Virtual Engineering Sciences Learning Lab: Giving STEM Education a Second Life

Stephanie E. August, *Member, IEEE*, Michele L. Hammers, Don Brian Murphy,
Allison Neyer, Penda Gueye, and Robert Q. Thames

Abstract—Engineering education in the 21st century faces multiple obstacles including limited accessibility of course resources due, in part, to the costs associated with acquiring and maintaining equipment and staffing laboratories. Another continuing challenge is the low level of participation of women and other groups historically underrepresented in STEM disciplines. As a partial remedy for these issues, we established a Virtual Engineering Sciences Learning Lab (VESLL) that provides interactive objects and learning activities, multimedia displays, and instant feedback procedures in a virtual environment to guide students through a series of key quantitative skills and concepts. Developed in the online virtual world Second Life^{TM}, VESLL is an interactive environment that supports STEM education, with potential to help reach women and other underrepresented groups. VESLL exposes students to various quantitative skills and concepts through visualization, collaborative games, and problem solving with realistic learning activities. Initial assessments have demonstrated high student interest in VESLL's potential as a supplementary instructional tool and show that student learning experiences were improved by use of VESLL. Ultimately, the VESLL project contributes to the ongoing body of evidence suggesting that online delivery of course content has remarkable potential when properly deployed by STEM educators.

Index Terms—Computer science education, computer uses in education, computer-assisted instruction, multimedia information systems

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1 INTRODUCTION

The Virtual Engineering Sciences Learning Lab (VESLL) project is an online interactive learning environment that introduces students to quantitative skills and concepts through visualization and interactive problem solving [1]. Initial content focuses on positional numbering systems, logic operations, gates, and flip-flops, and visualization of a rate flow problem from differential equations. VESLL is based in Second Life^{TM}. SL is a widely used free online virtual environment populated with content (locations, objects, and activities) imagined and created by its users (also known as "residents"). In SL, a private "island" has been created specifically for VESLL where users can explore content, solve puzzles and participate in activities, and interact with other users. SL uses common geographic terms such (such as "island" and "mainland") to designate virtual spaces within the environment; an island is a freestanding space where an owner has exclusive rights to develop ("build") content.

For general users, Second Life^{TM} is a free online service; therefore, while there are costs associated with maintaining the VESLL island, there is no additional cost (beyond basic Internet access) for the instructors, learners, and educational experts using VESLL. This low cost access can be differentiated from the costs usually associated with physical "real world" learning labs. For example, to demonstrate parallel and serial circuits, an instructor in a real world lab would rent the lab, purchase the material needed (batteries, bulbs, wires), store it, and possibly pay for a laboratory assistant to help supervise the activity. In VESLL, a comparable lab has been set up using virtual circuit components that can be virtually-generated on demand (or "rezzed") anytime a user wishes to work with the materials. Objects in SL require no physical storage or maintenance, and can be easily replicated and shared among multiple users.

VESLL addresses concerns raised by the National Science Foundation about the future of STEM education by tapping into the benefits of virtual learning labs as part of an ongoing effort to improve engineering education [2]. Cyberlearning generally appeals to today's youth and uses modes of information management and social interaction that are second nature to members of the current generation of learners [3], [4]. These online learning environments have strong appeal to youth and females in particular. There are calls for academia to exploit advances in technology including virtual worlds to reshape education and training [5], [6]. In addition, studies show that over the past years, a greater number of women than men have been online [7], [8], [9]. A study by Price [9] shows that female learners in online environments are confident, autonomous, and academically engaged, and have much more online activity than their male counterparts.

Early research suggests that multiple user virtual environment (MUVE) based learning resources can be designed to be equally appealing to both male and female learners [10]. As such, MUVEs like VESLL have substantial potential

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- *S.E. August, D.B. Murphy, A. Neyer, P. Gueye, and R.Q. Thames are with the Department of Electrical Engineering and Computer Science, Loyola Marymount University, Los Angeles, CA 90045.*
  E-mail: saugust@lmu.edu, {djscythe15, ngueye1}@gmail.com, waterrose9@aol.com, rthames@lion.lmu.edu.
- *M.L. Hammers is with the Department of Communication Studies, Loyola Marymount University, Los Angeles, CA 90045.*
  E-mail: mlhammers@lmu.edu.

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to contribute to ongoing efforts to recruit and retain women in the engineering sciences and related fields. Moreover, MUVEs have the potential to help address student preferences for more active learning methodologies [4], [11], [12].

This paper provides an overview of VESLL's educational innovations, discusses the project's current curricular content, and reviews data from a series of assessment workshops. While VESLL has yielded positive assessment results and garners interest among students and peers at our institution, our experiences working with SL's commercial platform also give rise to questions of long-term sustainability and ease of curricular modification.

2 PEDAGOGICAL INNOVATIONS

VESLL is a cross-disciplinary endeavor that emphasizes pedagogical innovations designed to enhance the integration of cooperative learning and problem-solving strategies [12], [13], [14], [15]. VESLL can be situated among other STEM-focused MUVEs. For instance, VESLL incorporates the use of in-world slide-show presentations for content delivery similar to that discussed by Sierra et al. [4] and replicates real-life objects for manipulation, experimentation, and visualization in ways similar to those found in Callaghan et al.'s Circuit Warz [11], Keeney-Kennicutt and Winkelmann's virtual chemistry laboratory [16] and Djorgovski et al.'s MICA (astrophysics) project [6].

VESLL takes advantage of the educational potential of SL's visually rich, interactive, 3D highly customizable environment. Several studies have reflected on the educational potential of MUVEs, including SL [3], [4], [11], [13], [17], [18], [19], [20], [21], [22]. In 2011, Mikropoulos and Natsis [23] conducted a ten-year review of virtual education research; they found that multisensory interaction channels, intuitive interactivity, immersion, collaboration and first order experience are among the dominant MUVE characteristics of interest to researchers and educators. VESLL incorporates several of these components in its pedagogical design, including immersion, collaboration, and first order experience.

While VESLL has the potential to utilize in-world delivery tools, e.g., voice-chat, pre-recorded audio and video files, that might allow it to serve as a platform for wholly online course delivery, we have currently emphasized its use as a supplement for face-to-face classroom experiences. Ultimately, VESLL furthers the current trend in MUVE-based pedagogical innovation by exploring many benefits of multi-modal, virtual learning environments, specifically:

1. Access to innovative educational resources;
2. Student autonomy and (physical) independence;
3. Self-regulation by the learners; and
4. Immediate feedback to student.

