Design of Virtual Learning Environments

Learning Analytics and Identification of Affordances and Barriers

http://dx.doi.org/10.3991/ijep.v5i4.4962

Pekka Qvist[1], Tuomas Kangasniemi[1], Sonja Palomäki[2], Jenni Seppänen[3], Pekka Joensuu[1], Olli Natri[1], Marko Närhi[1], Eero Palomäki[2], Hannu Tiitu[2], and Katrina Nordström[1]
[1] Aalto University School of Chemical Technology, Espoo, Finland
[2] Aalto University School of Science, Espoo
[3] University of Helsinki, Helsinki

***Abstract*—The future of educational technology has been envisioned to have increasing focus on simulations, game based learning, virtual learning environments and virtual worlds. The technologies aim to provide authentic learning and enable deeper, more complex and contextual understanding for students. To study the impact of virtual learning environments for natural sciences and engineering education, we have designed and implemented a virtual laboratory, LabLife3D, in Second Life. To date we have designed six virtual laboratory exercises in the biological sciences and chemistry and additionally created a system to gather behavioristic data during laboratory simulations for the purpose of learning analytics. This paper presents the design process of laboratory exercises and discusses the content-specific learning goals and outcomes. Additionally, this paper discusses the use of heuristic usability review used to improve the virtual learning environment. Lastly, the results from student and teacher interviews are presented, together with results of the learning analytics study. The discussion also includes student identified affordances and barriers for learning. We conclude that authentic and deep learning is possible within virtual worlds. Furthermore, the results of this study are not only limited to virtual worlds, but could also apply to other areas of digital educational technology.**

***Index Terms*—Virtual Worlds, Virtual Learning Environments, Learning Analytics, Educational Technology.**

I. INTRODUCTION

Virtual worlds (VWs), games and simulations represent the future of learning environments. They enable a wide range of learning activities from complex laboratory simulations to collaborative communication projects, facilitated by the creation of user-generated content, allowing for incremental improvements in response to evaluation and changing educational contexts. VWs such as e.g. Second Life (SL) have many significant advantages over real-life spaces including the provision of learning which would be too expensive or dangerous in the real world, facilitating student skills practice without the restriction of resource availability, and the ability to allow collaboration between geographically dispersed participants. The use of VWs accommodates a large range of learning styles with activities that can be tailored for students across a range of competencies. However, 3D virtual worlds and other digital learning tools are best understood as an alternative, and not a replacement, to face-to-face communication, that need to be leveraged with pedagogically sound approaches for achieving authentic learning outcomes. For the purposes of this paper, a virtual world is defined as a computer-, server-, or internet-based virtual environment that allows participants to move around and use various forms of communication (text chat, voice chat, or instant messaging). It allows participants to create a virtual identity which persists beyond the initial session [1].

Authentic learning is the most desirable way to achieve, deeper, more complex, and contextual understanding of particular disciplinary areas [2]. The key affordances must be identified and promoted, whilst barriers to learning should be minimized. According to Greeno [3] "an affordance relates attributes of something in the environment to an interactive activity by an agent who has some ability". By definition therefore, affordances are ingrained into authentic learning, which places the student into the role of the doer or actor. On the other hand, authentic learning also poses significant challenges as it may be too difficult, dangerous or expensive to provide such opportunities in traditional learning spaces [4]. Consequently, many educators have explored digital learning environments, or VWs, where simulations and learning-by-doing can be facilitated within disciplinary and professional contexts [2].

Second Life is an example of an immersive and interactive virtual world environment that can be as complex as the real world. Users can create 3D objects, and these can be seen and used also by other individuals in the VW [5]. Interaction in SL takes place through an Avatar and SL includes communication tools such as text and voice chats, and instant messaging. Sounds can be imported into SL, and audio and videos can be streamed into SL.

This paper presents design and implementation of virtual laboratories, student and teacher views on the affordances and barriers to learning in these environments, usability heuristics testing and the development of tools for learning analytics for monitoring student progress in such environments.

A. Advantages and Disadvantages of Virtual Worlds in Education

The most significant advantages of virtual worlds in general, and of Second Life in particular, are flexibility of construction, freedom from real-life hazards, and low cost of operation and repeated exercises [6, 7, 8]. Information technology also helps adjusting the teacher to student ratio [9], albeit this benefit is not exclusive to virtual worlds. Virtual worlds in education have also been shown to lead to increased engagement [8].

Brain activity has also been measured for tasks performed in real as well as in virtual reality environments [10]. Findings have also demonstrated that subject are more attentive, responsive, and utilize less mental effort in the virtual world, demonstrating that knowledge transfer of information gained in one world to the other world is possible. Moreover, students have been reported to be more engaged in learning tasks and to spend more time thinking and discussing the subject material [11]. Immersion into another world has also been noted and engagement in learning in the first person, which is more interactive and experiential [12]. Moreover, previous studies have shown that as learners are allowed to interact with information in the first person, this facilitates constructivist-based learning activities [13].

Furthermore, the interaction with virtual objects can be helpful in developing a stronger conceptual understanding, depending on the content. Engagement experiences are also present and, by using virtual worlds as the learning environment, enthusiasm for learning can increase. It has also been documented that the 3D virtual worlds facilitate the visualization of difficult content and offer tools for learning challenging concepts [14]. The benefits of Second Life, in particular, include providing "a social laboratory where role-playing, simulations, exploration, and experimentation can be tried out in a relatively risk-free environment" [15].

Some of the disadvantages include the time needed to learn the use of the virtual world, cost of initial development, technical issues such as frequent updates and out-of-date hardware, as well as attitudes towards such learning spaces, e.g. students or faculty not taking the virtual world seriously [16, 8, 17]. Moreover, according to Warburton, VWs can also be an isolating experience, since other users are not as easily found as in e.g. Facebook and other social digitalized environments.

B. *LabLife3D: The Second Life Project of Aalto University*

Practical skills are one of the core competencies in technology, engineering and the natural sciences. However, laboratory courses in the natural sciences, chemistry and biology, require extensive planning, and are expensive, as sophisticated equipment and reagents are needed. Course sizes often also pose safety challenges and even waiting lists to the courses may have to be used. Moreover, although learning-by-doing is the ultimate goal of practical laboratory classes and hands-on experimentation, the curriculum of many higher education institutions is very rigid and lacks space and time for students to take the time to rerun and reflect on experiments. As there is not sufficient time for the learning experience to mature many students can pass classes with only superficial learning without developing deep learning where theory connects with practice. Accordingly, a virtual laboratory, LabLife3D, was designed and implemented to bridge the gap between theory and practice. https://sites.google.com/site/lablife3d/

To date, six laboratory "practicals" have been designed (Table 1). The details of this development process, along with general considerations such as building the LabLife3D team, have been presented previously [18, 19, 20, 21, 22]. In addition to creation of scientific and technical contents, the more recent focus has been on studying the pedagogical aspects of VWs, namely student learning experiences, views of teachers on the use of virtual learning environments and the development of learning analytics to elucidate the affordances and barriers to learning.

