Designing Virtual Laboratories

Decarboxylation Reactions, Vacuum Distillation and Virus Identification by PCR in the Lablife3D Second Life Laboratory

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Abstract: Practical skills are one of the core competencies in technology, engineering and the natural sciences. However, the busy curriculum in many universities lacks space and time for the learning-by-doing experience to mature. Therefore, we have designed and implemented a virtual laboratory, LabLife3D, to Second Life, to bridge the gap between theory and practice. To date, we have designed five virtual laboratory exercises in the biological sciences and chemistry there: a virus isolation experiment, a laboratory safety tutorial, organic chemistry simulations on (a) decarboxylation reactions and (b) vacuum distillation, and a molecular biology simulation on identifying a virus with polymerase chain reaction (PCR). This paper presents their design process and outlines their contents. General design objectives in virtual laboratories are also discussed, along with laboratory simulations in Second Life by other groups. All the exercises have been designed in accordance with content-specific learning goals and outcomes, which are discussed. In addition to creation of contents, we have also recently studied the usability of our simulations and conducted a student assessment. Preliminary results of the student assessment are presented.

1 MOTIVATION

Three-dimensional (3D) virtual worlds represent recent developments in information technology and they will undoubtedly become significant learning spaces for future student generations, the so-called “Millennials” or “Digital Natives”. Evidently, though, virtual worlds have not gained as much attention in university education as have other professional computer applications, the social media or user-generated encyclopaedias. Moreover, 3D worlds are often not recognized as a specific entity. Rather, they are often referred to as only a part of e-learning, which has caused some of the interest in the more exciting applications of 3D virtual worlds to stagnate.

3D virtual worlds and other virtual learning spaces are best understood as an alternative, not a replacement, to face-to-face communication and traditional teaching methods. They have many significant advantages compared to solely real-life learning spaces, some of which include the following:

1. Virtual worlds are extremely flexible, allowing

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buildings and equipment to be placed, modified, expanded, and moved as needed.

2. Virtual worlds can be accessed at any time, and without real-life risks such as biological or chemical hazards.
3. Virtual worlds have low cost of operation and no cost at all for failed experiments. Furthermore, they allow repeating and rerunning the exercises, an important part of learning, for free.

Consequently, thousands of educators are currently exploring and using virtual worlds, of which Second Life has received most attention. Hundreds of colleges and universities, including Aalto University, have purchased and developed their own private islands in Second Life. It is a multi-user virtual environment developed by Linden Lab, mimicking real-life situations, with users represented by 3D characters called avatars.

2 BACKGROUND

2.1 General Advantages and Dis-advantages of Virtual Worlds in Education

The advantages and disadvantages of virtual worlds as means of education have been explored over a couple of decades. The most noteworthy advantages of virtual worlds in general, and of Second Life in particular, are listed above, namely flexibility of construction, freedom from real-life hazards, and low cost of operation and repeated exercises (e.g. Eschenbrenner et al., 2008; Holmberg and Huvila 2008; Palomäki, 2009). Information technology also helps adjusting the teacher to student ratio (Daniel, 2008), albeit this benefit is not exclusive to virtual worlds. Furthermore, virtual worlds have been proven to promote engaged learning, as discussed below.

Some of the disadvantages mentioned include the time needed to learn the use of the virtual world, high cost of 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 (e.g. Warburton, 2009; Palomäki, 2009; Inman et al., 2010). Moreover, according to Warburton, Second Life may be an isolating experience, since other users are not as easily found as in e.g. Facebook. In many ways this is an unfortunate truth, as at almost any moment of time, in almost any of its educational milieus, Second Life is empty; there is nobody around. The feeling of an eerie silence can easily discourage a newcomer.

2.2 Engaged Learning Promoted by Virtual Worlds

Engaged learning can be defined as commitment to a significant, in-depth, lifelong learning process, which extends beyond the classroom. Engaged learning is an integral part of all learning tools, verbal, digital, visual or emotional, which are used to increase personal and group commitment, regardless of prior success or talent thereof. Students learn in an environment that favours activity and experience and fosters immediate engagement (Biggs, 1999).

Virtual worlds in education have been shown to lead to increased engagement (Palomäki 2009). Brain activity has also been measured for tasks performed in real as well as in virtual reality environments (Mikropoulos, 2001). 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 (Mason, 2007). Immersion into another world has also been noted and engaging in learning in the first person, which is more interactive and experiential (Richter et al., 2007). Moreover, previous studies have shown that as learners are allowed to interact with information in the first person, this facilitates constructivist-based learning activities (Dickey, 2005).