Others have noted that MUVE's have the potential to reduce resource demands when compared to a physical laboratory [4], [17]. However, this study did not explore resource-related benefits.

3 VESLL AS A LEARNING TOOL

Rather than relying on purely verbal explanations, traditional two-dimensional presentation materials, or potentially expensive and time/space bound physical objects, VESLL permits students to interact in an online virtual environment with pre-designed virtual objects that have been scripted to replicate real-life phenomena and engage students in problem-solving activities within a visually rich environment. These objects and activities enhance learning by providing immediate and specialized feedback to student input. Moreover, students will be able to interact with these objects independently or in a group, at any time of the day or night while simultaneously viewing multimedia presentations and engaging in discussion with peers and instructors.

Existing functionality within SL has the potential to encourage collaborative learning in a variety of ways [12]. First, visitors in Second Life$^{\text{TM}}$ can choose the level of communication in which they would like to engage with other users. A built-in chat function allows a user to talk to nearby avatars. Users can control communication with other avatars by specifying with which "friends" and groups they would like to converse either via text chat or voice chat. In addition, the use of avatars, which allows for the incorporation of non-verbal communication such as gestures, can enrich the online collaborative experience for students working at a physical distance from one another [12]. Secondly, these features allow a user to collaborate freely with other SL visitors without requiring them to be co-located. One user might be in her dorm room while another has traveled home for the weekend. Thus, collaborating in a virtual world does not require the same degree of logistical coordination as required in the real world. As long as both have Internet access, are logged on to SL and visiting VESLL, they can work together to discuss and solve a problem.

The interactive nature of VESLL's objects and activities also enhance the learning experience by providing feedback in response to student input even in the absence of an instructor. Objects and activities notify students of incorrect answers and permit students to select different difficulty levels in order to control their learning experience. In addition, in the situation where a student feels that she needs further information on the parameters of a problem posed by an activity, instructional note cards and in-world slide presentations are available for easy review.

4 CURRICULAR CONTENT AND COURSE SEQUENCING

VESLL currently features curricular content in the following three areas: positional numbering systems, logical operations and circuit design, and differential equations. Content for each area includes interactive objects, instructional note cards, and feedback mechanisms. For each area, the activities are accompanied by in-world subject matter materials that permit users to review basic content by scrolling through pre-loaded slide shows much as they would scroll through a visual presentation. Overall, VESLL is designed to provide an introduction to each subject area, giving it potential relevance for a number of entry level science, engineering, and quantitative reasoning courses. VESLL's positional numbering content tested well across participants having different levels of familiarity with the content (see discussion of Tables 2, 3 and 4 below); however, assessment of the circuit lab activity indicates that prior familiarity with the content helped students navigate VESLL activities (see

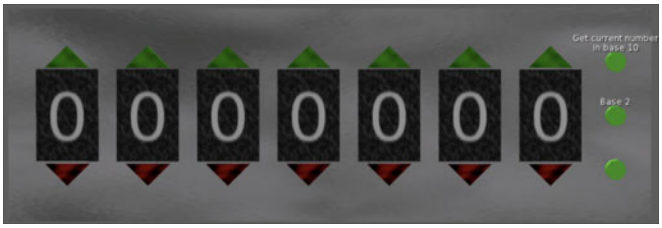

Fig. 1. HexWindow. Users controls whether to convert the number or use the window to count up/down as with an odometer.

discussion of Table 5, below). Currently, VESLL has been tested in introductory Computer Science courses.

4.1 Positional Numbering Systems

The HexWindow (Fig. 1) converts numbers in base 2, 8, 10, or 16 to their binary, octal, decimal, or hexadecimal equivalent, as requested by the user. The HexWindow has two settings. The first uses the familiar concept of an odometer to illustrate counting up and down in various bases and animates carry and borrow as the user clicks the increment/decrement buttons above/below each symbol. The second setting does not propagate the carry or borrow, which is useful when the objective is simply to convert a specific number to another base.

The HexLock (Fig. 2) is a tool for testing knowledge of number conversion. Digit panels similar to those used in the HexWindow form a combination lock; with user-selected Easy, Medium, and Hard challenge levels. Given a source number in a particular base and a target base, the user sets the digits on the panels to represent the target number. If the answer is correct, the lock opens and the user receives a virtual prize (a VESLL shirt, Fig. 3) that can be added to his/her avatar's inventory. If the answer is incorrect, the user can resubmit their answer until the correct answer is entered. If the user deems the conversion problem too difficult to manage, he/she can reset the level of difficulty to receive a new problem.

The Crossword (Fig. 4) and Word Jumble (Fig. 5) hex arithmetic word puzzles [24] are ordinary crossword and anagram puzzles, respectively. They use the same number tiles as the HexWindow and HexLock with the clues being given as hexadecimal arithmetic problems and the solutions forming words using the digits 0-9 and the alphabetic symbols A-F. When the user checks for errors, the puzzle tiles turn green or red, depending upon whether they are correctly or incorrectly set.

Fig. 3. VESLL shirt. Avatar that opens the HexLock receives the shirt as a prize.

The last positional numbering activity, dubbed the ChangeMaker (Fig. 6), uses an algorithm customarily employed for making change to explain conversion between bases. The user enters the source number and base, and a target base. The ChangeMaker displays a set of HexWindow-type tiles whose values reflect the target base. Below each tile appears the decimal equivalent of each position, e.g., if the base is n, the positions are labeled n^0, n^1, n^2, n^3 and so on from the least significant digit to the most significant digit. As each tile is set its decimal equivalent is displayed below the tile as part of a sum. The decimal equivalent of the source number appears as the minuend of a subtraction problem, the sum as its subtrahend. As the tiles are incremented and decremented, the sum (subtrahend) increases and decreases. The difference indicates to the user whether his/her tile settings result in a number greater or less than the target answer.

4.2 Logic Operations and Circuits

Knowledge of logical operations is fundamental not only to learning how computers store and manipulate data, but also to formulating and following arguments in everyday human-to-human communication. The VESLL Logic Lab

Fig. 2. HexLock. Entering the correctly converted number opens the lock.

