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LABLIFE3D – A SCIENCE- BASED 3D VIRTUAL LEARNING ENVIRONMENT

Designing virtual laboratories: From pedagogical
design to learning analytics



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Designing virtual laboratories: From pedagogical design to learning analytics

The digital native generation has been growing up in a world of virtual environments, digital games, social media and mobile internet. This generation is used to different forms of communication and has adapted itself to using various kinds of virtual environments since very young age.

LabLife3D is a virtual learning environment designed for the communication habits of the digital natives to answer their educational demands in the future. The objective of this study is to identify the affordances of this virtual learning environment and to recognize its barriers and enablers to learning. The study also aims to explore how the students can receive support and feedback for authentic learning from the teacher or the virtual learning environment.

During the project, a 3-dimensional virtual learning environment was developed in a virtual world (Second Life). This virtual microbiology and organic chemistry laboratory facilitates several learning activities and is also equipped with a data gathering system for research purposes using big data in learning analytics. Several motivators were identified during the project for choosing a virtual world as a learning platform, including opportunities for learning-by-doing and experiential learning.

This study also documents the requirements for the design team and software architecture, as well as provides insight into improving the learning environment based on user feedback and usability studies.

Feedback was gathered from several groups of students and a group of teachers together with automatically recorded data from the learning environment. The results suggest that virtual laboratory enables authentic learning, but that it can also create technical barriers to learning. Technology rejection can for example hinder acceptance of new digital learning methods, especially for teachers.

This study concludes that virtual environments of one or another form will become more significant for learning and education in the future.

KEYWORDS:

education, virtual world, virtual learning environment, learning analytics, big data, second life

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LABLIFE3D – VIRTUAALINEN KOLMIULOTTEINEN LUONNONTIETEIDEN OPPIMISYMPÄRISTÖ

Virtuaalilaboratorioiden suunnittelu: Pedagogisesta suunnittelusta oppimisen analytiikkaan

Diginatiivien sukupolvi on kasvanut maailmassa, jossa virtuaaliset ympäristöt, digitaaliset pelit, sosiaalinen media ja mobiili internet ovat arkipäivää. Nettisukupolvi on tottunut käyttämään monia erilaisia viestintämuotoja ja sopeutunut toimimaan erilaisissa virtuaalisissa ympäristöissä jo varhaislapsuudesta alkaen.

LabLife3D-projektin avainkysymys oli, millaisia oppimisympäristöjä kasvava sukupolvi tarvitsee tulevaisuuden opinnoissaan. Tutkimusprojektin tavoitteena oli selvittää, kuinka affordanssit oppimiselle voidaan tunnistaa, mitkä ovat oppimisen esteitä ja mahdollistajia virtuaalisessa ympäristössä ja miten oppija saa autenttiselle oppimiselle tukea joko opettajilta tai virtuaaliselta ympäristöltä.

Projektin aikana kehitettiin kolmiulotteinen oppimisympäristö virtuaalimaailmaan (Second Life). Virtuaalisessa mikrobiologian ja orgaanisen kemian laboratoriossa on mahdollista suorittaa useita erilaisia oppimistehtäviä. Ympäristö sisältää myös tiedonkeruujärjestelmän oppimisanalytiikan ja big datan tutkimusta varten. Tutkimuksessa tunnistettiin useita virtuaalimaailmojen opetuskäyttöä puoltavia seikkoja, kuten mahdollisuudet tekemällä oppimiseen ja kokemuseräiseen oppimiseen.

Tutkimus myös dokumentoi vaatimukset monialaiselle suunnittelutiimille ja ohjelmistoarkkitehtuurille sekä tarjoaa tietoa oppimisympäristön kehittämisestä käyttäjäpalautteen ja käytettävyytutkimuksien pohjalta.

Palautetta kerättiin useilta opiskelijaryhmiltä, opettajistolta ja automaattisen tiedonkeruujärjestelmän tallenteista. Tutkimuksen tulokset osoittavat, että autenttista oppimista tapahtuu virtuaalilaboratoriossa, mutta että teknologia voi olla esteenä oppimiselle. Lisäksi teknologian vastustus voi haitata uusien digitaalisten oppimismenetelmien käyttöönottoa ja hyväksyntää etenkin opettajien keskuudessa.

Tuloksista voidaan kuitenkin päätellä, että virtuaaliset ympäristöt muodossa tai toisessa tulevat olemaan yhä merkittävämpi osa oppimista ja koulutusta tulevaisuudessa.

ASIASANAT:

opetus, virtuaalimaailma, virtuaalinen oppimisympäristö, oppimisanalytiikka, big data, second life

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This bachelor's thesis is about a long research and development project LabLife3D and the continuum of subsequent projects ChemLife3D, BioRefinery3D and BioFactory3D (for the sake of ease of reading in the scope of this thesis LabLife3D is used as an umbrella term to cover all these different phases of the project) that I had the privilege to participate in from 2010 to 2014.

Phases of the project had funding from Technology Industries of Finland Centennial Foundation and Aalto University School of Chemical Technology. The funding had an important role to help the project materialize (or in this case perhaps virtualize) and allowed me to work with cutting edge virtual learning environment production together with the most amazing team.

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My father pioneered in bringing computers into education in Finnish schools since the era of the first microcomputers. What this thesis describes could be seen as a continuation of his work.

Thank you all.

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1 INTRODUCTION

The terms net generation or digital natives refer to the generations born after the millennials, in the era of the internet as a communications technology being an everyday mainstream medium (Jones & Shao, 2011). The generation born in the 1990s and 2000s have been growing in a world, where not only world wide web or email are the cornerstones of electronic communication, but where the continuous streams of social media reach them everywhere, on smartphones and tablets. For the young people of net generation even textual communication is becoming more and more “antique”, with the emergence of phenomena such as instant image sharing services, video blogging or vlogging, and digital games.

The digital natives have not only been growing in the world of new era of communication, but many of them have been living in a world where interaction takes new forms and places, in virtual environments, digital games and virtual worlds. The weltanschauung of the net generation does not only include our tangible world, but virtual worlds and digital games can form a persistent collective online shared space that can literally become the virtual reality, where shared virtual spaces also facilitate shared experiences, shared memories, shared emotions and shared cognitive events. In many cases the digital natives do not make a distinction between “real” and “virtual” environments, but for them the digital world is a continuum and expansion of the tangible world.

According to a research conducted in 2008, 99% of boys under 18 and 94% of girls under 18 in the USA reported playing videogames regularly (Lenhart, et al., 2008). The magnitude of the phenomenon is not always understood by the older generations, who are not familiar with digital games or virtual environments. As the digital natives have been growing up in a world of digital environments, the important question is, what kind of learning environments will they demand for their studies in the future (Hyötynen, 2012).