C. *Design Objectives for Virtual Laboratories*

VWs have received considerable interest as a medium for academic education in the past decade (Table 2). The 1st generation environments are represented by more passive elements, which cannot be considered to represent actual simulations. Most of the 1st generation environments mediate information only via passive objects, such as static 3D shapes, sound and video. At best, they may include a chat conversation with an automated avatar possessing an artificial intelligence of some elementary kind. Active user participation, requiring decision-making or completing a set of tasks, is generally absent. The simulation-type environments, or 2nd generation environments, can be classified in two distinct categories: ready-to-use simulations and teacher-initialized ones. The latter are most common in medicine, nursing and related fields, and they frequently engage multiple users in different roles communicating with each other. On the other hand, in the ready-to-use simulations, the user interacts only with the computer. This approach is more applicable for laboratory simulations of natural sciences such as chemistry and biology [21].

TABLE I.
THE LABORATORY EXERCISES AND FEATURES WITHIN LABLIFE3D

	Theme	**Status**	**References**
1	Virus isolation	Operational from Dec 2010	Palomäki, E. et al. 2010; Palomäki, E. et al. 2011; Nordström et al. 2010
2	Laboratory safety tutorial	Operational from Dec 2010	*same as above*
3	Decarboxylation reactions	Operational from Oct 2012	Kangasniemi 2012
4	Virus identification by RT-PCR (*)	Operational from Jan 2013	Olkinuora 2012
5	Learning analytics & data gathering	Operational from May 2013	Palomäki, S. 2014
6	A/B testing of virtual laboratories	Operational from Oct 2013	Palomäki, S. 2014
7	Vacuum distillation	Design ready	- -
8	Algae bioreactor simulation	Design ready	- -

(*) RT-PCR = Reverse transcriptase polymerase chain reaction

Careful design of the content and the functions of virtual laboratories is essential to their success. The characteristics of an effective virtual laboratory for engineering students as described by Arango, Chang, Esche and Chassapis [23] and Quinn [24] have been summarized by Olkinuora [22] as follows:

1. Context: The virtual laboratory should present a framework familiar to the students.
2. Realism: Clear connection between reality and the simplified model of the virtual laboratory.
3. A goal clear enough toward which to pursue.
4. No futile actions: The actions the students take should affect the outcome.
5. Exploratory feel: Enough possible alternatives and the possibility to explore their mutual relationships.
6. A slight degree of randomness to maintain curiosity.
7. Appropriate challenge: Not too easy but, not too difficult.
8. Appropriate feedback.
9. Relevance to other studies.
10. Visual appeal.

It is also important to avoid the generation of cognitive overload. Moreover, the user should be able to make actual errors without triggering an immediate response, and simply offering mere alternatives should be avoided. Some of the above named properties are clearly complementary and can be implemented at the same time. On the other hand, some of the above criteria may partly contradict each other. Some randomness can also be tolerated, whereas futile actions by the user should be avoided. Ultimately, however, the design process will involve compromises between the objectives.

Numerous experimental studies on different types of virtual learning have been conducted, with many of them reporting positive results but some also taking a critical stance towards the final outcomes [25, 26]. On the other hand, although some of the studies relate to simulated laboratories [27], only very few of them refer specifically to virtual laboratories in Second Life. The exception are Cobb, Henderson and Corcoran-Begg [28] who studied the educational performance of a virtual biotechnology laboratory, the UEL Lab (Table 2), in Second Life for learning the polymerase chain reaction (PCR) task ($N = 85$). Their results indicated that using Second Life did not significantly contribute to the learning outcomes. On the other hand, they did report that the Second Life test group performed better than the control group both before the experiment and after it. Hence, the conclusions are somewhat conflicting.

II. APPROACH

At first stages of exploring the possibilities to use VWs for education the focus was on creating the actual learning space, the virtual building, LabLife3D. The primary learning outcomes and goals that were identified emphasized the promotion of deep learning via connecting scientific theory with practice.

More recently, both the research and development of 3D learning environments has continued. Namely, the objective to expand the experiments to better mimic exercises that students typically carry out in the laboratory, where students also will need to make choices of which some also may lead to mistakes. The organic chemistry decarboxylation experiments and the molecular biology experiments have been used for further pedagogical studies on student and teacher experiences and identifying learning affordances. The molecular biology exercise was also used to study the development of learning analytics.

A. *Organic Chemistry Simulation: Learning Objectives, Content and Functions*

The organic chemistry simulation [21] mimics experimental research with the main focus on teaching scientific reasoning based on empirical results. In the simulation, the task of the student is to compare the reactivity of different carboxylic acids towards decarboxylation and decarbonylation and to deduce the theoretical explanation for the observations. The reaction variables (temperature, time, catalyst and solvent in addition to the acid substrate) are freely selectable from the alternatives given. The simula-

TABLE II.
A LIST OF EXISTING LABORATORY SIMULATIONS IN SECOND LIFE (NOT INCLUDING THOSE IN TABLE 1)

Organization	**Theme**	**Location in SL (*)**
Leicester U.	Molecular biology	Media%20Zoo/74/189/32
Imperial College London	Respiratory medicine	Imperial%20College%20London/185/47/27
Monash U.	Manufacture of drug tablets	Pharmatopia/108/111/29
U. of Queensland	Mathematics in pharmacology	Pharmatopia/108/111/29
U. of Nottingham	Mass spectroscopy	University%20of%20Nottingham/176/130/26
U. of East London	Molecular biology	UEL%20HABitat/200/207/26
Keuda Vocational College	Mashing in a brewery	Edufinland%20IV/82/227/24
Florida Inst. of Tech. (**)	Physical chemistry	ACS/151/10/89
U. of Calgary (***)	Molecular biology	LINDSAY%20Virtual%20Medicine/187/194/29
Texas Wesleyan U. (****)	Biology	Genome/75/212/36

(*) All the SL locators are preceded by http://maps.secondlife.com/secondlife/
(**) The link and the simulation used in November 2011. Currently not online or closed to the public.
(***) Possible technical issues. The authors were unable to make the simulation work.
(****) A borderline case. Includes only limited elements of simulation.

tion is controlled by clicking on the chemical containers and instruments, such as the synthesis station and a balance, in the laboratory 3D space. In addition, there is a control panel for general functions such as "Start" and "Exit". Instructions to the student are given in the HUD (see Figure 1).

During the design process, the focus was on four main issues. First, it was important that passing the simulation should not be too straightforward: instead of being a demonstration, it should include alternative outcomes or the possibility of making errors, or both. Although the organic chemistry simulation does not include the possibility of explicit errors, the array of different setup combinations, and hence reaction outcomes, is large (180 combinations in total). Moreover, the simulation leaves the planning of the research program to the student. All different reaction combinations are selectable, but it is not beneficial for the student to change the parameters without really thinking about the consequences.

Second, the study was focused on the design of scenarios created previously by others (Table 2) and noted that from the usability point of view, the user interface is very important. All previous simulations, listed in Table 2, require the use of the technical elements of Second Life, such as notecards, inventory, chat and multiple choice popup windows. Some simulations rely on them heavily. However, in our experience, these elements frequently confuse the beginner. Therefore, it may be more beneficial to encode the operations to the more intuitively understood 3D space whenever possible, and leave the use of the technical elements to the minimum – even if this slightly decreases photographic realism.