Fig. 4. Crossword Puzzle. Users solve arithmetic problems in base 16 to solve the puzzle.

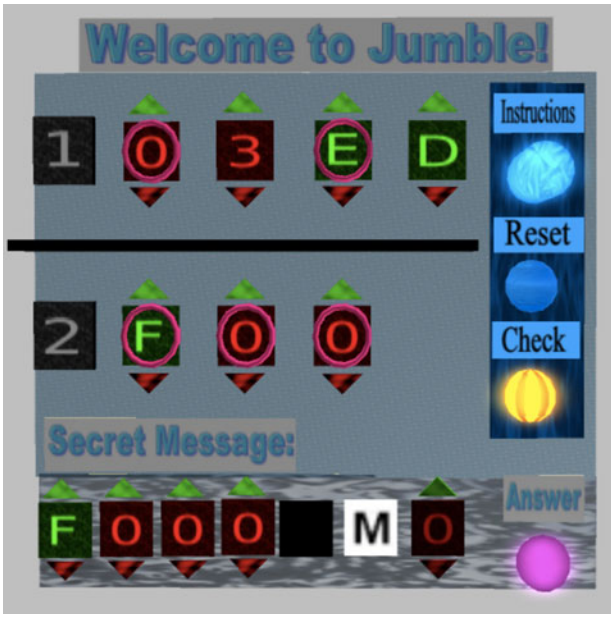

Fig. 5. Word Jumble. Solutions to hex arithmetic problems are used to solve the anagram.

Fig. 6. ChangeMaker. Analogy of making change guides number conversion.

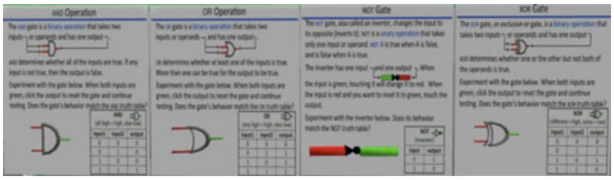

Fig. 7. Logic boards. In-world displays describing logical operations with interactive gates.

defines AND, OR, NOT, and XOR logical operations, presents the truth table as a convenient way to organize the all possible interpretations of bi-valued logical expressions, and provides a logic gate for user experiments with the particular operation (Fig. 7). In addition to these tutorial walls, the user can experiment with a simulated flip-flop (Fig. 8) and construct virtual circuits from a set of simulated gates (Fig. 9).

4.3 DiffEQ Tank

Differential equations describe principles, systems, and scientific laws that involve change over time. Engineers and scientists use them to investigate the behavior of circuits, which contain energy storage components such as capacitors and inductors, to solve problems in population or conservation biology, and to understand seismic waves and option trading. The VESLL DiffEQ Tank (Fig. 10) provides a

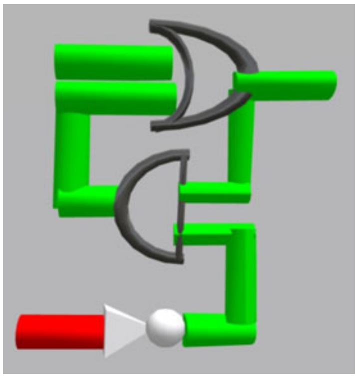

Fig. 8. Flip flop. Interactive flip flop display.

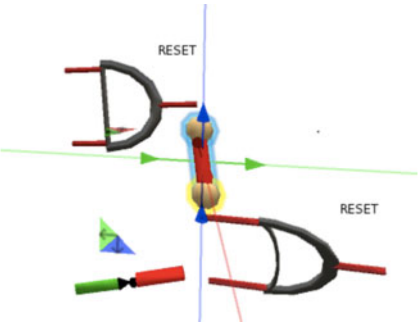

Fig. 9. Circuit under construction. Interactive circuit being assembled from gates and connectors.

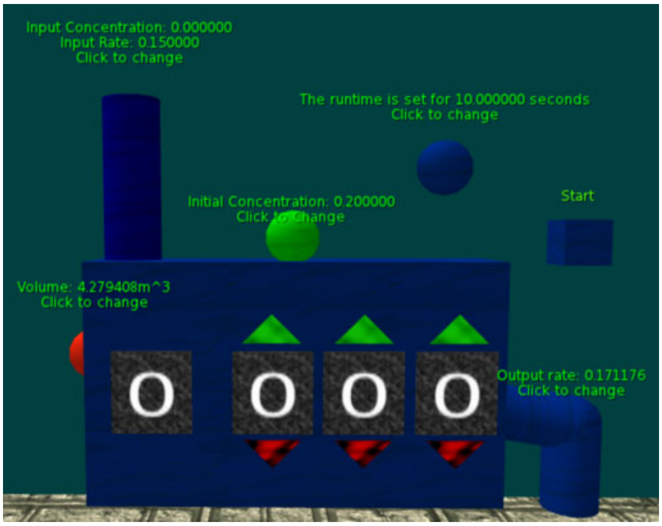

Fig. 10. DiffEQ tank. Simulates a rate flow problem.

visualization of a differential equation problem involving rate flow and concentration change in a tank of water. A tank with volume v has an initial amount of fluid with an initial concentration c_1 of a certain substance dissolved in it. At time $t = 0$, water with a new concentration c_2 begins to flow through an input pipe at rate r r_1. The water is mixed thoroughly in the tank then flows out of the tank at rate r_2. The user needs to find an equation for $a(t)$ that identifies the amount of substance *dissolved* in the tank at a given time t. The user can adjust all parameters in the simulation. The simulation runs, changing the size of the tank to reflect its current volume and changing the color of the input pipe, tank, and output pipe to reflect the current concentration in each. The user can enter the amount of the substance dissolved in the tank and receive immediate feedback on the accuracy of the answer.

5 ASSESSMENT

We conducted assessment during three summer workshops with participants from other institutions, followed by a comparative assessment during the regular academic year involving students at our university. These workshops focused on gathering feedback from participants on the quality of their experiences using the VESLL learning activities and their overall perceptions of VESLL as a learning tool. Participants in these workshops also were given pre-activity and post-activity knowledge assessments.