The different means and practices of communication between different generations create the need to better understand the world where the digital

natives have been growing up. The educational world is focused on trying to provide the best means of knowledge transfer, but in many cases the technology used to communicate the knowledge can be decades or centuries old. The need of a paradigm shift in education rises from the problem that the attempts to communicate with the digital native generation by using the technology of the earlier generations, and at worst cases even banning the use of modern digital technology, leads in many cases to sub-par results. The success of the paradigm shift depends on truly understanding how the digital native generation communicates, and creating environments that foster the natural flow of communication and interaction.

Virtual worlds have been an emerging technology for learning for the past decade, with the apex of the hype dating back to 2008 – 2010. The interest towards educational solutions of virtual worlds has since diminished, for a variety of reasons. Many learning environments in virtual worlds have suffered from poor production values. They have been described to have very limited or non-existent possibilities for interaction, and mostly providing information as static 3D-images, text or videos (Kangasniemi, 2012). The low fidelity of the user experience has in many cases been the primary reason to shatter the first impression, and it can be difficult to steer an individual to see all the benefits of a given technology if they have made their mind based on this first impression.

Nevertheless, there has been an ongoing discussion about the cognitive process of learning, especially learning-by-doing and experiential learning, which has involved the argument that regardless the learning material, the comprehension of instructions takes place through perceptual simulations of the action. Abstract learning materials, such as written text become meaningful with a mental simulation of the process. By using digital learning technology such as virtual worlds, games or simulations, it is possible to aid the natural cognitive process by allowing the learner to experience the action before studying the abstract theory behind the process or action. (Gee, 2012)

2 HISTORY AND BACKGROUND OF VIRTUAL WORLDS

There is an abundance of literature about definitions of virtual worlds, as well as documents of inner workings of virtual worlds for the purpose of content creation. Furthermore there is a plentitude of research available on applications of virtual worlds in education. In the scope of this thesis, the history, background and inner workings of virtual worlds will be discussed only briefly while providing references to relevant comprehensive sources.

2.1 History and definitions

Some starting points for the human intrigue towards virtual worlds which could be augmented or virtual representations of our known world, or something completely artificial, can be tracked back to science fiction, especially the genre of cyberpunk. (Bartle, 2003)

William Gibson paints a vivid picture of how virtual worlds of the science fiction future might be perceived, in his groundbreaking classic cyberpunk novel *Neuromancer* that was written in the era of fledgling microcomputers which had a minuscule fraction of capabilities of an average smartphone of the present day.

Cyberspace. A consensual hallucination experienced daily by billions of legitimate operators, in every nation, by children being taught mathematical concepts... A graphic representation of data abstracted from banks of every computer in the human system. Unthinkable complexity. Lines of light ranged in the nonspace of the mind, clusters and constellations of data. Like city lights, receding... (Gibson, 1984, p. 67)

Moreover, Neal Stephenson expands the concept in the novel *Snow Crash*, describing a Metaverse as a collective virtual shared space in the appearance of an urban environment, the users of the Metaverse represented as avatars of any form of their choosing, experiencing the Metaverse from a first person perspective. (Stephenson, 1992)

As Hiro approaches the Street, he sees two young couples, probably using their parents' computers for a double date in the Metaverse, climbing down out of Port Zero, which is the local port of entry and monorail stop. He is not seeing real people, of course. This is all a part of the moving illustration drawn by his computer according to specifications coming down the fiber-optic cable. The people are pieces of software called avatars. They are the audiovisual bodies that people use to communicate with each other in the Metaverse. Hiro's avatar is now on the Street, too, and if the couples coming off the monorail look over in his direction, they can see him, just as he's seeing them. They could strike up a conversation: Hiro in the U-Stor-It in L.A. and the four teenagers probably on a couch in a suburb of Chicago, each with their own laptop. But they probably won't talk to each other, any more than they would in Reality. (Stephenson, 1992, p. 33)

Second Life founder Philip Rosedale explained in an interview that he had received the novel *Snow Crash* as a gift, and that the book inspired him so much that he was determined to create a virtual world, which later became Second Life. "You looked at that, and you said, 'Well, we could actually do that. There's not really a whole lot of reasons why we couldn't do exactly what's in that book'". (Sydell, 2010)

Wagner James Au documents the life of the virtual world not only on his blog (Au, 2015), but also on his book *The Making of Second Life*, where he gives the readers his definition of the virtual world.

It is not a story about computers or software programs defined by the torrential flickering of ones and zeroes. The world that comes into being through that process is, in every meaningful sense, a part of the one we already know. And even if you have no home inside it now, odds are that you eventually will. (Or at the very least find yourself becoming an occasional visitor.) For that reason it is, above all, not a story about a fantasy world totally cut off from what we call real. (Au, 2008, p. ix)

While the poetic descriptions can present a technoromantic view of virtual worlds, Au (2008, p. x) also gives a much more concise and pragmatic definition, by saying that "Second Life is an immersive, user-created online world".

Richard Bartle has researched virtual worlds and games since the textual worlds of the 1980s. His research covers the whole history of virtual worlds. He provides a definition, arguing that "essentially, a virtual world is an automated, shared, persistent environment with and through which people can interact in real time by means of a virtual self". (Bartle, 2010)

There are further excellent definitions, such as virtual worlds being “any computer generated physical space represented graphically in three dimensions, that can be experienced by many people at once” (Castronova, 2005, p. 22), or “places of human culture realized by computer programs through the Internet” (Boellstorff, 2008, p. 17).

2.2 Inner workings of virtual worlds

Creating virtual space and environments, relevant content, scripts and software for a virtual world can be a complex task, requiring many different skillsets, much alike the skills needed for digital game development.

The knowledge areas and skillsets required to produce full interactive mixed media experiences for virtual worlds could include:

- Building or 3D modeling
- Texture design and texturing, or 2D graphics design skills
- Animation
- Scripting or software development
- Sound editing and spatial sound design
- Terraforming or land editing
- Creation of complete virtual environments
- Managing and administrating various resources (groups, regions, estates)

Gröndahl (2010) gives a comprehensive overview of various areas of content creation in Second Life, and Haas (2012) further describes the software architecture and software development requirements for creating educational virtual environments in a virtual world such as Second Life.

A vast archive of reference material of all the areas how Second Life works is gathered in the Wiki documentation (Second Life Wiki, 2012), and there is a wide range of popular video tutorials covering most aspects of Second Life (Second Life Wiki - Video Tutorials, 2014).

3 APPROACH AND METHODS

3.1 Background and motivation

During LabLife3D project Nordström et al. (2010) identified several key motivators that rationalize and justify the need for 3-dimensional virtual environments for educational use especially in chemistry and microbiology education:

- Practical skills gained through laboratory experimentation belong to the core competencies in natural sciences.
- Laboratory equipment, facilities and reagents inflict heavy expenses for the school and faculty.
- Students are burdened by large class sizes and overlapping schedules.
- Curriculum lacks the time and space for proper learning-by-doing experience.
- Students can pass laboratory classes without developing critical thought process or connecting theory with practice.
- Many biological and chemical phenomena are not visible to the human eye, thus learning requires a cognitive ability to link the theory into the practical experiment.