Very useful examples are the control panel designed by Florida Institute of Technology (Table 2) and the precise instructions given by the HUD, as used in the University of Leicester's virtual laboratory (Table 2). The possibility of the simulation happening in real time instead of symbolic time is also interesting, as presented in the SL Chemistry Lab of FIT (Table 2). However, due to the long reaction times in the present experiment, the dimension of time was not included in the simulation.

Third, wherever possible, our organic chemistry simulation gives the student real experimental data from the literature instead of extrapolations. This proved to be, in fact, by far the most challenging part of the whole design. While suitable data for the experiment could be found from the literature, finding a complete set of results, encompassing all the combinations of every acid substrate, every temperature, etc., turned out to be impossible. Therefore the alternatives had to be chosen carefully to maximize both the presence of real data points as well as to ensure the reliability of the extrapolations. Fourth, a random element of experimental variation (1 to 5 %-points) was decided to be added to all measurements the student performs in the simulation.

B. Molecular Biology Simulation: Learning Objectives, Content and Functions

The primary learning outcome of the molecular biology simulation [22] is to give the student the opportunity to learn the process of identifying a virus from a human cell sample. The virus being studied is an enterovirus, identified in accordance to standard scientific methodology, based on a specific enterovirus protein known as VP1. Another aim is to encourage critical thinking of the choice of methodology and the reactions thereof. Many phases in molecular biology exercises are embedded into chemical reactions and the aim is therefore to deepen the students understanding of the intricate relationship between biology and chemistry.

Upon entering the laboratory an introduction and short instructions are given for performing the task. Avatars will wear appropriate clothing: lab coat and gloves. The objects mentioned below work by clicking on them. The task begins with extracting RNA from a sample of virus in host cell matrix (Figure 2). Buffer is added, incubation and centrifugation are performed, and a DNA-decomposing enzyme, DNase, is added to recover pure viral RNA after a series of extractions and centrifugations. The polymerase chain reaction (PCR) is then performed, followed by electrophoresis to visualize the sample and to verify that the experiment is proceeding as planned. In each of the

Figure 1. Screenshot: The organic chemistry simulation on decarboxylation reactions. HUD window on the left

aforementioned steps, the student must choose the correct process conditions such as the amounts of chemicals and temperature cycles for PCR. This requires the student to familiarize himself/herself with the principles that form the basis of the operations. At some points a text may appear which will highlight the reason for the choices that need to be made.

Having verified the success this far, the sample is sequenced. As most laboratories outsource sequencing these days, no sequencing scenario was designed and the correct RNA sequence is delivered to the student, provided that the extraction of the RNA has been successfully performed. In the final phase, the student submits the sequence of the virus to a real-life online gene database, BLAST (http://blast.ncbi.nlm.nih.gov/) to search for a match.

At the end the student gets a printout of all the steps done and is asked to write a report on the exercise for the teacher. It shows what happened to each object in each step, and the student can reflect on what was actually done in the laboratory. This reflection enhances the learning especially if mistakes had been made, as then it is very important that the student understands what the correct choice would have been and why.

The objectives in designing the user interface and the general structure of the molecular biology simulation were similar to those of the chemistry decarboxylation experiment. That is, the simulation is not too simple to pass, its active elements are embedded to the 3D space if possible, the simulation uses real data, and adds random experimental variation. In addition, as already noted, there is a possibility of making mistakes without receiving immediate notice. It was also decided that the actions taken in the virtual laboratory should include some simplification to avoid cognitive overload (e.g., not all details of pipetting modelled). The content of the simulation was presented to the programmers with the help of a flowchart, representing the state of the virtual objects.

C. *Usability Testing: Heuristic User Interface Evaluation*

As part of the aims to develop sophisticated laboratory experiments in VWs, a formal usability test on the user interface of the organic chemistry experiment was also conducted instead of simply troubleshooting the usability concerns. The test was designed and conducted by personnel not directly involved in the design and implementation of the simulation.

The test method used was the heuristic evaluation [29]. Its benefits are the relative speed and ease of carrying out the test, while being able to effectively find both small and large usability issues. The test was conducted with three evaluators having little prior experience with VWs, with none of them being a student in the course the experiment was used a month later. The test was performed in two separate sessions. They began with getting familiar with Second Life, followed by performing the experiment through individually and making notes on the usability issues, and finally giving a subjective assessment of the severity of the problems found. An instructor more familiar with the experiment and with VWs was present. In total, one session took about 2.5 hours.

Evaluators were given a list of general points of focus called heuristics, to help them to recognize and categorize the possible shortcomings. The heuristics were divided in two sets: those of technical and pedagogical usability. Here, the emphasis was on technical usability, referring to the technical properties of the user interface and the ability of the evaluator to use the programs. The heuristics of technical usability used were modified from the original Nielsen's [30] heuristics for evaluating specifically e-learning environments [31].

1. Is the status of the system visible?
2. Is the language understandable to each user?
3. Does the user have an appropriate freedom to control navigation and operations? Is navigation simple enough?

Figure 2. Screenshot: The molecular biology experiment. HUD window on the upper left

4. Is the system logical and standardized?
5. Can mistakes be prevented? Are the error messages understandable?
6. Can objects and functions be readily identified, rather than requiring memorizing?
7. How much flexibility to modify the user interface there is available?
8. Is time spent efficiently?
9. Is the design aesthetically pleasing and/or minimalistic?
10. Is appropriate guidance available? In what format is it displayed?

The technical usability issues found were related to both the experiment in particular and to Second Life in general. Examples include virtual buttons not registering the click in some instances, inconsistencies in the instructions given by HUD, Second Life icons overlaying the HUD, and users knowing not how to e.g. zoom in the view in SL.

Besides identifying actual usability issues, our goal was to construct a more general checklist for performing similar tests in future. The list includes the setup of test session as stated above, plus practical notions, of which probably the most important is making sure beforehand that the computers and programs work well. A convenient size for the test group is three to five persons. This way some 50 % to 80 % of the existing usability issues can be found [32].

D. Data Gathering and A/B Testing Setup

To further improve the usability of the virtual learning environment and to better analyze student behavior for creating a methodology for assessing learning during the laboratory exercises, a data gathering and learning analytics system was designed and developed [33]. It was concluded that for the purposes of analytics, the data collecting mechanisms should try to capture as much of student actions and behavior as possible. The virtual environment allows recording behavioristic data during laboratory experiments and exercises that might be difficult or impossible to capture in the real-world laboratory.

The system implemented in the virtual laboratory allowed recording the students "touching" (or clicking with mouse) various objects and elements in the laboratory. The events were identified by the student avatar name and stored with a timestamp into the analytics dataset in a database. The system could also track various phases of the laboratory experiment and beside just recording mouse clicks, the data trail included various data points relevant to the chemistry experiment at hand. This would allow the student or teacher to play back the whole experiment at a later time for re-evaluation and reflection. The recording system was implemented in all the objects relevant to the laboratory exercise, but also was deployed into a selection of objects and elements in the laboratory that had no direct relevance to the exercise at hand (e.g. first aid and fire prevention related objects, extra laboratory equipment and glassware etc.), because there were presumptions that students could be distracted by irrelevant material in the virtual laboratory.