During the summer assessment workshops students demonstrated primarily positive attitudes toward the VESLL learning experience and expressed interest in seeing this kind of interactive, virtual content integrated into their coursework. While general responses were positive, results did vary among workshops, which we attribute to the disparate make-up of the workshop populations; specifically, we note that the first and third workshops were populated by lower division community college students, entry-level college students in computer science and engineering related fields, and advanced high school students with interests in computer science and engineering related fields respectively, while the second workshop was populated primarily by advanced undergraduate and entry level graduate students in the engineering sciences. In addition, the second and third workshops included faculty participants who arguably provided very different perspectives than the student-users. These differences in educational background and familiarity with the base content of the activities are discussed in more detail below.

During each workshop, we assessed participants' prior familiarity with a variety of online networking and collaboration tools. While students in each workshop were highly familiar with popular social networking tools, e.g., Facebook and text messaging, they were not as familiar with virtual world platforms such as SL; familiarity with virtual environments, if any, came from computer-console games and massively multiple online role-playing game ("MMORPG") environments such a Call of Duty^{TM}, World of Warcraft^{TM}. Despite the differences among platforms, the familiarity with online games may help explain why workshop participants did not have significant trouble adjusting to the SL environment.

When asked what kind of online tools would be most helpful to their academic progress, workshop participants across all three workshops responded: virtual computer room, video games, and real world examples and realistic problem solving in a virtual environment. This shows a general interest in projects, like VESLL, that integrate virtual tools into academic activities.

During each workshop students were exposed to the basic functions of SL (notecard distribution, group chat, private chat, avatar movement, and object manipulation). In addition, different VESLL activities were demonstrated, tested, and assessed. Feedback was reported on a five point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, and 5 = Strongly Agree).

In addition to the summer assessment workshops, we conducted a simple comparative assessment during a regular academic semester that allowed us to compare two groups of students—one group that covered course content relying on traditional teaching methods and one group that was exposed to VESLL as a supplement to traditional teaching methods; each of these groups was pre and post-tested, allowing us to compare initial subject-matter knowledge as well as knowledge acquisition between groups.

One assessment challenge we did not fully anticipate was in the form of access to student populations and classroom facilities during assessment workshops. However, while smaller sample sizes may pose some limitations in terms of inferential analysis, the descriptive data available to us from our series of samples provides valuable insight to the general appeal and basic functionality of VESLL and is consistent with findings from similar projects.

Below we summarize key portions of the quantitative assessment data from the workshops. First we review data for the overall VESLL project and then we focus on data for the individual learning activities. In Section 6, we briefly review the results from our knowledge-based assessments.

5.1 VESLL in General

At the end of each workshop, participants were asked to answer a series of questions related to their overall experience using VESLL. As noted above, profiles of the participants for each workshop were significantly different; this may help explain the variation in scores among the workshops (see Table 1). Despite variations in responses among workshops, we note a generally positive response to VESLL and an interest in having this kind of learning tool integrated into curricular content. Across all three workshops, participants found the VESLL activities to be "interesting ways to learn the material" (Table 1, item 1). Participants also enjoyed exploring the Second Life^{TM} environment (Table 1, item 2) and found that using Second Life^{TM} made the learning experience more interesting than regular classroom lectures (Table 1, item 3). In addition, participants expressed strong interest in seeing additional SL learning activities (Table 1, item 13). When asked what they liked most about VESLL, participant comments focused on the interactive nature of the experience, citing opportunities to interact with in-world objects and with other users. Additionally, participants commented on VESLL's "game-like" environment and the appeal of being able to learn in an environment that provided more individual autonomy and visual interest than traditional classroom environments.

In addition to providing positive general feedback on VESLL and SL, students responded positively to specific aspects of the VESLL experience. In two of the three workshops, students provided positive feedback with regard to VESLL's potential to facilitate working with others on assignments (Table 1, item 6) and to substitute for traditional group work (Table 1, item 12). Participants commented positively on being able to communicate in-world

TABLE 1
Overall VESLL Assessment

Question	Workshop								
	1			2			3		
	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation
1. The workshop activities were interesting ways to learn the material.	4.71	7	.49	4.71	7	.49	4.55	11	.69
2. I enjoyed exploring the Second Life^{TM} environment.	4.71	7	.49	4.86	7	.38	4.36	11	.81
3. Using Second Life^{TM} made the learning experience more interesting than a regular classroom lecture.	4.71	7	.49	4.43	7	.79	4.27	11	.65
4. I found using the Second Life^{TM} avatar to be difficult to manipulate/work with.	2.0	7	1.0	2.0	7	1.0	3.27	11	1.35
5. I would be likely to use learning activities of this kind as part of my studying/preparation for class.	4.29	7	.76	3.71	7	.76	3.55	11	1.21
6. Having access to activities like this online would make it easier to find time to work with classmates on assignments.	4.57	7	.79	3.43	7	.98	4.09	11	.94
7. I would be willing to learn more about Second Life^{TM} in order to use learning activities as part of my voluntary studying.	4.43	7	.76	4.14	7	.90	3.82	11	1.33
8. I would be receptive to having Second Life^{TM} learning activities integrated into my coursework/assignments.	3.86	7	1.07	3.71	7	.76	4.00	11	1.18
9. Getting immediate feedback on answers improved the learning experience.	4.43	7	.53	4.43	7	.53	4.64	11	.50
10. Using the avatar to interact with objects in Second Life^{TM} made some of the activities challenging.	3.14	7	1.07	3.17	7	1.80	3.09	11	.94
11. These activities made me more interested in learning the material than I was before the workshop.	4.33	7	.82	3.86	7	1.07	4.09	11	.54
12. Collaborating with other students on learning activities in Second Life^{TM} would be a good alternative to traditional group work.	4.43	7	.53	3.71	7	.76	4.27	11	.69
13. I would be interested in seeing different kinds of learning activities in Second Life^{TM}.	4.57	7	.53	4.57	7	.53	4.55	11	.69

and to both work with and compete against other users as part of the learning experience. Students also appreciated VESLL's feedback delivery mechanisms (Table 1, item 9); in fact, one student commented that what s/he liked most about VESLL was "learning the correct answers instantly."