In addition, it was identified that in the digital learning environment it is safe to practice even dangerous experiments, and also once the virtual laboratory has been created and established the costs become negligible. In the real laboratory, materials and reagents can be fairly expensive, the equipment can wear out, and in the worst case scenario the experiment can fail and the reagents will go literally down the drain. From this perspective, experimenting with chemicals in the virtual environment is also an ecological choice. Experiments can be conducted independently even without supervision, and they can promote discovery and in-depth learning. Lastly, it was noted that Finland has been falling behind in the use of digital learning tools, thus research and active development in this area is of importance. (Biorefinery3D brings together science and technology, 2013)

3.2 Aims and objectives

The aims of the project were defined in the first phases of the whole LabLife3D project. The virtual learning environment should promote student engagement, experimentation and critical thinking, and the ability to evaluate the biological or chemical experiment at hand. In addition, the virtual learning environment should facilitate learning and experimentation in a safe risk-free environment, and lastly make it possible for non-biotech/chemistry major students to be able to take part in laboratory experimentation thus the virtual laboratory could be an enabler for multidisciplinary learning and studies. (Nordström, et al., 2010)

Moreover, one of the aims of the project was to define a framework for course planning and design, to promote constructivist learning and principles for good teaching. The pedagogical objectives were set to support students with different learning styles, and to provide individual approaches for learning. (Palomäki, et al., 2011)

3.3 Research questions and hypotheses

The objective of the research was defined in the early phases of the project, but the research questions were further extended as the project evolved. Three key research questions were identified. Firstly, how can the affordances of virtual learning environments that support authentic learning be identified. Second, what are the barriers and enablers to learning in a virtual learning environment, and lastly, what would be the means of support from either teacher or the learning environment, that would promote authentic learning. (Nordström, et al., 2014)

Additionally, one of the hypotheses suggested that three-dimensional virtual worlds would become a significant learning environment, especially for the student generations of the future, or in other words for the digital natives. (Kangasniemi, et al., 2013)

3.4 Pedagogical design

Palomäki (2009) has conducted a thorough review of virtual worlds in education, discussing the various didactical approaches and the problems of virtual worlds in learning. He has also presented a model to produce higher education courses utilizing 3-dimensional virtual environments.

For the pedagogical design, throughout the phases of LabLife3D project, the research and development team followed the guidelines of roles and responsibilities, and collaborated within a wide multidisciplinary team of experts from various fields that always included not only subject specialists, but also teachers and pedagogical and didactic experts. (Palomäki, et al., 2011)

3.5 Virtual learning environment design

One of the most important spatial design requirements for virtual learning environments is that the design will positively support and facilitate the learning activities.

High fidelity of the 3-dimensional environment may allow the learner to achieve the state of flow, through psychological immersion into the environment, which has been identified as a learning affordance of virtual worlds. The learning environment can facilitate learning tasks that may lead to increased intrinsic motivation and engagement. Moreover, a high enough level of visual or sensory realism of the virtual environment that is consistent with the real world, can contribute to facilitating learning tasks that may lead to improved transfer of knowledge and skills through contextualization of learning. (Dalgarno & Lee, 2010)

In the early phases of the project, a sketch and a blueprint of the virtual laboratory were created. This process followed the practices of real laboratory design, with all the required equipment for the learning tasks and experiments sketched on the floorplan.



Figure 1. LabLife3D exterior and main entrance in Second Life.

Figure 1 illustrates the visual appearance of the laboratory facility, and the level of visual fidelity that was achieved with the spatial design for the virtual learning environment.



Figure 2. The main lobby to the virtual laboratory facilities.

To achieve the high fidelity of visual realism as shown in figure 2 to promote the learner immersion and engagement, in the implementation phase of the first

iteration of the virtual laboratory, the design blueprints were transferred into a virtually realized version of the laboratory with a design process employing various forms of spatial design.

3.5.1 Creating software specifications for laboratory experiments

Developing specifications for the learning tasks were the phases of the project with most intense levels of multidisciplinary collaboration. There was a continuous dialogue between the subject specialists, the pedagogical experts and the virtual environment developers. With carefully defined roles and responsibilities of the whole team, creating software specifications for the learning activities was a relatively trivial task.

As a byproduct, members of the research team produced two master's theses documenting the creation of the theoretical background for the learning activities that would subsequently be formulated into software specifications. Moreover, Kangasniemi (2012) discusses the decarboxylation reactions of fatty acids and Olkinuora (2012) describes the design process of molecular biology experiments involving purification of RNA and amplification of a gene by PCR.

To give an example of research required to produce virtual learning activities for the decarboxylation reactions, all the possible permutations and outcomes of the experiment were explored either by literature review or by conducting the experiments in a real laboratory. (Kangasniemi, 2012)

3.5.2 Object-oriented model as a specification framework

During the design of the molecular biology laboratory, a simple object-oriented model was developed in order to communicate the microbiological phenomena to software development in a way that could easily formulate specifications for the software. The model allowed both the subject specialists and the software developers to easily understand what is undergoing in the experiment.

The model presented in table 1 describes a sample which is similar to an object in object-oriented model, which has three different kinds of sets of attributes with different levels of visibility.

Table 1. Sample attribute visibility in the object-oriented design model.

Attribute type	Visibility
Human observable	Perceptible attributes which could be seen, felt or otherwise observed without any special equipment, such as for example color of the sample, liquid/solid state or hot/cold temperature felt by hand
Measurable	Attributes which would require special equipment to conduct the measurement, such as properties measured with a scale, a microscope, a spectrometer or any other equipment in the laboratory
Hidden	Attributes which could not be observed with or without any special equipment, mostly comprising of attributes related to the inner workings of chemical reactions happening within a sample, or attributes related to logical flow of the software

Table 2 presents the simple model describing two kinds of methods that the object or sample could be subjected to.

Table 2. Methods that can process or observe the sample.

Method type	Behavior
Process	The sample undergoes a change, such as adding a chemical, processing the sample with laboratory equipment like vortex or incubator, or subjecting the sample to a temporal process, that could be waiting for certain amount of time
Observation	Allows observing the non-hidden states of the sample, either by human sensory means, or by using the laboratory measuring equipment

With these three attribute types and two method types, the design model could allow specifications for relatively complex natural sciences experimentation. Olkinuora (2012) further discusses how the design model was applied in developing the theoretical background for the virtual molecular biology learning tasks.

3.5.3 Visual design of virtual laboratories

Design of the visual and spatial appearance of virtual 3-dimensional learning environments is a combination of various skillsets. Building the environment is in essence 3D-modeling. However, to be able to reach desired levels of immersion and engagement for the learners, many other areas of creating high fidelity user experience are required. These include architecture, understanding of visual and spatial aesthetics, ability to incorporate pedagogical specifications into a 3-dimensional world and also keeping in mind many areas of technological and usability concerns.