The preliminary feedback from some teachers regarding the molecular biology simulation suggested that the exercise could be too easy for some students, because the virtual laboratory appeared too neatly organized and clean and did not appear to involve enough "clutter" that can be found in a real-world laboratory. In the virtual laboratory the bottles of reagents and chemicals were arranged in an organized manner, which could lead the student to click with mouse through the selection of the chemicals without connecting them to the task at hand on cognitive level to promote meaningful learning. This presented an opportunity to put the newly designed learning analytics tools into use.

The laboratory spaces were modified to include the original tidy variant (A) and to create a digital replica of that workstation, in which some objects were shuffled around and extra clutter items were placed in the laboratory space to try to create a more realistic representation of a laboratory environment (B). Both of the laboratory spaces were separate from each other and the students did not know which laboratory they were assigned. As the laboratories had the data gathering system deployed, this created a possibility to do an A/B testing study on student behavior and learning in differently organized laboratory environments. This was also a good opportunity to assess the possibilities that the VWs offer to quickly modify and rearrange working and learning spaces and to study their effects, with nearly no extra costs implicated.

III. FINDINGS

A. Student Feedback on the Use of Second Life

The organic chemistry experiment and the molecular biology experiment were tested as course exercises by groups of first- to third-year students and feedback was collected [34]. Organic chemistry exercises were performed in four groups (two time slots, both with two simultaneous groups) on Mondays and Fridays. First to 3rd year students were randomly selected to participate. There was a stark contrast in the completion and feedback given by students participating in the different time slots. The students in Monday groups (N = 13) felt, in general, that the experiment was reasonably interesting and supported previous knowledge to some extent, and they actually learned something. They felt that the desired outcome of the exercise was clear. However, students also stated that it was possible to pass the simulation without giving any thought to the scientific content, even though they had not opted to do so (Table 3).

The Friday groups (N = 16) responded more critically. About half of the students had no interest at all towards the exercise, did not grasp its purpose and felt they had not learned anything. Moreover, unlike the previous group, they admitted actually exploiting the possibility to pass the task without thinking about the scientific content (Table 3). The notes made by the observers support these differences. It is possible that the differences in the two time slots can partially be explained by differences in previous experience with virtual worlds and IT skills in general (both better Monday), plus age (in Friday, freshmen only). It was also recognized that Fridays may not be the best day to conduct these types of studies.

TABLE III.
KEY FIGURES FROM THE STUDENT ASSESSMENT OF THE ORGANIC CHEMISTRY EXPERIMENT

Question (option A / B / C)	Monday Groups			Friday Groups		
	A	B	C	A	B	C
Experience with virtual worlds (none / some / much)	31%	54%	15%	63%	25%	13%
Desired outcome understood? (no / in part / completely)	0%	54%	46%	47%	53%	0%
How much did you learn? (nothing / some / much)	8%	85%	8%	56%	44%	0%
Supported previous knowledge? (no / slightly / well)	15%	85%	0%	56%	44%	0%
Possible to pass without thought? (no / yes, chose not / yes, did so)	15%	77%	8%	0%	31%	69%
Change of attitude during exercise (neg. / none / pos.)	8%	54%	38%	6%	69%	25%

Based on the experiences gained from the organic chemistry exercise and the student feedback, a new feedback form was designed for use in the molecular biology exercise, based on a Likert scale and paid attention to a more detailed instruction package for the student. Namely, a script was made, in which the students were presented with a fictional case which mimicked a real-life scenario. In this case, the students were part of a team, which was investigating the incidence of a suspected enterovirus infection, which a patient had contracted during a visit to an endemic area. Students had to design and implement the identification of the causative virus by using RNA isolation, purification, detection and sequencing. The exercise was conducted in two simultaneous groups of 10 students each. The students reported they had clearly understood the assignment and also most of the actions taken during exercise. A decisive majority stated that they had learned something new, albeit not very much. The difficulty level was considered appropriate (Table 4).Overall, the student response from the molecular biology experiment was positive [35, 36]. Based on these observations it was evident that the molecular biology simulation was either better pedagogically designed than the organic chemistry experiment, or better connected to the course contents or both. Notably, the chemistry simulation was based on voluntary participation, and not connected to a specific course. On the other hand, the molecular biology exercise was part of a Microbiology course requirements, with extra points awarded and also covered in lectures.

B. *Teacher Views on Virtual Worlds as Learning Environments*

Sixteen Aalto University teachers participated in the interviews, for which the molecular biology laboratory exercise was used as a demo. Prior to the interviews each teacher took part in the molecular biology exercise in Second Life in the University IT class. Teachers were guided through the exercise according to the same script that was used in the student test situation. The interviews were conducted as 45 minute sessions immediately after the demo. Each teacher was interviewed separately and the interview was recorded. The interview consisted of questions under three major themes, namely: 1) previous experience on using SL or similar VWs, 2) assessment of the scientific content of the exercise including the presentation of the assignment to students, the design of the laboratory, the level of difficulty and the technical issues, and 3) the teacher role and advantages or disadvantages for use as part of teaching. Teachers were also asked to provide suggestions for improvement of the exercise itself, the layout of the laboratory or other possible issues.

The majority of teachers had no previous experience with SL. All except one teacher felt that the exercise left them with a positive feeling on use of SL in teaching. The majority (10/16) were able to start the demo without any problems. Most of the comments concerned technical issues, namely a) moving around with the Avatar, ability to set the view (zooming etc.), moving test tubes or similar objects, for example controlling the Avatar movements. Eleven teachers also felt that this would be an excellent method for familiarizing students with laboratory environments, layouts, instruments and general outlines for experimental work.

The teachers felt that the actual classroom implementation must be very carefully planned, and the role of the teacher as an interactive facilitator will be important to define. The teacher should be active at the beginning to assure that students can all get started, and technical issues do not cause hurdles for the students. As the exercise proceeds the teacher should circulate in the classroom (if the exercise is done as a group during a given time and in a set place) and the teacher should give students freedom to proceed and offer assistance only when students really need it and not too soon. If the exercise is completed as an independent on-line exercise, the teacher needs to plan

TABLE IV.
KEY FIGURES FROM THE STUDENT ASSESSMENT OF THE MOLECULAR BIOLOGY EXPERIMENT

Assertion	Strongly disagree	Disagree	Agree	Strongly agree
I am familiar with virtual worlds.	45%	35%	5%	15%
I understood the assignment.	0%	0%	30%	70%
I learned new things.	0%	5%	75%	20%
I understood all the actions taken in the exercise.	0%	15%	70%	15%
The difficulty level was appropriate.	0%	15%	35%	50%
My attitude changed more positive during the exercise.	5%	16%	63%	16%

how she/he is available in SL, taking into consideration that the teacher facilitation as an Avatar may be quite different from face-to-face facilitation. However, teachers did add that facilitations via an Avatar opens up possibilities for the teacher to be present in many situations at the same time and students can complete the exercise when it suits them best. SL could also promote more introvert students to ask more questions due to the diminishing hierarchy of the teacher – student interaction in an immersive environment. However, there was also concern about the level of interaction that occurs between students during an SL exercise and it was evident that teachers did not realize that there are many possible communication channels that may be integrated into SL (e.g. chats, Facebook, Twitter etc.).