Despite the uniformly positive scores across the workshops on these items, feedback on other aspects of the VESLL experience was mixed. Participants did indicate some problems with avatar control and object manipulation within SL (see Table 1, items 4 and 10). Additionally, comments provided in response to a question about what participants liked least about VESLL primarily focused on problems with the SL interface (e.g., difficulty in moving objects or positioning the avatar, in-world lag when loading objects). This emphasis on the SL interface carried over into comments in response to a question about what would most improve VESLL as a learning environment; participants expressed a desire for the environment to run more "smoothly" and for object manipulation to be less difficult.

While they found the workshop activities and SL experience interesting, participants indicated only slight likelihood that they would integrate SL activities into their studying/class preparation (Table 1, item 5) and only mild to moderate interest in having SL activities incorporated into their coursework (Table 1, item 8). The modest interest in having SL activities integrated into their coursework may be related to some of the problems participants identified with the SL interface. The fact that participants consistently found the online activities to be more interesting that traditional lecture formats, but were not consistently positive about using SL themselves suggests that VESLL has not yet maximized on the content delivery potential that exists in MUVE-based learning tools.

In addition to assessing participants' overall satisfaction with the VESLL experience, we also assessed their experiences with specific activities. Across the three workshops, participants possessed varying degrees of initial familiarity with learning content, e.g., positional numbering systems and logical operations. Below we discuss the specific assessment data in light of the differing levels of prior knowledge reported by the participants.

5.2 HexWindow and HexLock Activities

HexWindow and HexLock activities form part of VESLL's introduction to positional numbering systems. Because these activities were presented first in the VESLL workshop, this data establishes a baseline for understanding the participants' initial knowledge of the learning content. Notably, we see that the participants in Workshops 1 and 3 had relatively little prior knowledge of the learning content (see Table 2, item 1); given their lack of prior familiarity we paid

TABLE 2
HexWindow and HexLock Activities

Question	Workshop											
	1			2			3			In-Class		
	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation
1. Prior to this activity I was familiar with lesson content.	2.25	8	1.39	4.20	5	.84	2.09	11	1.70	3.0	22	1.23
2. I was able to complete the activity as instructed.	4.38	8	.74	5.00	5	.00	4.18	11	.75	4.32	22	.72
3. The visual presentation instructions for this activity were easy to understand.	4.13	8	.83	4.40	5	.55	3.64	11	1.03	n/a		
4. The notecard instructions for this activity were easy to understand.	4.25	8	.71	4.20	5	.84	3.64	11	.92	3.82	22	1.01
5. The activity helped me understand the content.	4.13	8	.83	4.40	5	.89	4.73	11	.65	3.59	22	1.05
6. The activity was an interesting way to learn the content.	4.25	8	.71	4.33	5	.58	4.64	11	.67	4.00	22	.98
7. The activity was visually appealing (e.g., colors, overall design).	4.13	8	1.13	4.67	5	.58	4.09	11	.70	4.05	22	.95
8. I had trouble using Second Life to complete the activity (e.g., clicking, accessing, or moving objects).	2.25	8	1.04	1.40	5	.55	2.10	11	1.37	2.23	22	1.07
9. Working with a partner on this activity was helpful.	4.25	8	.71	4.0	5	1.0	4.45	11	.69	3.91	22	.87
10. Overall this activity was a positive learning experience.	4.50	8	.76	4.60	5	.55	4.82	11	.40	3.91	22	.92

particular attention to their feedback on items such as item 5 ("The activity helped me understand the content"). Responses to this item for both Workshops 1 and 3 were positive, with Workshop 3 participants (the ones with the least familiarity with the content) showing the most positive feedback (Mean = 4.78). We note that participants in these two workshops expressed slightly less positive feedback than participants in Workshop 2, when asked whether the notecard and presentation instructions for the activities were understandable; we believe that this indicates a need to better refine our teaching materials for truly introductory level students (Table 2, items 3 and 4). Across all three workshops, participants indicate that the activities helped them learn, was an interesting way to learn the material, and provided positive learning experiences (see Table 2, items 5, 6, and 11).

In addition to the three formal summer workshops, the HexLock activities were informally tested in an introductory Computer Science course for non-majors (CMSI 182). Student response to VESLL content from this informal assessment was slightly positive (see Table 2), however the scores were less strong than in the formal workshops. Written comments from the in-class workshop focus on frustration over the content, indicating that many participants felt unprepared to work the activities in-world. Notably, there was no content-based presentation on this day; students were merely introduced to SL and then asked to complete the activities. By comparison, the formal Workshops provided content-based presentations preceding the activities and garnered more positive feedback than the in-class demonstration; this suggests the importance of integrating the VESLL activities into a complete learning experience, whether by providing prior exposure to the content or providing additional support through in-world pre-recorded lectures and pre-loaded presentation/lecture notes.

5.3 Jumble Puzzle and Crossword Puzzle

With regard to the Jumble and Crossword puzzles students across all three workshops strongly agreed that the activity helped them understand the content (see Tables 3 and 4, item 5). Participants in Workshops 1 and 3 indicated noticeably higher levels of familiarity with the learning content than they did during the Hex Activity assessments and participants in Workshop 2 indicated slightly higher levels of familiarity. These increases arguably are attributable to their exposure to the prior VESLL activities; one workshop participant even commented that her/his prior exposure came from "another activity we did earlier." Even for participants in Workshop 2 who expressed a relatively high level of familiarity with the content prior to these activities, the activities still helped them improve their understanding and provided a positive learning experience (See Tables 3 and 4, item 11). Despite the prior exposure to the content obtained through the series of VESLL activities, participants found the Crossword and Jumble activities to be interesting ways to learn (Tables 3 and 4, item 6).

Note that for some of the activities, data is not available for all three workshops. We encountered occasional errors when administering the in-world assessments; as a result, in two instances (the Crossword Puzzle and Circuit Lab) we found that assessments were repeated by some participants. We did not anticipate this particular problem and did not build protocols into our assessment process that would permit us to identify the duplicate completions. For this reason, we have elected not to report data in cases where reported completions exceeds the number of workshop participants.