The laboratory experience for the learner has to be consistent, therefore as more learning activities and tasks get implemented, they should follow a consistent visual theme and appearance, and follow usability design principles. (Kangasniemi, et al., 2013)



Figure 3. Decarboxylation reactions experimentation and learning task in action.

A typical session on the organic chemistry decarboxylation learning task is illustrated in figure 3. Notable differences to real laboratories are specific user interface elements to control the flow of experimentation. Furthermore, many of the user interaction elements such as measuring device readout displays, control

buttons, bottles of chemicals and computer screens are significantly larger than similar elements in a real-world laboratory. The larger scale is justified for usability concerns, as the learners must be able to easily navigate the laboratory, and also locate the relevant objects and interface elements.

The space of virtual worlds does present unique challenges, for example most of the environments have to be created larger than their real-world counterparts, to allow easy enough navigation and to not create a space that feels too small or cramped. There are many examples in the virtual worlds of attempts to create 1:1 scale replicas of real-world environments, which end up working inadequately, for a variety of reasons, one being the perspective of the camera in the virtual world emphasizing the different need of scale for the virtual environments.



Figure 4. Space in the lobby for student group discussions and reflection.

Virtual spaces can also give freedom from real-world constraints. In the original floorplan blueprint design of the laboratory, a student break room was proposed, for informal gatherings and discussions. On figure 4 is shown the finalized virtual laboratory facility. The design had shifted into a welcoming lounge, where the space could be utilized as an environment for group discussions and reflection of learning tasks. Such virtual environments can have even a more significant role when the virtual worlds are used as a distance learning facility.

3.5.4 Requirements for the virtual environment and software design team

Palomäki (2009) discusses the roles and responsibilities of a team for virtual learning environment production, and the first project team composition is further explained and enumerated by Palomäki et al. (2011).

Project management, subject expertise, pedagogical and didactic knowledge, and support areas such as www-producing are well defined, however the virtual environment development portion of the roles and responsibilities could benefit from defining a few more specialist areas as presented on table 3, to cover the need of high fidelity 3-dimensional environment production.

Table 3. Roles and responsibilities for virtual environment development.

Role	Responsibility	Required
Producer	Leading development and coordinating between subject specialists and virtual environment developers	Yes
Builder	3D-modeling of environments and objects	Yes
Texture artist	2D graphics design for textures and other elements	Yes
Scripter	Software development and programming	Yes
UX designer	User experience, user interface and usability design	Yes
Animator	Creating animations, if needed, for the development	No
Sound designer	Creating a spatial soundscape	No
Environment designer	Compiling the full virtual learning environment from separate objects or elements	No

The bare minimum team composition is labelled as required, however sometimes the skillset areas might overlap in ways that one person might be able to cover several areas of skills and competencies. Nevertheless, if the production is not very small scale, a larger team is required to cope with the development needs of creating a 3-dimensional rich media environment with interactive software elements. Large scale productions could likely require several persons on various roles. Overlooking the complexity of development has possibly lead to limited success of many educational virtual environments.

3.6 Learning analytics driven design

Siemens & Long (2011) discuss the future of education and recognize data gathering and learning analytics as one of the most dramatic forthcoming changes in higher education. In many fields, data-driven decision making is noted to improve productivity. However, in the field of higher education, learning analytics is still a relatively new research area.

Digital learning environments such as virtual worlds propose a vast amount of possibilities to higher education, especially regarding learning analytics, since methodical gathering of behavioristic data and instant recording of learning activities enable areas of analytics that have not been possible before the era of digital learning environments. The development could benefit both the learners and the teachers.

3.6.1 Designing and implementing data gathering for learning analytics

For the learning analytics to work properly, as much of the learner behavior should be captured, as possible. Digital virtual environments have an advantage over real-world laboratories, since many triggered events can be captured and stored with simple pieces of software.

In LabLife3D, when research goals to review data gathering and learning analytics were included in the project, a robust system was developed and deployed to capture learners “touching” objects in the laboratory, or in other words clicking objects and elements with mouse. Each event with accompanying relevant data was stored in a database. Along with mouse clicks the system also stored various steps of the learning activity and all the important data such as the measurable attributes that the student could have been observing. With minimal further development, each learning activity and task could be played back step by step.

The data gathering system was designed in a way that it could be incorporated with relative ease into almost any learning environments in virtual worlds.

3.6.2 A/B testing of virtual learning environments

In the preliminary testing of the molecular biology laboratory, the critique from some teachers concerned the arrangement of various items in the laboratory. To summarize, it was noted that the laboratory was too neat and clean and the reagents, chemicals and equipment were organized on the shelves and tables in a too orderly manner, as illustrated in figure 5. The feedback was emphasizing that real-world laboratories are seldom so tidy, and with the reagents pre-arranged on the shelves in organized manner, the arrangement caused the learning task to become too easy and monotonous consisting only of selecting the right chemicals.



Figure 5. A tidy version of the PCR workstation.

Based on the feedback from the pre-study test group, the arrangement and tidiness of the laboratories was discussed in length. There were many opinions for and against the tidy laboratories. Some noted that with good laboratory working practices, the student should always prepare their own workstation to be

as tidy as possible. However, the conclusion was reached that the laboratory was lacking lots of the clutter and non-relevant material often found in real-world laboratories.

Instead of doing a complete redesign of the whole laboratory, a possibility for A/B testing different learning environments was proposed. With the data gathering system already implemented, a decision was made to create another set of the laboratory rooms and workstations which would be arranged in less tidy and more realistic fashion, as presented in figure 6.



Figure 6. A more realistic version of the PCR workstation.

One notable advantage of virtual worlds in researching different kinds of working and learning environments is that organizing the A/B testing presented no extra cost to the research project. Once the software for the simulations and learning tasks exists, the digital environment allows creating digital copies of laboratory spaces and workstations. Different versions of learning environments can be compared against each other, with learner behavior and data recording taking place in the background all the time. Similar arrangement in the real-world laboratories would be highly expensive if not impossible to create.

The study aimed to create a research method and process for systematizing the data collection from the laboratories, enabling comparison between different kinds of learning environments with even larger study groups. It was also noted that driving the research further would eventually lead into gathering big data for learning analytics. (Palomäki S. , 2014)

3.6.3 Towards big data

Employing big data, or vast datasets, in learning analytics has been identified as a potentially transformative idea for higher education. There are possibilities to model learning interactions based on vast data collection, but moreover the analytics could provide higher education teachers and staff new models to improve teaching, learning, organizational efficiency and decision making, and serve as a catalyst for systemic change. It has been also noted that with large datasets or big data, the data itself is in a key role for value generation, and can be a critical value layer for higher education institutions. (Siemens & Long, 2011)

Lumosity and Human Cognition Project have the largest existing dataset of human cognitive performance, and it serves as a good example, how big data can benefit both individuals and researchers on several areas. For the individuals, Lumosity generated dataset offers a possibility for comparisons to other users of the service and it can provide cognitive profiles that have been created from the behavior of millions of users of the system. For research, Lumosity dataset has been the source material for various areas of cognitive research such as effects of lifestyle or aging in cognitive abilities. (Sternberg, et al., 2013)

There are still many unanswered questions regarding how big data and learning analytics could best serve the educational field, but without doubt, learning analytics and big data will have an important role in the future of higher education. (Siemens & Long, 2011)

Furthermore Siemens & Long (2011, p. 40) point out that “learning analytics is essential for penetrating the fog that has settled over much of higher education”.