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 environments 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 (Barab et al., 2000). 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" (Graves, 2008).

2.3 Lablife3D: The Second Life Project of Aalto University

Practical skills are one of the core competencies in technology, engineering and the natural sciences. However, current laboratory courses are burdened by heavy expenses for modern and safe equipment and reagents, large course sizes and even waiting lists to the courses. Although learning-by-doing is the ultimate goal of practical laboratory classes and hands-on experimentation, the curriculum of many higher education institutions lacks space and time for the learning experience to mature. Many students pass classes with only superficial learning without developing deep learning where theory connects with practice. Accordingly, we have designed and implemented a virtual laboratory, LabLife3D, to bridge the gap between theory and practice. This is a pioneering project in the use of Second Life in the Finnish University setting. LabLife3D is housed in the Aalto Archipelago in Second Life virtual world. For more, see the home page of our project at https://sites.google.com/site/lablife3d/

To date, we have designed five laboratory “practicals” (Table 1). The virtual laboratory building, LabLife3D, was completed in late 2010, along with the first two exercises: a virus isolation simulation and an organic chemistry laboratory safety tutorial. The details of this development process, along with general considerations such as building the LabLife3D team, have been presented previously (Palomäki et al., 2010; Palomäki et al. 2011; Nordström et al., 2010). Later in 2011 and 2012, two further laboratory simulations were designed (Kangasniemi, 2012; Olkinuora, 2012). In addition, the design of a fifth practical, an organic chemistry simulation, has been completed, although its implementation has only recently begun. Similar to traditional laboratory classes, all the virtual exercises have been designed in accordance with learning goals and outcomes as described below. Besides creation of contents, we have also recently studied the pedagogical aspects of Second Life, namely with reference to the role of the teacher as a facilitator of group work and the responses of students to different ways of teacher facilitation.

Currently, in addition to the use of the simulations in microbiology and organic chemistry courses, the LabLife3D team is also collaborating with language teachers at Aalto University. The virtual laboratory is used as a teaching and learning platform for Swedish terminology of biotechnology and chemistry, helping the students in the challenge that multiple languages pose to them (Palomäki and Nordbäck 2012), as Swedish is the 2nd official language in Finland, and a compulsory language requirement in all university degrees.

2.4 The Other Existing Science-related Learning Environments in Second Life

Although Second Life has received considerable interest as a medium for academic education, relatively few of the numerous learning environments can be considered to represent actual simulations. Most of these settings mediate information only via passive elements, such as static 3D objects, 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. These passive settings may be called 1st generation SL learning environments.

The simulation-type environments, or 2nd generation environments, can be readily classified in two distinct categories: ready-to-use simulations and teacher-initialized ones. As the name suggests, the teacher-initialized simulations are not executable to anyone at any time, but they can be participated only at scheduled times. They are most common in

Table 1: The laboratory exercises within LabLife3D.

	Theme	Status	References
1	Virus isolation	Operational from Dec 2010	Palomäki et al. 2010; Palomäki 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	Vacuum distillation	Design ready, implementing	- -

(*) RT-PCR = Reverse transcriptase polymerase chain reaction 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 seems more typical to the laboratory simulations of natural sciences such as chemistry and biology. (Kangasniemi, 2012).

While constructing the Aalto University Second Life exercises we have been able to visit other Second Life laboratory simulations (Table 2). Many of the existing settings have allowed us to learn and experiment further in our own development activities.

2.5 General Design Objectives in Virtual Laboratories

Clearly, 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 (2007) and Quinn (2005) have been summarized by Olkinuora (2012) 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.

This list can be extended with avoiding cognitive overload, and the possibility of making actual errors without triggering an immediate response, in addition to the possibility of mere alternatives. Some of the above named properties are clearly complementary and can be implemented at the same time. On the other hand, others may partly contradict each other, as it is with exploratory potential and adequate randomness versus the need for no futile actions. Thus, 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 (for review, see Mikropoulos and Natsis 2010, and Strangman et al., 2003). Although some of the studies relate to simulated laboratories (e.g. the 2D laboratory of Josephsen and Kristensen 2006), only very few of them refer specifically to virtual laboratories in Second Life.

The exception are The exception are Cobb, Heaney, Corcoran and Henderson-Begg (2009) 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

Table 2: 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.