All the teachers expressed a positive interest towards the use of virtual worlds, such as SL in their teaching. On the other hand, there were certain reservations, which fell into four thematic areas. First, teachers felt that SL cannot substitute for real life experimentation in the laboratory, but it can be useful in giving more variety to teaching methods. SL can give students also a false sense of working in a laboratory, but then again, it was stated that SL can give a much deeper idea of complex content, than standard textbooks. Some of the hesitation about using SL or virtual worlds in teaching was clearly the rather modest technical abilities of the teachers in comparison to those of the majority of their students. Second, the role of the student and the teacher changes, which influences their mutual interaction. Teachers felt that it is still important to maintain also face-to-face communication, even in the case that they would create an Avatar and become immersed into the SL world. Teachers also felt that it is important to be able to be present and interact whenever a student has a question. Student reflection on his or her performance may also be difficult. There was also concern that students may not form normal day-to-day social networks in SL compared to the real world. The third issue concerned assessment, and teachers emphasized that there is a need to be able to verify the identity of the student as the one who has completed the exercise. The anonymous nature of SL was thought to be a challenge for assessment. Teachers also felt that it is important to be able to design appropriate assessment in order to assess the disciplinary content and skills related to such contents as assessment should not take into account whether or not the student excels in the technical implementation of SL. Fourth, resources were a major issue for concern, e.g. questions such as who will do this, who will pay for it, where will teachers find the extra time to learn the technicalities as well as the planning and implementation. Teachers are hard pressed for time and the majority of teachers felt that their technical skills were insufficient for planning and implementing virtual worlds in their teaching.

Most teachers viewed SL as a positive addition to teaching, but they did not feel able to start developing their own exercises in SL and the accompanying course materials.

C. Identifying Barriers and Enablers for Learning

Warburton has created a framework of enablers and barriers for teaching and learning by analyzing Second Life as a virtual learning environment [16, 33]. The framework was applied to provide further insight into the feedback from student interviews regarding the molecular biology simulation. Table 5 summarizes the enablers that were identified by the students and presents selected quotes from the interviews.

Firstly, regarding *visualization and contextualization of inaccessible content*, the students identified that the laboratory exercise closely resembled the structure of the real-world laboratory process with the exercise advancing in steps involving a decision tree that allows making mistakes leading to incorrect results. The students also identified that the virtual laboratory allows safely to experiment with potentially dangerous or infectious objects such as samples containing viruses.

Secondly, the students identified the layout of the virtual learning environment simulating real life laboratory in detailed manner, thus providing *authentic content for learning*. Experiencing the exercise in the virtual laboratory, using the equipment, and choosing programs and variables made the experiment and process easy to conceptualize and remember. Thirdly, the virtual laboratory experiment was identified to be an *immersive experience* by the students, and they found the session to be exciting and fun.

Fourthly, the students noticed that VWs could present opportunities to quickly work on experiments that could take hours or even days due to long waiting times in the real-world laboratory, whereas in the virtual laboratory the simulation could skip or compress the time during the process. This allowed *physically unlimited simulations*. Lastly, the students concluded that virtual learning

TABLE V.
ENABLERS FOR LEARNING IN THE MOLECULAR BIOLOGY VIRTUAL WORLD EXERCISE ACCORDING TO STUDENT INTERVIEWS

Enablers	**Student interviews**
Visualization and contextualization of inaccessible content	"It's good way to practice the structure of centrifuge which reminds me of a tree-structure"; mistakes are not crucial like in the real laboratory
Authentic content and culture	"This exercise makes the steps of PCR more concrete and it's easier to remember numbers, such as temperatures"
Trying identities	
Immersive experience	"It was fun"
Physically unlimited simulations	"It saved me some time, because I didn't have to wait for the results"
Increased sense of community	
Creating content	

TABLE VI.
BARRIERS FOR LEARNING IN THE MOLECULAR BIOLOGY VIRTUAL WORLD EXERCISE ACCORDING TO STUDENT INTERVIEWS

Barriers	Student interviews
Technology	"Sometimes you just click something by accident and that's the reason for the mistakes"; HUD was hard to follow
Identities are not stable	
Culture	"Maybe you are too lazy to think, when the mistakes are not crucial"
Co-operation	"I experienced peer pressure, when the others were so quick with it (exercise)"
Time	"It took too much time to teleport and dress up the laboratory coats"
Costs	
Standards	
Social discovery	

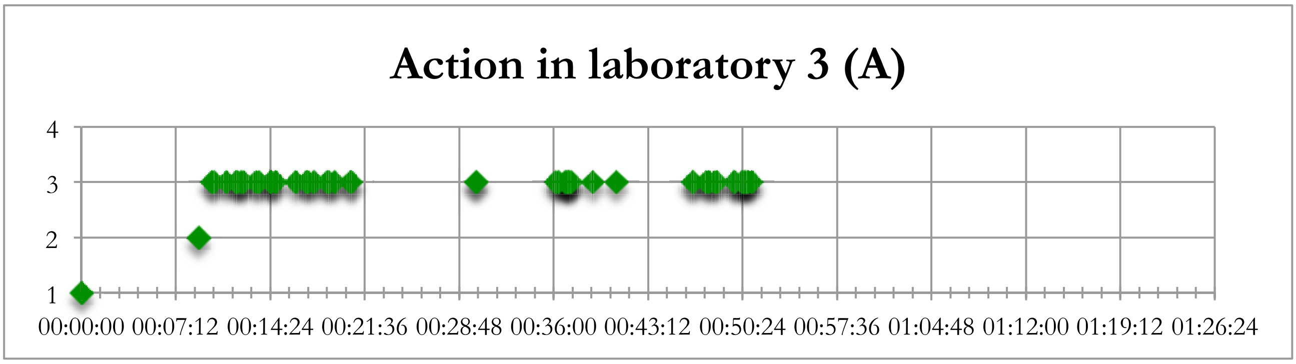

Figure 3. Combining time and events in successful exploration of the exercise

environments can provide new ways of learning by presenting inaccessible material and content in authentic, engaging and interesting way.

Most learning environments and exercises in Second Life and also other VWs face various challenges and difficulties [16, 33]. Table 6 provides an overview of the barriers to learning, which were identified by the students. Firstly, the students responded that the *technology* in form of the user interface for the VW was difficult and challenging to use, involving possibilities to mistakenly click wrong or irrelevant objects, which in worst case scenario could lead to the failing of the experiment. Also some students noted that they had not paid enough attention to some of the user interface elements relevant to the exercise at hand.

Secondly, even though the virtual laboratory allowed simulations with skipping or compressing time, thus making the processes advance faster that in the real-world laboratory situation, according to the students some steps of the laboratory exercise could take too much *time*, such as wearing the lab coat and other required safety gear. Thirdly the students identified *culture* to be one of the barriers to learning, because making errors and mistakes in the virtual laboratory might not necessary be crucial or hazardous as in the real-world laboratory, leading to the possibility of learning not to be careful enough. Lastly, the students noted that while *co-operation* with other students can be possible when sharing the same workspaces, the lack of co-operation could present negative effects in the form of competition and peer-pressure. Namely, if other students are progressing through the exercise faster and slower learners might form a concept that they are worse than the others. Furthermore, the laboratory experiments designed so far did not yet promote learning possibilities in the form of teamwork and co-operation as the study had been focusing on the advantages of the VWs from individual learner point of view.