TABLE 3
Assessment of Jumble Puzzle Activities

Question	Workshop								
	1			2			3		
	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation
1. Prior to this activity I was familiar with lesson content.	3.43	7	1.62	4.67	3	.58	3.0	2	2.83
2. I was able to complete the activity as instructed.	3.71	7	1.25	4.67	3	.58	4.5	2	.71
3. The visual presentation instructions for this activity were easy to understand.	4.29	7	.49	4.67	3	.58	5.0	2	0.00
4. The notecard instructions for this activity were easy to understand.	4.43	7	.53	4.67	3	.58	5.0	2	0.00
5. The activity helped me understand the content.	4.57	7	.53	4.67	3	.58	5.0	2	0.00
6. The activity was an interesting way to learn the content.	4.57	7	.53	4.33	3	.58	5.0	2	0.00
7. The activity was visually appealing (e.g., colors, overall design).	4.43	7	.53	4.67	3	.58	4.0	2	1.41
8. The size of the puzzle tiles made working with the puzzle difficult.	2.57	7	.98	4.67	3	.58	1.50	2	.71
9. I had trouble using Second Life to complete the activity (e.g., clicking, accessing, or moving objects).	2.00	7	.82	2.33	3	1.15	2.0	2	1.41
10. Working with a partner on this activity was helpful.	3.71	7	.76	4.0	3	1.0	3.50	2	.71
11. Overall this activity was a positive learning experience.	4.57	7	.53	4.67	3	.58	5.0	2	0.00

5.4 Circuit Lab

The circuit lab, which involved both more advanced learning content and more complicated interaction with SL objects, underwent the most developmental change in between workshops. The activities for this portion of VESLL are still under-development as we attempt to resolve challenges posed by SL's user interface with regard to object manipulation.

Feedback on this activity was less strongly positive than for the positional numbering activities (see Table 5); we note that participants in Workshop 2 had a slightly more positive response to the circuit lab activities than did the participants in Workshop 3, who had far less prior knowledge of the content. In this instance, it appears that prior knowledge of the content may have helped make the activity more accessible to some participants and highlights the need to ensure that students are provided with in-world support materials and an overall content delivery program that are appropriate for their knowledge level. Lack of initial familiarity with the content is one part of the context for understanding the circuit lab's assessment data; in addition, we have to consider the fact that the circuit lab garnered a good deal of critical feedback focusing on challenges participants faced while using the SL interface to manipulate the in-world gates as part of the circuit building activity. Participants in both workshops showed moderately high levels of trouble using SL to complete the activity (Table 5, item 8) and the written comments for this activity also focus on usability limitations.

TABLE 4
Assessment of Crossword Puzzle

Question	Workshop					
	1			2		
	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation
1. Prior to this activity I was familiar with lesson content.	3.00	7	1.73	4.5	2	.71
2. I was able to complete the activity as instructed.	4.14	7	1.07	4.5	2	.71
3. The visual presentation instructions for this activity were easy to understand.	4.5	7	.55	4.5	2	.71
4. The notecard instructions for this activity were easy to understand.	4.43	7	.53	4.5	2	.71
5. The activity helped me understand the content.	4.57	7	.53	4.5	2	.71
6. The activity was an interesting way to learn the content.	4.57	7	.53	4.5	2	.71
7. The activity was visually appealing (e.g., colors, overall design).	4.57	7	.53	4.5	2	.71
8. The size of the puzzle tiles made working with the puzzle difficult.	2.14	7	1.07	4.0	2	1.41
9. I had trouble using Second Life to complete the activity (e.g., clicking, accessing, or moving objects).	2.00	7	.82	2.0	2	1.41
10. Working with a partner on this activity was helpful.	3.86	7	.69	4.0	2	1.41
11. Overall this activity was a positive learning experience.	4.57	7	.53	4.5	2	.71

TABLE 5
Assessment of Circuit Lab Activities

Question	Workshop					
	2			3		
	Mean	Participants	Standard Deviation	Mean	Participants	Standard Deviation
1. Prior to this activity I was familiar with lesson content.	4.71	7	.49	2.56	9	1.74
2. I was able to complete the activity as instructed.	3.43	7	1.51	3.11	9	1.45
3. The visual presentation instructions for this activity were easy to understand.	4.14	7	.69	3.89	9	.60
4. The notecard instructions for this activity were easy to understand.	4.14	7	.69	3.56	9	1.13
5. The activity helped me understand the content.	3.71	7	1.50	3.56	9	1.33
6. The activity was an interesting way to learn the content.	3.71	7	1.5	3.56	9	1.33
7. The activity was visually appealing (e.g., colors, overall design).	4.00	7	1.15	3.33	9	1.32
8. I had trouble using Second Life to complete the activity (e.g., clicking, accessing, or moving objects).	3.71	7	1.38	4.33	9	.71
9. Working with a partner on this activity was helpful.	3.29	7	1.25	4.33	9	.71
10. Overall this activity was a positive learning experience.	4.00	7	1.15	3.78	9	1.20

Feedback on difficulties using the Circuit Lab also showed up in the overall assessment data as well, with a number of comments suggesting improvement to the ease of object manipulation and placement. Despite the challenges presented by the interface, participants indicate moderately positive reactions to the Circuit Lab's helpfulness and interest level (Table 5, items 5 and 6). Overall, we view this feedback not only as instructive for the further development of the circuit lab activity, but also as indicative of the kind of design and interface issues facing MUVE design.

5.5 Differential Equations Activity

The activity that incorporated the visualization of a rate flow problem was tested with students from a course an Ordinary Differential Equations course in Fall 2011. The workshop was divided over two class periods, one devoted to a SL introduction, the second to the rate flow exercise. Unfortunately, the logistics surrounding this demonstration meant that both meetings were plagued with technical issues related to an unanticipated update to the SL browser; these technical issues and other logistical problems, e.g., confusion over workshop paperwork, created a general sense of time-pressure and otherwise inhibited the demonstration's effectiveness. Assessment data for this demonstration is generally less positive than that seen for the other VESLL activities (Table 6). Our general conclusion is that this particular activity, at its current stage of development, would best used by a differential equations instructor in class as a visualization tool providing empirical evidence to supplement lecture and as a hands-on experiment rather than as a primary means of content delivery.