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.

3 CONSTRUCTING THE AALTO UNIVERSITY LABORATORY SIMULATIONS

3.1 Desired Learning Outcomes of the Original Lablife3d Platform

When we first began to explore Second Life as a tool for teaching and learning biotechnology and chemistry, we focused on creating the actual space, the virtual building, LabLife3D. The primary learning outcomes that we wished to achieve all emphasized the promotion of deep learning via connecting scientific theory with practice. As a result of our earlier work, we created a microbiology exercise which allows the user to become familiar with working with viruses at a general level (Table 1). In addition, students could become familiar with the specific requirements for working in a clean room in addition to specialized culture techniques needed to grow viruses, which we are not able to carry out in a normal student laboratory.

Moreover, the focus of the original chemistry laboratory was on laboratory safety, which students could familiarize themselves with before the real-life practical class. In this setting, students learn to take into account sufficient number of safety features; protective clothing, correct cleaning of chemical spills etc.

More recently, however, we have become aware of a need to develop further our 3D experiments. Namely, it has been our objective to expand the experiments to better mimic the kinds of 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. Accordingly, we have designed a complete chemistry experiment on decarboxylation reactions (section 3.2) and a vacuum distillation experiment (section 3.3). In addition, in our first efforts to create experiments into Second Life, the microbiology practical on virus isolation was very focused on creating the appropriate laboratory spaces and becoming familiar with design of 3D worlds. It did, however, not offer a complete practical laboratory experiment. Consequently, we have recently added an experimental scenario, a molecular biology experiment, to our original virus exercise, as described in more detail below (section 3.4).

3.2 The Organic Chemistry Simulation on Decarboxylation Reactions

3.2.1 Learning Objectives, Content and Functions

Unlike the microbiology simulation and the laboratory safety tutorial built previously, the organic chemistry simulation (Kangasniemi, 2012) is not a strict laboratory practice exercise. Instead, it mimics experimental research at a more general level, 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 simulation 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).

3.2.2 Design Objectives and Process

During the design process, there were four matters of special concern. First, it was important that the simulation should not be too straightforward to pass: instead of being a demonstration, it should include alternative outcomes or the possibility of making true 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 fruitful for the student to change the parameters without really thinking about the consequences.

Second, we analyzed the features of scenarios created by other groups (Table 2). From the usability point of view, the most important observation concerned the user interface in general. All the

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

existing simulations require the use of the technical elements of Second Life, such as notecards, inventory, chat and the multiple choice popup windows. Some simulations rely on them heavily. However, in our experience, these elements frequently confuse the beginner. Therefore, it appears that 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.

Other very useful examples were 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 hardest 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. Finally, we decided to add the element of random experimental variation (1 to 5 %-points) to all measurements the student makes in the simulation.

3.3 The Organic Chemistry Simulation on Vacuum Distillation

3.3.1 Learning Objectives, Content and Functions

At the present time work is on-going on modelling a vacuum distillation in a laboratory setting. In contrast to the previous organic chemistry simulation (section 3.2), the newer one mimics the hands-on actions and operations in the laboratory very closely.

Vacuum distillation was chosen as the topic of the simulation for a three main reasons. First, vacuum distillation is an actual exercise taught at Aalto University organic chemistry laboratory courses. Moreover, building and operating the system in real life is quite a complicated task for the first-timer, involving even slight risks such as water spills and broken distillation pieces (expensive). Therefore, learning the process first with a detailed 3D simulation should offer substantial help. Finally, there is a possibility of making a wide range of mistakes in the simulation, giving a sense of realism.

The simulation is divided into three phases. First, the glass apparatus is assembled by clicking on the pieces on the table. In the next phase, the student connects the hoses for cooling water and suction. Here, all possible flawed connections are possible without triggering an immediate notice, but the configuration is checked by requiring the student to turn on the cooling water before proceeding. Almost all errors lead to water spill and reset. The final phase, heating and distilling, happens within a dimension of time. In this phase, a number of switches are operable: the heating plate, the pump and its valves, the 3-way joint, and the manometer valve. If the system is correctly assembled, boiling will commence once the oil bath is hot enough. The simulation will end after enough distillate has been collected.