4 RESULTS AND DISCUSSION

4.1 Results from learning analytics

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. (Palomäki S. , 2014)

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. (Nordström, et al., 2014)

4.2 Student experiences

Student feedback was gathered with two types of forms, but also other means for collecting feedback and qualitative assessment data were piloted. Students in two groups ($N = 13$ and $N = 16$) completed the organic chemistry learning tasks, and the feedback revealed observations, that the students were finding the learning tasks too easy, the learning activities did not promote critical thinking, and the students of the other group summarized that it was too easy to click on the objects in the learning workstation of the laboratory, and they had not learned anything new. (Nordström, et al., 2014; Kangasniemi, et al., 2013)

The feedback from the first two groups of students was used to further develop the assessment forms but also to provide better instructional material to accompany the learning activities. Moreover, a narrative script was also developed to describe a fictional real-life scenario that the students had to research. The improved material was used for the molecular biology learning activity, and the overall student feedback and response for the molecular biology experiment was positive. The majority of this group ($N = 20$) were of the opinion that they had learned something new, and the level of difficulty of the learning activity was suitable. (Nordström, et al., 2014; Kangasniemi, et al., 2013)

4.3 Teacher experiences

Teacher experiences were gathered by 16 interviews, after the teachers had an opportunity to complete a learning task in the virtual laboratory. The majority of the teachers had no prior experience with virtual worlds, however a vast majority gave positive feedback regarding using of virtual worlds in education. Most of the negative comments were related to technological barriers, yet a majority of the group of teachers thought that a virtual laboratory could provide an excellent environment to familiarize students to laboratory practices and experimenting. Regardless of the positive view on the educational possibilities, the teachers responded not having enough time, or not possessing the relevant technological skills, and thus they did not feel like being able to personally start to develop virtual learning tasks and related course material. (Nordström, et al., 2014)

4.4 Acceptance of new technologies and the importance of user experience

De Freitas et al. (2009) noted that usability and accessibility issues with technology can be disruptive to the actual learning and the benefits of the learning environment were limited because of the technical problems.

It could be concluded that technological disruptions or interruptions can shatter the immersion and engagement in the learning activity and thus break the

psychological state of flow, if any existed. Technology of the virtual worlds on the high point of the education applications hype, 5 – 10 years ago, was on an early adopter level and even with technological advances on several fronts, the usability and user experience level of virtual worlds still has not quite caught up with the entertainment digital games industry.

Despite the fidelity 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 actual use or rejection. The attitude of the individual might furthermore be subjected to social influence. (Malhotra & Galletta, 1999)

Keeping this in mind it might not be a straightforward issue to research and find all the possible reasons why an educational technology solution could be perceived as useful or why it might be rejected by either students or teachers. Technology acceptance model was not used during this project, but it may provide a better understanding of both the student and the teacher responses.

Nordström et al. (2014) point out that the difference between student and teacher attitudes towards the use of virtual worlds as educational environment is revolving around the perception of teachers that they might not have the skills or competencies to participate in using new digital technologies and virtual environments in education.

Regarding student acceptance of new technological education environments, Palomäki (2009) discusses different learning styles. One possible conclusion could be that virtual worlds are not for everyone, but for those who are fluent with new technologies and game-like environments with an early adopter attitude, the virtual learning environments could be more beneficial than some other forms of education. However, it should be kept in mind that as each individual learner has his or her own learning style, trying to force everyone to go through one model, might not lead to desirable results. In that sense, virtual learning environments could be seen as one equal alternative to many other modalities of learning.

4.5 Discussion

Several areas of interest were identified in the original articles on LabLife3D project that this study is based on. These areas of interest might facilitate identifying the affordances of virtual learning environments that support authentic learning. Moreover, groundwork was laid for research methods that include qualitative feedback gathering from both students and teachers (Nordström, et al., 2014), and quantitative analysis of large datasets using learning analytics (Palomäki S. , 2014). The results in many phases of the project also lead to iterative improvement of the virtual learning environment. This improvement was based on agile development and rapid prototyping which encourage active discussions between the project team and the pilot groups during the whole project.

Secondly, technical problems proved to be most common hindrances to learning, when using virtual learning environments. Students have the ability to complete exercises in a virtual world, but usability issues can detract from learning. Some of the issues are very specific to virtual worlds, however similar issues could arise in other forms of immersive digital learning environments, such as serious games or simulations. As part of the project a heuristic usability study model was developed for assessing the usability of virtual learning environments. (Nordström, et al., 2014; Kangasniemi, et al., 2013)

Virtual environments can still facilitate enablers to learning, as the studies showed that students can learn scientific content as well as methodology for natural sciences practices by working in the virtual laboratory. On the basis of preliminary work on the quantitative analytics tools it could be concluded that by means of learning analytics, the factors that best enable learning could be identified and predicted more effectively. (Nordström, et al., 2014; Palomäki S. , 2014)

Authentic learning in the virtual environment would require overcoming the technical problems and further emphasizing user experience and usability design (Nordström, et al., 2014; de Freitas, Rebolledo-Mendez, Liarokapis, Magoulas, & Poulavassilis, 2009). Many of the technical barriers can be overcome, but it would

require more resources dedicated to the virtual environment development and testing.

For teachers to be able to support authentic learning using virtual environments, the first requirement would be that teachers have more time and resources allocated to incorporate modern digital learning environments to their teaching and course material. They also need support for developing their technical competencies. It could also be concluded, that the present student generation handles modern technologies relatively fluently and therefore teachers would not be required to act as technology experts, because they could trust the students to be comfortable enough with modern technologies. (Nordström, et al., 2014)

In this sense it could be recognized that teachers could focus on being subject experts, mentors and facilitators of learning, and that the technology is there to facilitate teaching, and that it should not require extra work or effort from the teachers.

Teachers' reluctance regarding technology acceptance could be seen as one of the hindrances to adopting new digital learning environments as a more widespread medium for education. Technical or usability barriers can explain this to an extent, however, the digitalization of learning and teaching is inevitable, and teacher education would need to adapt to this paradigm shift. (Nordström, et al., 2014)

It could be also concluded that as Jones & Shao (2011) point out, the changes taking place within the student generation are complex, and relate to many forms of newest digital technology, social media and the mobile internet. Moreover, the gap between students and teachers is not fixed, and even if it has been reported that students demand for new technologies, it has also been reported that students prefer moderate use of digital technology in their courses.