D. Learning Analytics

Previous research by Siemens and Long has shown that recorded user activity data could give an insight into the learning process [37]. The data gathering system collected mouse clicks by the students and the time spent in the exercise. All the events in the system were recorded with a timestamp allowing further analysis of total time of the exercise and also creating and visualizing timeline patterns of data trails created during the experiments.

Figure 3 presents the timeline data trail from laboratory number 3, which belongs to group A (tidy work spaces) in the test study. The student in laboratory number 3 got the correct result from the exercise indicated by green color. Similarly, Figure 4 shows the data trail from laboratory number 7 belonging to group B (cluttered work spaces). This student did not get the correct result thus being visualized with red color. In both Figures the timeline zero point is the first event recorded when the student enters the laboratory workspace. Time spent on the exercise is shown in minutes on the X-axis. Entering the lab has value 1. Y-value 2 indicates that student has clicked "Start experiment" in the laboratory. Value 3 shows all the other events recorded during the exercise.

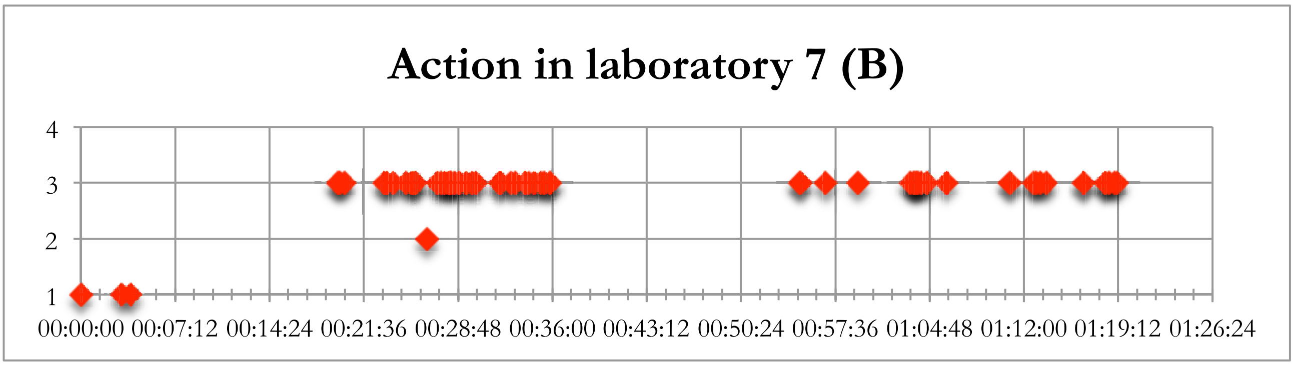

Figure 4. Combining time and events in unsuccessful exploration of the exercise

Analyzing the timelines reveals a slight pattern for those who have ended up with the correct result. The exercise started with several quick actions when the student worked on the first workstation, as seen in Figure 3 between 7 and 21 minutes. The instructions were perceived clear and the exercise consisted mostly of following the instructions step by step. On the second workstation, the student had to make decisions regarding selecting the correct reagents. Students were provided with background material to support the decision making. All the participants had a gap between data trail events on this point, which suggests that time was spent on reviewing the instructions and background material. Right after this first decision, the student had to choose a program out of three options. Most of the students with the correct result had a gap also here. The rest of the exercise was more straightforward and the events on the data trail appeared in faster pace.

Study sessions showed that there are several measures that could be used to give the students and the teachers a better insight into the learning processes as Siemens and Long have proposed. The events of data points recorded into the database alone do not provide meaningful insight for the students or the teachers, but visualizing the data on a timeline and combining time spent in the exercise and the other recorded event data could reveal more. The combined analysis on time and click events suggested four types of student approaches to the exercise: careful, learn by doing, repeat the same mistakes and unmotivated [33].

The collected data is a valuable tool for both the teachers and the students. Teachers could identify the common errors and adjust their teaching to it. They could also identify the type of learner approach and give individual support based on the needs of the students. Students themselves found the data of their performance interesting. Seeing a visualization of their own mistakes provided them information on subject and also on their own learning process that helped them in focusing their further learning activities. Some students found it also motivating to see how they managed compared with others. However, students could also feel threatened if the exercise felt too competitive through comparison among other students.

The preliminary results of the research conducted on learning analytics, suggest that the data set and sample size is still somewhat small for quantitative analysis. The study, however, produced a method for collecting and logging data from the virtual world learning activities, and observations how the data could be analyzed or interpreted. Furthermore, the study showed that learning analytics could be used as a tool for both individual learner, and also for giving different views into the data for teachers.

The research suggests that gathering data of learner actions in the virtual learning environment could provide both insight into the learning process, but also create methods to enhance or evaluate learning. Large sample sizes towards big data could aid in creations of a predictive model that could advise both the students and teachers [33, 38]. Moreover, learning analytics based on big data could be used as a quantitative tool to start to identify and measure both affordances and barriers in learning. However it was noted that while the preliminary study does set a baseline, the whole field would require further research to achieve these goals [38].

E. Understanding both Student and Teacher Views with Technology Acceptance Model

Authentic learning in the virtual environment would require overcoming the technical problems and further emphasizing user experience and usability design [38, 39]. Many of the technical barriers can be overcome, but despite the quality of the user experience that the technology can provide, there may be other underlying problems, such as social technology acceptance. It is not only the perceived usefulness or the perceived ease of use of a technology, but also the attitude of an individual towards using a technology, that might lead to either productive use or prompt rejection. The attitude of the individual might furthermore be subjected to social influence by a peer group as presented by Malhotra and Galletta in the expanded Technology Acceptance Model [40].

Beside the social influence, the Unified Theory of Acceptance and Use of Technology (UTAUT) presented by Venkatesh et al. suggests that many other factors influence the behavioral intention of an individual regarding the acceptance of a given technology, such as facilitating conditions (e.g. computers and network), gender, age, experience and voluntariness of use [41]. Regarding all the different factors affecting technology acceptance, it should be kept in mind that the derived social effects, peer pressure and perceived relation to the technology from not only the point of view of an individual but a social group could play a significant role in how new education technologies will be either accepted or rejected.

Furthermore, the Technology Acceptance Model could also be used in future studies as a cross-reference framework to better understand the results and insight gathered from learning analytics and student and teacher interviews, and the relations that groups or individuals might have towards a selected technology, thus the implications are not only relevant for VWs such as Second Life but also other forms of digital learning environments and educational technology.

IV. CONCLUSIONS

The aim of our virtual biology laboratory experiments is to mimic the work of a real-world scientist in the fields of chemistry and molecular biology and thus support linking theory with practice. Moreover, we wish to provide students with tools that may deepen the learning process as an additional tool to learning in the real-life wet-lab. From the learning outcomes recognized in virtual teaching laboratories by Strangman et al. content area knowledge and conceptual change could be expected to be an outcome of the virtual world experiments that we have designed [26].

Contrary to Helmer, who argues that too many similar components with the real world might be seen as distracting and disadvantageous for learning [42], we feel that a high degree of photographic realism adds to student motivation to use virtual tools for learning. As stated by Josephsen & Kristensen, real life student laboratories may actually place too much emphasis on procedural tasks which possibly lead to a cognitive overload for the learner and therefore may even hinder the learning process [27]. In order to overcome such drawbacks, we have specifically worked on minimizing the attention to detail and focusing on the order of steps and the interpretation of data. The experiments should be clearly tied to a context, there should be a clearly defined goal and the goal should link theory to practice and to scientific research methodology.