6 DISCUSSION OF KNOWLEDGE TEST OUTCOMES

In order to evaluate VESLL's potential impact on student learning, participants in each of the workshops and in the regular-semester quasi-experiment were given pre- and post-workshop assessments designed to test their knowledge of positional numbering systems. In each of the three assessment workshops we see some improvement in the post-workshop results. For example, in Workshop 3—the workshop where participants had the least prior knowledge of the content—we see the most improvement. The average score increased from 27.46 percent on the pre-test to 69.67 percent on the post-test ($n = 11$).

TABLE 6
Assessment of Differential Equations Activity Activities

Question	Workshop		
	In-Class		
	Mean	Participants	Standard Deviation
1. Prior to this activity I was familiar with lesson content.	3.83	12	.72
2. I was able to complete the activity as instructed.	3.00	12	1.28
3. The visual presentation instructions for this activity were easy to understand.	3.50	12	1.00
4. The notecard instructions for this activity were easy to understand.	3.64	12	.67
5. The activity helped me understand the content.	3.08	12	1.16
6. The activity was an interesting way to learn the content.	3.25	12	1.36
7. The activity was visually appealing (e.g., colors, overall design).	3.67	12	1.44
8. I had trouble using Second Life to complete the activity (e.g., clicking, accessing, or moving objects).	2.42	12	1.31
9. Overall this activity was a positive learning experience.	3.18	12	1.25

During the comparative assessment, in which we integrated VESLL's positional numbering activities into an undergraduate computer science class for non-science and engineering majors (CMSI 182), we further explored the likelihood that VESLL might potentially contribute to student in-class learning. Using two sections of CMSI 182, both being taught the same content by the same instructor, we introduced VESLL to one section and relied solely on traditional lecture and in-class problem-sets in the other section. Each section took a pre-test to assess prior knowledge of the subject matter and then, after exposure to the course content, took a post-test to evaluate knowledge development. What we see from our comparison between the non-VESLL traditional lecture-only group and the VESLL lecture plus in-world SL activities group, is that the VESLL group performed marginally better on the post-test than their non-VESLL counterparts. We note that both groups started out with similar levels of prior knowledge and both groups showed improved knowledge; the VESLL group ($n = 11$) improved their scores by an average of 12.45 points and the non-VESLL group ($n = 20$) improved their scores by an average 11.50 points. We note that the difference between the two groups' improvement scores was not statistically significant (Mean DIFF = 0.95, $t = 0.29$, $p = 0.767$). This data, therefore, does not indicate that VESLL is better than traditional classroom delivery. However, our results do suggest that VESLL is at least as effective as traditional classroom delivery in terms of student learning. In addition, feedback from the VESSL group was similar to that from the workshops, indicating that students ($n = 13$) found VESLL activities to be an interesting way to learn course content (Mean = 4.15, SD = 0.56), found VESLL to be a more interesting learning experience than a traditional classroom experience (Mean = 4.31, SD = 0.75) and liked the immediate feedback available through VESLL (Mean = 4.54, SD = 0.52).

Overall these results, while not establishing VESLL as superior to other approaches to content-delivery indicate VESLL potential for effective content-delivery, combined with strong student interest in VESLL as a learning tool. These results are consistent with those of Beltrán Sierra, Gutiérrez, and Garzón-Castro [4] and Keeney-Kennicutt and Winkelmann [16]. Beltrán Sierra, Gutiérrez, and Garzón-Castro conducted a comparison of traditional content delivery with traditional content delivery as supplemented by MUVE components in two engineering programs over a year and half. Their results showed that despite no significant difference in student grades, both students and teachers found the MUVE enhanced content delivery to encourage student motivation and improve course quality. Similarly, Keeney-Kennicutt and Winkelmann found significant differences in knowledge-based outcomes in only one of their experiments; despite this limited evidence of improved student learning, Keeney-Kennicutt and Winkelmann found that students reported positive experiences with MUVE-based experiments and identified some advantages that the MUVE-based experiences might have over physical, real-world lab activities. Ultimately, we join others [4], [11], [16], [22] in contending that well-thought out integration of learning tools like VESLL may have a variety of benefits for students. Increased student motivation, interest in the learning process, as well as in the subject matter itself, are important intangibles that may not be best measured merely by attention to measurable knowledge acquisition.

7 PLATFORM LIMITATIONS AND OTHER LESSONS LEARNED

Our experience with VESLL indicates that virtual environments have tremendous potential for engaging youth in learning STEM concepts. Students enjoy the opportunity to explore a virtual world and experiment independently with hands-on activities. Students not familiar with virtual worlds and with SL in particular do need to spend time becoming familiar with navigation commands, but we have found that a one-time one-hour training period is both entertaining and sufficient. On the down side, like Bowers et al. [3] we also found that SL offers many distractions, a potential problem depending upon the type of learner. We achieved the best results when we provided the SL orientation, followed it with a brief opportunity to enjoy making avatars fly, dance, and change clothes, then a break, and resumed the workshop with a reminder that when one is exploring VESLL the same rules of behavior, social interaction, and clothing standards apply as in a brick-and-mortar science museum or classroom.

Students valued the VESLL activities as supplemental learning experiences that would augment and not entirely replace traditional, instructor-led classroom activities. Ultimately, the intent of VESLL is to provide a means to attract non-traditional students to STEM studies and to facilitate STEM learning, rather than supplant the classroom, so the students' views are in line with our goals.

While SL is readily available around the world on computers with a browser, 512 MB of memory, and Internet access, we agree with others [25] that it is neither an ideal delivery nor development platform. The most favorable SL user experience requires access to a computer with 1-3 GB of memory, a high-speed Internet connection, and a good graphics card, such as NVIDIA 9800 [26]. The current generation of students is accustomed to games that have high quality graphics and fast response times. While some users have lower expectations for educational software, others miss the high-end nature of gaming environments that is difficult to achieve in SL.

The lack of control over video, sound, permissions, and modifications limit the content that can be provided in the SL environment. For example, the level of granularity for sound in SL is defined by the length and width of the parcel, without regard for the height. Thus, if audio is permitted in one room on one level of a multi-story virtual building, when the audio is played it can be heard in the entire column of space defined by the room rather than being contained within one level (or virtual room) within the structure. Permissions and modification rights need to be carefully managed to avoid inadvertently giving users the ability to use but not alter VESLL objects; these rights also must be managed carefully during the object development and scripting stages of a project, otherwise transferring objects among team members for collaborative purposes can become problematic. For instance, when transferring an object to a team member the original owner of the object has to ensure that the future owner has all rights (modification and transfer) to not only the object but also any embedded scripts. Because objects are often made up of multiple "linked" pieces, rights must be given in a way that include all subsumed pieces. Failure to properly manage these permissions can make collaboration challenging and ultimately limit the rights that are passed on to the end-user/owner.