A growing mass of the younger generations uses games, simulations and virtual environments on a daily basis for entertainment, as Lenhart et al. (2008) note. This could suggest that virtual environments of one or another form will become more significant also for learning and education in the future.

5 SUMMARY OF THE ORIGINAL ARTICLES

5.1 Article I: “LabLife3D: A new Concept for Learning and Teaching Biotechnology and Chemistry in the 21st Century”

Nordström, K., Qvist, P., Palomäki, E., Natri, O., Joensuu, P., Närhi, M., Kähkönen, E., Jokela, R., Hemminki, M., Korpelainen, P., & Vepsäläinen, J. (2010). LabLife3D: A new Concept for Learning and Teaching Biotechnology and Chemistry in the 21st Century. *Aalto University Reflektori 2010, Symposium of Engineering Education, December 9-10, 2010* (pp. 106-108). Espoo: Aalto University, Lifelong Learning Institute Dipoli.

5.1.1 Research problem, description and results

Several factors burden the laboratory courses in higher education, and three were identified as large class sizes, heavy expenses and scheduling problems for students. It was also noted that the busy curriculum does not give enough time for the students to truly reflect on the learning-by-doing part of the laboratory practical experiments which can lead to theory not connecting to practice.

The aims of the project were set to give students higher level of engagement and possibility for critical thought processes to develop, to create a virtual environment for safe experimentation and offer the students from other major disciplines to experience laboratory experiments. The first implementation phase created a plan to develop the virtual laboratory facility in Second Life virtual world and eventually lead to pilot student groups test the first practical experiments and learning tasks in September and October 2010.

Several advantages were identified during the first phase of the project. The virtual laboratory can be used as an addition to existing real-life laboratory classes. Practical experiments can be repeated with no extra costs and students can experiment independently without any hazard risks.

5.2 Article II: “LabLife3D: Teaching Biotechnology and Chemistry to Engineering Students by Using Second Life”

Palomäki, E., Qvist, P., Natri, O., Joensuu, P., Närhi, M., Kähkönen, E., Jokela, R., Hemminki, M., Korpelainen, P., Vepsäläinen, J., & Nordström, K. (2011). LabLife3D: Teaching Biotechnology and Chemistry to Engineering Students by Using Second Life. In H. Ruokamo, M. Eriksson, L. Pekkala, & H. Vuojärvi (Ed.), *Proceedings of the 4th International Network-Based Education 2011 Conference* (pp. 124-131). Rovaniemi: University of Lapland.

5.2.1 Research problem, description and results

It was identified that engaged learning is an important part of any form of learning, and virtual environments and virtual worlds can provide higher levels of engagement, and lastly the millennial generations prefer technology as a significant part in their learning and education. Moreover, the 3-dimensional virtual environment and interacting with objects in the virtual world can help building conceptual understanding, and facilitate visualization of complex theoretical concepts.

During the planning phase, beside the implementation of the virtual laboratory facility itself, an approach to course planning was designed to integrate the virtual laboratory experimentation to existing classes and coursework. With the course planning the research team administrative roles and responsibilities were identified and defined, and also the pedagogical content and learning tasks were designed.

The pilot phase of LabLife3D during the first year met the objectives that were set for the project. The project aimed to research how teaching and learning could happen facilitated by a virtual environment. The student feedback indicated that the virtual learning environment had advantages over the traditional teaching methods, which suggested to continue the project and research of virtual learning environments.

5.3 Article III: “Designing virtual laboratories: Decarboxylation reactions, vacuum distillation and virus identification by PCR in the LabLife3D Second Life Laboratory”

Kangasniemi, T., Olkinuora, S., Joensuu, P., Natri, O., Qvist, P., Ketola, M., Närhi, M., Jokela, R., Palomäki, E., Tiitu, H., & Nordström, K. (2013). Designing Virtual Laboratories: Decarboxylation Reactions, Vacuum Distillation and Virus Identification by PCR in the LabLife3D Second Life Laboratory. *CSEDU 2013 - Proceedings of the 5th International Conference on Computer Supported Education, Aachen, Germany, 6-8 May, 2013* (pp. 661-672). SciTePress.

5.3.1 Research problem, description and results

3-dimensional virtual worlds had been recognized as an area of technology that might be one of the important learning spaces for digital natives and the future generations of students. The virtual learning environments were identified to be good alternatives, not replacements, for traditional teaching. Three key benefit areas of virtual worlds were identified. Firstly, the virtual worlds allow flexibility that the real-world spaces could not offer. Secondly, the virtual worlds have no time constraints to learning, and the virtual laboratory can be accessed any time without any risks of hazards. Lastly, the cost of developing and operation of virtual learning environment is low compared to real-world laboratory.

Furthermore the paper studied the advantages and disadvantages of virtual learning environments and the importance of high engagement levels that virtual environments can facilitate in learning. The paper also described the LabLife3D project and implementation of the virtual laboratory and the learning tasks.

The paper concluded, with study of student feedback and evaluation of teachers' role, that a simulation should allow flexible paths for students to experiment, high degree of photorealism adds to student motivation, and that for further development the learning tasks should have clear goals and provide strong integration of theory and practice.

5.4 Article IV: “Multidisciplinary Learning Affordances of a Science-Based Virtual World Environment”

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

5.4.1 Research problem, description and results

The paper presented three research questions. Firstly, what are the affordances of virtual learning environment that facilitate authentic learning? Secondly, what are the barriers and enablers to learning in virtual learning environments? And lastly, what kind of support from either teachers or the virtual learning environment would promote authentic learning?

Furthermore, the paper described the study design and process to gather both student and teacher feedback. Both quantitative and qualitative methods were used for students, with aid of both feedback forms and implementation of learning analytics data gathering methods in the virtual laboratory facility itself. Teachers' feedback was gathered with interviews. The feedback from the pilot groups suggested already changes to the virtual learning environment that were implemented in the later phases of the project, and also some necessary changes to the feedback gathering itself were identified. The research with learning analytics formed preliminary methodology, how analytics of big data gathered by virtual learning environments could be used in the future, in addition to other forms of feedback collection, to further improve the learning environment.

The study identified technical issues mostly as barriers to learning, but also recognized that students did learn scientific content and methodology by completing the virtual learning tasks. Lastly the paper noted that teachers felt that they are not qualified enough to use digital environments for their teaching, although digitalization of both learning and teaching will be inevitable.

5.5 About joint publications

This introductory part of the thesis was written solely by the author.

During the project phases regarding articles I and II, the author participated in designing the specifications for the learning tasks and the author also had the sole responsibility of the virtual learning environment production in the virtual world – including production management, building, texturing, scripting, UX design, animations, sound design and environment design. The author also co-presented the conference presentations related to articles I and II.