One technological solution does not fit all and each individual student has his or her own personal learning style. When interpreting the results from interviews and learning analytics, one should keep in mind that the results will also portray the level of technological acceptance or rejection. Furthermore, to provide deeper, more meaningful, and contextually relevant authentic learning experiences, the focus should be on lowering the barriers to learning. As Siemens and Long discuss, learning analytics will provide tools and possibilities to give a better insight into cognitive processes of learning for both individuals and institutions [37]. These possibilities could also be used in the future to provide more tailored and personalized learning experiences to better suit and match the personal learning style of each individual.

Even though the underlying technology platform used during this study has been Second Life, the majority of our results regarding learning analytics and improving virtual learning environments can be applied also to other digital learning systems.

ACKNOWLEDGMENT

The contribution to LabLife3D by the following individuals is acknowledged: Päivi Korpelainen, Elina Kähkönen, Jari Vepsäläinen, Marianne Hemminki, Outi Tarakkamäki, Kati Vilonen, Martti Ketola, Sebastian Olkinuora, Paulus Artimo, Jaana Brusin, and Hanna Virtanen.

REFERENCES

[1] T. Ritzema and B. Harris, "The use of second life for distance education," Journal of Computing Sciences in Colleges, vol. 23, no. 6, pp. 110-116, 2008.

[2] H. Farley, "Facilitating immersion in Virtual Worlds: An examination of the physical, virtual, social and pedagogical factors leading to engagement and flow," in Learning and Teaching in Second Life: Educator and Student Perspectives, 2013.

[3] J. G. Greeno, "Gibson's affordances," Psychological review, vol. 101, no. 2, pp. 336-342, 1994. http://dx.doi.org/10.1037/0033-295X.101.2.336

[4] M. M. Lombardi, "Authentic learning for the 21st century: An Overview," in ELI PAPERS, Educause, 2007.

[5] S. Kluge and L. Riley, "Teaching in Virtual Worlds," Science and Information Technology, vol. 5, pp. 127-135, 2008.

[6] B. Eschenbrenner, F. Nah and K. Siau, "3-D virtual worlds in education: Applications, benefits, issues, and opportunities," Journal of Database Management, vol. 19, pp. 91-110, 2008. http://dx.doi.org/10.4018/jdm.2008100106

[7] K. Holmberg and I. Huvila, "Learning together apart: Distance education in a virtual world," First Monday, 13(10), 2008. http://dx.doi.org/10.5210/fm.v13i10.2178

[8] E. Palomäki, "Applying 3D Virtual Worlds to Higher Education," Espoo, 2009.

[9] C. Daniel, The Educational Attributes of Some of the World's "top 50" Universities: A Discussion Paper, Perth: University of Western Australia, 2008.

[10] T. A. Mikropoulos, "Brain Activity on Navigation in Virtual Environments," Journal of Educational Computing Research, vol. 24, pp. 1-12, 2001. http://dx.doi.org/10.2190/D1W3-Y15D-4UDW-L6C9

[11] H. Mason, "Experiential Education in Second Life," in Proceedings of the Second Life Education Workshop 2007, 2007.

[12] J. Richter, L. Anderson-Inman and M. Frisbee, "Critical Engagement of Teachers in Second Life: Progress in the SaLamander Project"," in Proceedings of the Second Life Education Workshop 2007, 2007.

[13] M. D. Dickey, "Three-Dimensional Virtual Worlds and Distance Learning: Two Case Studies of Active Worlds as a Medium for Distance Education," British Journal of Educational Technology, vol. 36, p. 439–451, 2005. http://dx.doi.org/10.1111/j.1467-8535.2005.00477.x

[14] S. A. Barab, K. A. Hay, K. Squire, K. Barnett, R. Schmidt, K. Karrigan, L. Yamagata-Lynch and C. Johnson, "Virtual Solar System Project: Learning Through a Technology-Rich, Inquiry-Based, Participatory Learning Environment," Journal of Science Education and Technology, vol. 9, pp. 7-25, 2000. http://dx.doi.org/10.1023/A:1009416822783

[15] L. Graves, "A Second Life for Higher Ed," US News & World Report 14(2), pp. 49-50, 2008.

[16] S. Warburton, "Second Life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching," British Journal of Educational Technology, vol. 40, no. 3, pp. 414-426, 2009. http://dx.doi.org/10.1111/j.1467-8535.2009.00952.x

[17] C. Inman, V. H. Wright and J. A. Hartman, "Use of Second Life in K-12 and Higher Education: A Review of Research," Journal of Interactive Online Learning, vol. 9, p. 44.

[18] E. Palomäki, O. Natri, P. Joensuu, M. Närhi, E. Kähkönen, R. Jokela, M. Hemminki, P. Korpelainen, J. Vepsäläinen and K. Nordström, "LabLife3D: Teaching biotechnology and chemistry to engineering students by using Second Life," in Joint International IGIP-SEFI Annual Conference 2010 19th–22nd September 2010, Trnava, Slovakia, 2010.

[19] E. Palomäki, P. Qvist, O. Natri, P. Joensuu, M. Närhi, E. Kähkönen, R. Jokela, M. Hemminki, P. Korpelainen, J. Vepsäläinen and K. Nordström, "LablLife3D: Teaching Biotechnology and Chemistry to Engineering Students by Using Second Life," in Proceedings of the 4th International Network-Based Education 2011 Conference, Rovaniemi, 2011.

[20] K. Nordström, P. Qvist, E. Palomäki, O. Natri, P. Joensuu, M. Närhi, E. Kähkönen, R. Jokela, M. Hemminki, P. Korpelainen and J. Vepsäläinen, "LabLife3D: A new Concept for Learning and Teaching Biotechnology and Chemistry in the 21st Century," in Aalto University Reflektori 2010, Symposium of Engineering Education, December 9-10, 2010, Espoo, 2010.

[21] T. Kangasniemi, "A new environment for chemical education: The decarboxylation reactions of fatty acids and experimenting with them in a 3D virtual laboratory built in Second Life," Espoo, 2012.

[22] S. Olkinuora, "Design of a Molecular Biology Laboratory in Second Life," Espoo, 2012.

[23] F. Arango, C. Chang, S. K. Esche and C. Chassapis, "A Scenario for Collaborative Learning in Virtual Engineering Laboratories," in 37th ASEE/IEEE Frontiers in Education Conference, Milwaukee, 2007. http://dx.doi.org/10.1109/fie.2007.4417818

[24] C. Quinn, "Soapbox: Making Learning Fun," 18 August 2005. [Online]. Available: http://www.gamasutra.com/view/feature/2375/soapbox_making_learning_fun.php. [Accessed 10 8 2015].

[25] T. A. Mikropoulos and A. Natsis, "Educational virtual environments: A ten-year review of empirical research (1999–2009)," Computers & Education, vol. 56, pp. 769-780, 2010. http://dx.doi.org/10.1016/j.compedu.2010.10.020

[26] N. Strangman, T. Hall and A. Meyer, "Virtual Reality and Computer Simulations and the Implications for UDL Implementation: Curriculum Enhancement Report," 2003.