While the SL development environment makes it easy to create simple content, the creation of complex, interactive objects is challenging within the confines of Linden Scripting Language, SL's proprietary development language. The storage requirements for dynamic visualization of an algorithm for clustering objects quickly exceed available memory. Thus, for example, developers can provide snapshots of a clustering algorithm in a limited context, but cannot display the entire process of clustering a few hundred objects.

Use of a proprietary platform ties the project to the fate of the vendor. While Linden Labs is currently stable, continued availability of SL will be determined largely by Linden Lab's ability to maintain its user base and adapt to new delivery platforms, such as hand-held devices. The cost of the SL license doubled over the course of the project, raising questions about the long-term sustainability for many institutions. Linden Labs frequently updates the SL viewer making frequent changes that are not always backward compatible, causing developers to scramble and retest with each release, especially in terms of training materials used to orient our users to the SL environment. An open source platform may alleviate some of these concerns yet has the disadvantage of shifting the maintenance of the application server to the content provider [25].

8 CONTRIBUTIONS

Our work on the VESLL project is still largely exploratory and developmental. Assessments indicate that there is strong interest among college and college-bound students with a predisposition toward math and the sciences. Potential student users see virtual experiences, like those offered by VESLL, as being interesting content-delivery tools that serve to enhance traditional learning experiences. It is important for future developers to understand and manage potential platform limitations at all stages of development; commercial platforms, like SL, may be ideal in terms of their cost-efficiency and apparent ease of access for student-users, however the limits of their programming languages and maintenance fees, make them less than ideal for developers and institutional-owners. Moreover, frequent software updates, often with significant changes to the end-user interface, make developing orientation materials and maintaining machines with up-to-date software challenging.

The lessons learned as part of VESLL's initial development also suggest that translating traditional content into MUVE can easily slip toward reifying existing traditional classroom practices. For example, in-world presentation materials are an opportunity to explore alternative forms of content delivery (such as pre-recorded video, etc.); however, technical the limitations of the SL platform (e.g., media players being rendered obsolete by software upgrades, in-world lag related to audio delivery, the "cone"-like zoning of sound) made execution of some content-delivery methods unstable or otherwise inappropriate.

Student feedback on the limitations we experienced as we developed VESLL highlight the sophistication our students have with regard to virtual environments; they are reluctant to tolerate lag, awkward viewing angles, or other interface-based obstacles. Visual complexity and aesthetic appeal are important parts of keeping today's MUVE savvy student interested and engaged; just being "online" is not enough to make a learning tool, like VESLL, a valuable content-delivery option–the potential of the MUVE has to be carefully exploited in ways that seamlessly integrates innovation into user-friendly content delivery methods.

9 CONCLUSION

As our work shows, developing in SL poses several problems; however, in general, VESLL garnered positive feedback and shows potential for further development. In order to maximize the multi-modal potential for content delivery through an immersive online environment, such as SL, projects like VESLL must pay sufficient attention not only to the technical content delivery apparati, but also to the aesthetic dimensions of the environment. In-world lag, awkward viewing angles, clunky interface controls, and other performance-based issues, have the potential to detract from the learning experience.

Despite the challenges we have faced with regard to SL's limitations as delivery platform, assessment data demonstrates not only that VESLL has strong potential for providing positive learning experiences, but also that students are interested in seeing more tools of this kind integrated into their educational content. The potential benefits of providing students with imaginative, interactive ways to engage STEM content make projects like VESLL an important, arguably essential, area of exploration.

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Stephanie E. August received the BA degree in Slavic languages, and the MS and PhD degrees in computer science from UCLA (1972, 1986, and 1991, respectively). She is an associate professor in the Department of Electrical Engineering and Computer Science, Loyola Marymount University, Los Angeles. Her research interests include natural language understanding, analogical reasoning, interdisciplinary new media applications, and STEM education. She has authored papers on natural language processing, reasoning by analogy, and STEM education, and received two US National Science Foundation (NSF) DUE grants. She is a member of the AAAI, ASEE, ACM, CCSC, IEEE, and the IEEE Computer Society.

Michele L. Hammers received the BS degree in business administration from Boston University in 1992, the J.D. from the University of Texas at Austin School of Law in 1995, the MA degree in interdisciplinary humanities from Arizona State University in 2000, and the PhD degree in communication studies from Arizona State University in 2004. She is currently an associate professor in the Department of Communication Studies, Loyola Marymount University in Los Angeles, CA. Her research interest include the ways in which the female body is perceived and understood in various public and professional arenas and the potential of virtual worlds for student learning and for individual identity development. She is a member of the National Communication Association.

Don Brian Murphy received the BS degree in computer science from Loyola Marymount University in 2010. He is currently interning as a software developer at Medaxis. He has contributed to the XMLPipeDB program suite, the social networking site Serengeti, and the Virtual Engineering Science Learning Lab (VESLL) project at LMU. He has coauthored papers on virtual environments in education.

Allison Neyer received the BA degree in English with a minor in computer science from Loyola Marymount University in Los Angeles, CA, and the J.D. from Loyola Law School in Los Angeles, CA. She is currently working toward the BS degree in computer science at Loyola Marymount University in Los Angeles, CA, in preparation for becoming a patent attorney. She has coauthored papers on virtual environments in education.

Penda Gueye received the BS degree in electronic media from Towson University in 2005 and the MS degree in systems engineering from Loyola Marymount University in Los Angeles in 2011. She is currently a quality control manager for a digital media company in the Washington DC area. She has also produced documentaries for a film production company in Virginia.

Robert Q. Thames received the BS degrees in electrical engineering and computer science from Loyola Marymount University in Los Angeles in 2014. He was a research assistant on US National Science Foundation (NSF) projects at LMU, as an intern at the Jet Propulsion Laboratories in Pasadena, California, a consultant at Datapop, Inc., and is currently a software developer at Google, Inc.