center, University of Ulster, into the use of virtual worlds and virtual learning environments for teaching engineering topics. The Engineering Education Island project was introduced and a number of complex, highly interactive and engaging simulations were described which demonstrated that it is possible to make complex and highly interactive demonstrations in virtual worlds for teaching purposes. The work was extended further to demonstrate the integration of virtual learning environments and virtual worlds with hardware peripherals, harnessing the relative strengths of each platform, e.g. the course management features of virtual learning environments, immersive/highly interactive nature of virtual worlds and the unpredictable behaviour of electronic/electrical circuits to create learning experiences for students. Finally the paper demonstrated that it is possible to bring all of these elements together in a cohesive fashion to create a game based approach to teaching electronic/electrical engineering material using a team based collaborative/competitive format. This approach offers a new engaging and highly interactive way to teach engineering.

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