[27] J. Josephsen and A. K. Kristensen, "Simulation of laboratory assignments to support students' learning of introductory inorganic chemistry," Chemistry Education Research and Practice, vol. 7, pp. 266-279, 2006. http://dx.doi.org/10.1039/B6RP90013E

[28] S. Cobb, R. Heaney, O. Corcoran and S. Henderson-Begg, "The Learning Gains and Student Perceptions of a Second Life Virtual Lab," Bioscience Education, vol. 13, 2009.

[29] J. Nielsen, "Heuristic Evaluation," in Usability Inspection Methods, Usability Inspection Methods ed., J. Nielsen and R. L. Mack, Eds., New York, John Wiley & Sons, 1994.

[30] J. Nielsen, "10 Usability Heuristics for User Interface Design," January 1995. [Online]. Available: http://www.nngroup.com/articles/ten-usability-heuristics/. [Accessed 10 8 2015].

[31] P. Sampola, "The development of the user-centric usability evaluation method adapted to the evaluation of Virtual Learning Environments [title from abstract in English; text is in Finnish]," Vaasa, 2008.

[32] J. Nielsen, Usability Engineering, Boston: Academic Press, 1993.

[33] S. Palomäki, "Using student-produced data trails for evaluating and enhancing learning in virtual worlds," Espoo, 2014.

[34] T. Kangasniemi, S. Olkinuora, P. Joensuu, O. Natri, P. Qvist, M. Ketola, M. Närhi, R. Jokela, E. Palomäki, H. Tiitu and K. Nordström, "Designing Virtual Laboratories: Decarboxylation Reactions, Vacuum Distillation and Virus Identification by PCR in the LabLife3D Second Life Laboratory," in CSEDU 2013 - Proceedings of the 5th International Conference on Computer Supported Education, Aachen, Germany, 6-8 May, 2013, 2013.

[35] J. Brusin, "Improving the Second Life learning Environment: Biorefinery 3D (in Finnish)," Espoo, 2013.

[36] H. Virtanen, "Digital learning spaces: Supporting education with Second Life virtual world (in Finnish)," Espoo, 2013.

[37] G. Siemens and P. Long, "Penetrating the Fog: Analytics in Learning and Education," Educause review, vol. 46, no. 5, pp. 30-32, 2011.

[38] K. Nordström, P. Qvist, T. Kangasniemi, S. Palomäki, S. Olkinuora, M. Närhi, O. Natri, J. Seppänen, P. Artimo and P. Joensuu, "Multidisciplinary Learning Affordances of a Science-Based Virtual World," in Society for Engineering Education (SEFI) 42nd Annual Conference, Birmingham, UK, 15.-19.9.2014, 2014.

[39] S. de Freitas, G. Rebolledo-Mendez, F. Liarokapis, G. Magoulas and A. Poulavassilis, "Developing an evaluation methodology for immersive learning experiences in a virtual world," in 2009 International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES 2009), 2009. http://dx.doi.org/10.1109/VS-GAMES.2009.41

[40] Y. Malhotra and D. F. Galletta, "Extending the Technology Acceptance Model to Account for Social Influence: Theoretical Basis and Empirical Validation," in Proceedings of the 32nd Hawaii International Conference on System Sciences - 1999, 1999. http://dx.doi.org/10.1109/hicss.1999.772658

[41] V. Venkatesh, M. G. Morris, G. B. Davis and F. D. Davis, "User Acceptance of Information Technology: Toward a Unified View," MIS Quarterly, vol. 27, no. 3, pp. 425-478, 2003.

[42] L. Helmer, "Second Life and Virtual Worlds," 2007.

[43] J. Biggs, "What the student does for enhanced learning," Higher Education Research and Development, vol. 18, pp. 57-75, 1999. http://dx.doi.org/10.1080/0729436990180105

[44] A. Kolmos, X. Du, J. Holgaard and L. P. Jensen, Facilitation in a PBL environment, Aalborg: Aalborg University.

[45] E. Palomäki and E. Nordbäck, Bringing Playfulness and Engagement to Language Training Using Virtual Worlds: Student Experiences, Results, and Best Practices from a Virtual Language Course, Prague, Czech Republic, 2012.

[46] J. Gibson, The Ecological Approach to Visual Perception, Boston: Houghton-Mifflin, 1979.

[47] E. Rosenbaum, E. Klopfer and J. Perry, "On Location Learning: Authentic Applied Science with Networked Augmented Realities," Journal of Science Education and Technology, vol. 16, no. 1, pp. 31-45, 2007. http://dx.doi.org/10.1007/s10956-006-9036-0

[48] F. Wang and M. J. Hannafin, "Design-based research and technology-enhanced learning environments," Educational Technology Research & Development, vol. 53, no. 4, pp. 5-23, 2005. http://dx.doi.org/10.1007/BF02504682

[49] T. Reeves, "Design research from a technology perspective," in Educational design research, Routledge, New York, 2006.

AUTHORS

Pekka Qvist is with the Department of Biotechnology and Chemical Technology, Aalto University School of Chemical Technology, Kemistintie 1, 02150 Espoo, Finland (e-mail: pekka.qvist@ aalto.fi).

Tuomas Kangasniemi was with the Department of Chemistry, Aalto University School of Chemical Technology, Kemistintie 1, 02150 Espoo, Finland (e-mail: tuomas.kangasniemi@ aalto.fi).

Sonja Palomäki was with the Department of Industrial Engineering and Management, Aalto University School of Science, Otaniementie 17, 02150 Espoo, Finland (e-mail: sonja.palomaki@ aalto.fi).

Jenni Seppänen is with the Department of Teacher Education, University of Helsinki, PO Box 9, 00014 Helsinki, Finland. (email: jennisep@ mappi.helsinki.fi).

Pekka Joensuu is with the Department of Chemistry, Aalto University School of Chemical Technology, Kemistintie 1, 02150 Espoo, Finland (e-mail: pekka.joensuu@ aalto.fi).

Olli Natri is with the Department of Biotechnology and Chemical Technology, Aalto University School of Chemical Technology, Kemistintie 1, 02150 Espoo, Finland (e-mail: olli.natri@ aalto.fi).

Marko Närhi is with the Department of Biotechnology and Chemical Technology, Aalto University School of Chemical Technology, Kemistintie 1, 02150 Espoo, Finland (e-mail: marko.narhi@ aalto.fi).

Eero Palomäki is with the Department of Industrial Engineering and Management, Aalto University School of Science, Otaniementie 17, 02150 Espoo, Finland (e-mail: eero.palomaki@ aalto.fi).

Hannu Tiitu is with the Department of Mathematics and Systems Analysis, Aalto University School of Science, Otakaari 1, 02150 Espoo, Finland (e-mail: hannu.tiitu@ aalto.fi).

Katrina Nordström is with the Department of Biotechnology and Chemical Technology, Aalto University School of Chemical Technology, Kemistintie 1, 02150 Espoo, Finland (e-mail: katrina.nordstrom@ aalto.fi).

This study has been supported by a grant from the Technology Industries of Finland Centennial Foundation. This article is an extended and modified version of a paper presented at the 5th International Conference on Computer Supported Education (CSEDU 2013), 6-8 May 2013, Aachen, Germany.Submitted, 11 August 2015. Published as resubmitted by the authors on 11 August 2015.