Regarding article III, the author continued to take part in the learning content design, and developed a software architecture model that could help the subject experts easier define the specifications for the learning activities and laboratory tasks. During this phase of the project, the author got assistance in software development and could delegate this portion of the production to a software engineer. The author continued to hold all the other responsibilities of the virtual environment production. Furthermore, the author collaborated with the team members creating the usability study and gathering feedback from students and teachers and provided insight into usability feedback gathering methods.

Regarding article IV, the author continued to hold the aforementioned responsibilities regarding the virtual environment production. The author also continued to collaborate with designing the learning tasks (vacuum distillation and algae bioreactor simulation which did not get to be implemented yet in the scope of this project). The author also suggested utilizing methods to support learning analytics and data gathering which lead to A/B testing of the different learning environments. Moreover, the author designed the architecture of the data gathering system and database to collect the learning analytics data.

During the whole project, the author worked in close collaboration with the multidisciplinary research and development team and while the author had most of the technical responsibilities of implementation in the virtual world, the whole project and the research has been collective work by the whole team.

5.6 Project and publications timeline

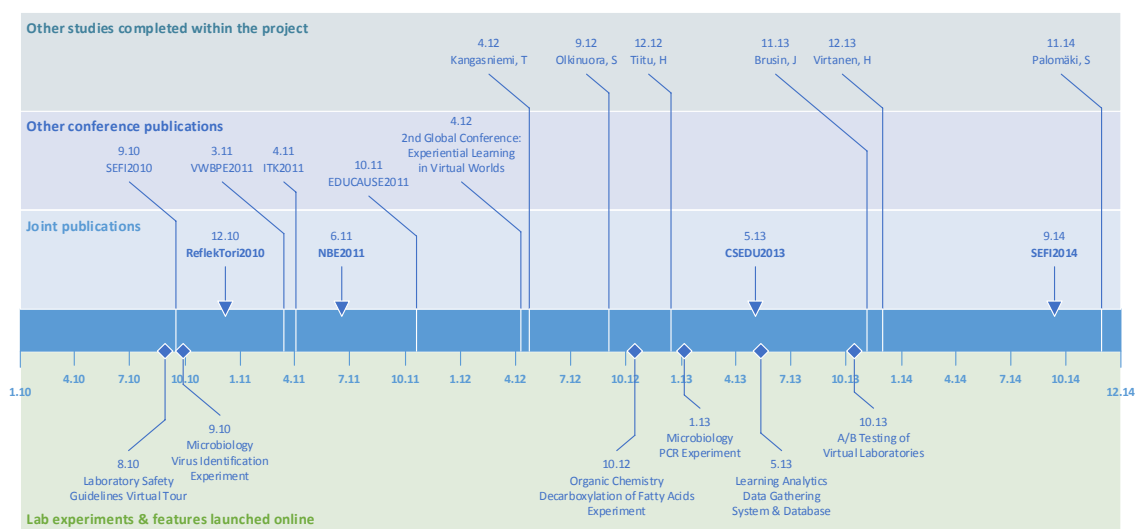


Figure 7. Timeline of the project, publications and implemented features.

The overall project timeline from 2010 to 2014 is shown on figure 7. The timeline illustrates the joint publications and also other conference publications, posters and presentations that are relevant to this project. The joint articles denoted in the project timeline are specified in table 4. Other studies such as master's theses are presented on the timeline as well as also the laboratory learning activities and other features that were implemented during the project. As of writing this thesis, all the experiments and learning tasks are available in the virtual laboratory in Second Life. In autumn 2014 the laboratory was used by 130 students.

Table 4. Joint articles presented on the project timeline.

Joint article	Title
ReflekTori2010	Article I: "LabLife3D: A new Concept for Learning and Teaching Biotechnology and Chemistry in the 21st Century"
NBE2011	Article II: "LabLife3D: Teaching Biotechnology and Chemistry to Engineering Students by Using Second Life"
CSEDU2013	Article III: "Designing virtual laboratories: Decarboxylation reactions, vacuum distillation and virus identification by PCR in the LabLife3D Second Life Laboratory"
SEFI2014	Article IV: "Multidisciplinary Learning Affordances of a Science-Based Virtual World Environment"

Table 5 presents the other conference publications, presentations and posters during the project timeline. The author was involved in co-creating the material for the poster presentation (VWBPE2011) and deploying the poster in Second Life, where it was displayed in form of a steampunk-styled science building (steampunk was the visual theme of VWBPE conference in 2011). In the virtual building for the poster, videos and informative presentations of the project were shown. The author also co-presented two of the conference presentations denoted in table 5 (ITK2011 & EDUCAUSE2011). The last conference presentation mentioned in table 5 was a multidisciplinary study about using the virtual laboratory as a language learning facility, emphasizing the possibility to use the virtual environment in several different areas of education which do not have to be limited to chemistry or microbiology.

Table 5. Conference publications presented on the project timeline.

Conference publication	Reference
SEFI2010	Palomäki, E., Natri, O., Joensuu, P., Närhi, M., Kähkönen, E., Jokela, R., Hemminki, M., Korpelainen, P., Vepsäläinen, J. & Nordström, K. (2010). <i>LabLife3D: Teaching Biotechnology and Chemistry to engineering students by using Second Life</i> . In: Joint International IGIP-SEFI Annual Conference 2010. Trnava, Slovakia 19-22 September 2010.
VWBPE2011	Palomäki, E., Qvist, P., Natri, O., Joensuu, P., Närhi, M., Kähkönen, E., Jokela, R., Hemminki, M., Korpelainen, P., Vepsäläinen, J. and Nordström, K. (2011). <i>LabLife3D - A New Concept for Biotechnology and Chemistry Education at Aalto University</i> . Poster in 4th Annual Virtual Worlds Best Practices in Education Conference, Second Life.
ITK2011	Palomäki, E., Qvist, P. (2011). <i>LabLife3D – Mikrobiologian ja kemian laboratorio virtuaalimaailma Second Lifessa</i> . Presentation in ITK 2011 Interactive Technology in Education conference, Hämeenlinna, Finland, April 7-8.
EDUCAUSE2011	Palomäki, E., Nordström, K. & Qvist, P. (2011). <i>LabLife3D: Second Life for Biotechnology and Chemistry Blended Learning</i> . Presentation in Educause 2011, Philadelphia, USA, October 18-21.
2 nd Global Conference: Experiential Learning in Virtual Worlds	Palomäki, E. and Nordbäck, E. (2012). <i>Bringing Playfulness and Engagement to Language Training Using Virtual Worlds: Student Experiences, Results, and Best Practices from a Virtual Language Course</i> . A paper presented at 2nd Global Conference on Experiential Learning in Virtual Worlds, Prague, Czech Republic, April 12–14.

Table 6. Other studies presented on the project timeline.