3.3.2 Design Objectives and Process

The design objective was to make the simulation as realistic as reasonable and possible, with maximum freedom to control the switches in real time and in a free order. However, some compromises had to be made in order to limit the array of erroneous alternatives. Checking the hose connections by requiring the cooling water to be turned on first was one such limitation, fitting well to the storyline of the exercise. The level of modelling the physical state of the distillation system was also constrained to a certain extent. Temperature and time are modelled in a continuous manner, with the time-profiles of temperature being based on real measurements. However, pressure and the rate of collecting the distillate are modelled simply as on/off variables.

During the design process, it was found that pseudocode, comprising of `if`, `else` and `while` clauses, was a convenient way to express some critical parts of the simulation to the programmers. The basic setup was described in natural language, though. To familiarize themselves with the topic, the programmers also followed and recorded a real-life vacuum distillation exercise.

3.4 The Molecular Biology Simulation on Identifying a Virus with Reverse Transcriptase PCR

3.4.1 Learning Objectives, Content and Functions

The primary learning outcome of the molecular biology simulation (Olkinuora, 2012) 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 from a host cell culture (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 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.

3.4.2 Design Objectives and Process

The objectives in designing the user interface and the general structure of the molecular biology simulation were similar to those of the decarboxylation experiment (section 3.2), although the content and the desired learning outcomes were different. That is, the simulation is not too simple to

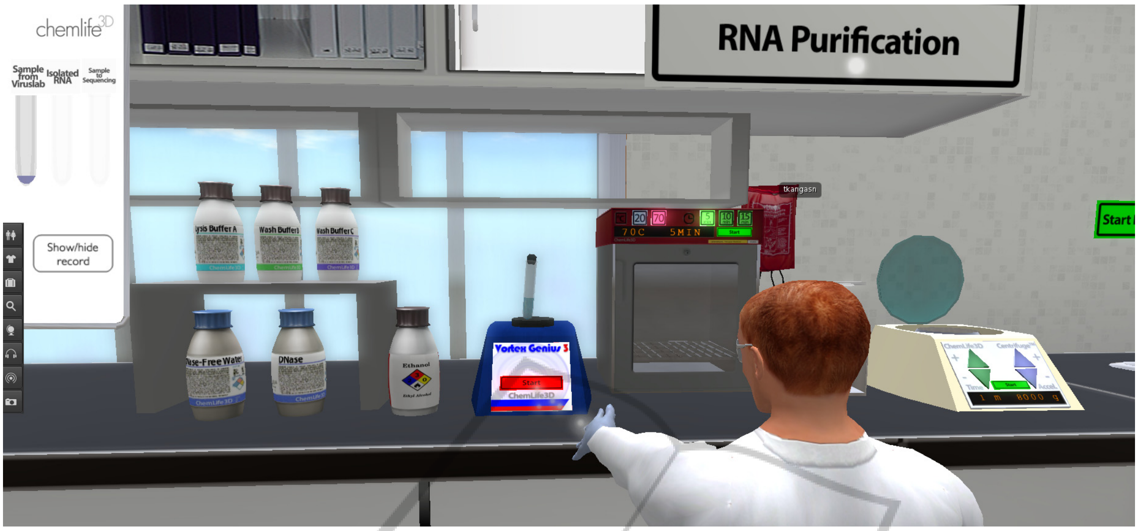

Figure 2: Screenshot: The molecular biology simulation. HUD window on the upper left.

pass, its active elements are embedded to the 3D space if possible, it uses real data, and adds random experimental variation. In addition, as already noted, there is a possibility of making real 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.

4 USER INTERFACE TESTING: TECHNICAL AND PEDAGOGICAL VIEWPOINTS

4.1 Usability Testing: Heuristic User Interface Evaluation

As part of our aims to develop sophisticated laboratory experiments in Second Life, a formal usability test was conducted on the user interface of the organic chemistry experiment (section 3.2) in addition to normal troubleshooting. The test was designed and conducted by personnel not otherwise involved with the simulation (Tiitu, unpublished).

The test method used was the heuristic evaluation (Nielsen, 1994). 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. Three evaluators completed the test, all of them having little prior experience with Second Life. The test was performed in two separate sessions about two and half hours each. The evaluators began with getting familiar with SL, followed by performing the experiment individually and making notes on the usability issues. Finally a subjective assessment was given on the severity of the problems found. An instructor not contributing to the evaluation was present.

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: (1) technical and (2) pedagogical usability. In the following, the emphasis is on the 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 (2005) heuristics for evaluating specifically e-learning environments (Sampola, 2008).

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?
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 (Nielsen, 1993).

4.2 Preliminary Results of Student Assessment

Both the organic chemistry experiment on decarboxylation (section 3.2) and the molecular biology experiment (section 3.4) were assessed as course exercises by groups of 1st to 3rd year engineering students, who filled in anonymous feedback forms. However, at this time, analysis of the data is on-going and a preliminary summary is presented below.

Each exercise session was facilitated by a teacher with background in the core subject and experience in using Second Life. The feedback forms were designed by personnel other than the teachers and SL designers as part of two on-going M.Sc. theses (Brusin and Virtanen). The same individuals also monitored the teacher–student interactions in each group. At this time, no comparative studies between the test groups and a control group were carried out.

Organic chemistry exercises were performed in four groups (two simultaneous groups at two times). A marked difference was noted between the two 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. They also felt actually having learned something new and said that they understood the scientific objectives. However, the students stated that it was possible to pass the simulation without really thinking much (Table 3).

On the contrary, the Friday groups (N = 16) were much more critical. About half of the students reported they were not interested at all in the exercise, did not grasp its purpose and felt they did not learn anything. Moreover, unlike the previous group, they admitted actually exploiting the possibility to pass the task mechanically without thought (Table 3). The notes made by the observers support these differences. The fact that the Monday group had better IT skills and more prior experience with virtual worlds should explain some of these differences. In addition, the Monday group was, on average, more advanced in their studies. In student life, the day of the week (Monday vs. Friday) may have a role to play, too!

Overall, 97 % of the students replied that the most convenient way to interact with the teacher was face-to-face discussion, instead via their avatar.

In contrast to the rather mixed feedback from the organic chemistry exercise, the student response from the molecular biology exercise was unanimously positive, even though the students were no more familiar with virtual worlds. An updated version of the feedback questionnaire was used, though. The exercise was conducted in two simultaneous groups of 10 students each as part of a 2nd year microbiology course. The students reported they had clearly understood the assignment and also most of the actions taken during exercise. A majority thought having learned something new, albeit not very much. The level of scientific challenge was considered appropriate (Table 4).

Table 3: 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 (negative / none / positive)	8%	54%	38%	6%	69%	25%

Table 4: 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%

It therefore appears that the molecular biology simulation was either better designed from the pedagogical point of view, or better connected to the course contents than the organic chemistry simulation was – or both. The scientific content of the latter may have been too difficult, and the structure of the simulation too straightforward.

However, the difference may not be entirely due to the content of the simulations themselves. Although both exercises were voluntary, giving extra points to the exam, the inclusion of the molecular biology exercise was announced at the very beginning of the course, with an essay as an alternative. For the organic chemistry course, the SL exercise was just an extra. The former setup may have helped the students take the exercise more seriously, as part of the learning outcomes of the whole course, instead of thinking it just as means of collecting a point to the exam.

4.3 Evaluation of the Teacher's Role

We are also currently studying the role of the teacher as a facilitator of student learning in Second Life. Notably, to our knowledge, there are no previous systematic studies on what the role of the teacher should be. We are therefore in the process of elucidating if teacher roles as facilitators differ from roles that have been studied in context of problem based learning (Kolmos et al., 2008).

Our preliminary observations suggest that the role of the teacher as a facilitator for a Second Life experiment may not as be as important as e.g. the design of the virtual exercise and student motivation. In the molecular biology exercise, students responded quite similarly in both groups, even though the teachers had a distinctly different style, the other instructing in a more active and authoritarian manner, and the other leaving much more time for independent work. In the organic chemistry exercise, the teachers' styles did not differ much from each other, and thus no significant comparison could be made.

5 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. (2003), content area knowledge and conceptual change could be expected to be an outcome of the virtual world experiments that we have designed.

Contrary to Helmer (2007), who argues that too much similarity with the real world might be seen as distracting and disadvantageous for learning, we feel that a high degree of photographic realism adds to student motivation to use virtual tools for learning. Our experience with students suggests that sufficient freedom of operation is probably very important, too. A simulation too straightforward to pass does not provoke the necessity to think one's actions.

As stated by Josephsen and Kristensen (2006), 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. 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.

Furthermore, the experiments should have a clearly defined goal and the goal should link theory to practice and to scientific research methodology. Our experience implies, too, that the exercises should be clearly tied to a context, meaning not only a connection to the theoretical course matter but also having a sensible function as a part of the course.

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