Other study	Reference
Kangasniemi, T	Kangasniemi, T. (2012). <i>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</i> . M.Sc. (Tech.) Thesis, Aalto University School of Chemical Technology, Espoo.
Olkinuora, S	Olkinuora, S. (2012). <i>Design of a Molecular Biology Laboratory in Second Life</i> . M.Sc. (Tech.) Thesis, Aalto University School of Chemical Technology, Espoo.
Tiitu, H	Tiitu, H. (2012). <i>Virtuaalisen kemian opetuslaboratorion käyttökelpoisuuden arviointi</i> . Erikoistyö, Espoo, Aalto University School of Science.
Brusin, J	Brusin, J. (2013) <i>Improving the Second Life learning Environment: Biorefinery 3D</i> (in Finnish), M.Sc. (Tech.) Thesis, Espoo, Aalto University School of Chemical Technology.
Virtanen, H	Virtanen, H. (2013) <i>Digital learning spaces: Supporting education with Second Life virtual world</i> (in Finnish). M.Sc. (Tech) Thesis, Aalto University School of Chemical Technology.
Palomäki, S	Palomäki, S. (2014). <i>Using student-produced data trails for evaluating and enhancing learning in virtual worlds</i> . M.Sc. (Tech.) Thesis, Aalto University School of Science, Espoo.

Moreover, table 6 lists other studies that were completed during the course of the project timeline, including several master's theses and one usability study. Lastly, table 7 lists the implemented and designed features of the virtual facility.

Table 7. Features implemented and designed for the virtual laboratory.

Implemented and designed features	Status
Laboratory Safety Guidelines Virtual Tour	Implemented
Microbiology Virus Identification Experiment	Implemented
Organic Chemistry Decarboxylation of Fatty Acids Experiment	Implemented
Microbiology PCR Experiment	Implemented
Learning Analytics Data Gathering System & Database	Implemented
A/B Testing of Virtual Laboratories	Implemented
Organic Chemistry Vacuum Distillation	Designed
Algae Bioreactor Simulation	Designed

6 CONCLUSION

Developing complex virtual learning environments is a task that requires not only a team of multidisciplinary experts from various fields, but also people with inspired attitude and a wish to develop new practices and new ways of working. It requires willingness to step into the shoes of early adopters regarding newest technology platforms, and to actively campaign against technology rejection. Only expertise or motivation alone do not drive projects forwards, but there are also times when patience and long term commitment are needed.

It is not possible to create a paradigm shift that would change the current familiar ways of working at least to some extent within a time-frame of only a few years. Funding is of key importance in helping to promote the important research for finding new methods of learning, new methods of working and ways to strive to modernize areas even such as the higher education.

Comparisons between virtual learning environments and entertainment games are easily made since the competencies to create either are very close to each other. There are also many other resemblances that virtual worlds, educational games and entertainment games share. However, in the industry for entertainment games, it is common that large game projects can run for years, and the required funding to produce a good quality entertainment game soars in a completely different magnitude compared to the educational technology development budgets. The shift for starting to see developing new modern methods and technologies for education as something as important as entertainment will not happen overnight, but this change is already in progress.

The last word is given to three members of the research team, who summarize what it is all about. Virtually anything is possible.

Our aim in this project is to develop an alternative for conventional teaching. BioRefinery3D tries to bind theory and practice together in a way that would be too expensive or even impossible otherwise. We hope the game-like approach of our biorefinery makes learning more engaging, inspiring and fun for the students. (Artimo, Seppänen, & Palomäki, 2013)

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Practice paper

LabLife3D: A New Concept for Learning and Teaching Biotechnology and Chemistry in the 21st Century Aalto University

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Keywords: Second Life, laboratory work, blended learning, microbiology, chemistry

Background and aims

Practical skills are part of the core competencies of natural sciences, where skills and experience are gained through extensive laboratory experimentation. However, current laboratory courses at Aalto TKK are burdened by a) large class sizes b) heavy expenses for modern and safe equipment, facilities and reagents c) overlap with other courses which sets constraints on student schedules. Moreover, although “learning by doing” is the ultimate goal of practical laboratory classes, it is evident that the current curriculum does not allow for enough space and time for the learning experience to mature and many students pass laboratory classes without developing a critical thought process of connecting theory (lectures/teaching) with practice (laboratory). Consequently the present proposal focuses on bridging the gap between theory and practice by creating a new concept of learning by using the 3D Second Life – platform. Many phenomena of the biological, chemical and similar experimental sciences are not visible to the human eye, and consequently student learning relies on a cognitive ability to integrate theory from a multitude of different classes to the physical experiment at hand.

The aims of the project are to 1) engage students to experiment and critically evaluate the inherent behavior of biological or chemical material in a shared local space 2) facilitate such engagement by experimentation in a learning space such as on the LabLife Island in Second Life and thus conducting experimentation in a risk-free environment, integrated with other practical work and experimentation, 3) offer the possibility for other, non-

biotech/chemistry majors across Aalto University (e.g. students from HSE, Taik) to take part in experimentation, which is not possible through their own disciplines, but will help to e.g. visualize even difficult content and contribute to their multidisciplinary knowledge of experimental work, which is a major activity of many commercial and design ventures engaged in the life sciences. Consequently, the aim is to offer a new concept of blended learning which engages the student in a non-imposing environment to reflect, design and analyze experimental phenomena. Virtual objects encourage the development of stronger conceptual understanding and provide visualization for complex and demanding content.

Content and design of the laboratories in Second Life

The project began at the beginning of January 2010 with 1) Team administrative details and 2) Content and learning related details. Administrative details comprised the definition of the roles of the actors of the planning and implementation team and signing of agreements for IPR between the team and Aalto. Content and learning related details were implemented by initial visits to other Second Life learning platforms, planning and building of the laboratories for biotechnology and chemistry and designing the “classes” to be implemented in the Second Life environment.

The building of the laboratory proceeded by fist, drawing the blueprint of a laboratory, where one section is dedicated to cleanroom facilities and the other to chemistry. The laboratory is housed in a facility, which is now situated in the Aalto Archipelago and can be accessed by visitors on request also. The building also has a lobby for students to discuss and reflect on their work. Existing real-life laboratories were photographed and the necessary equipment was installed into the lablife3D-laboratory. Two laboratory “practicals” have been designed, one for microbiology (working with viruses in a cleanroom facility) and one for chemistry, focusing on safety in the laboratory. Piloting of these “practicals” has been performed in September and October 2010 with students from two courses participating. A pedagogical script for the group work was then created and student feedback was collected as the piloting proceeded. Before entering LabLife3D students named their Avatars and were designated into pairs, where an attempt was made to try to pair individuals with familiarity with virtual worlds (e.g. games) with those students with less experience. Prior to entering the LabLife3D laboratory an introductory tutorial session (Figure 1) was mandatory in order to familiarize the students with technical details and the assignments to be done in the Second Life laboratory.

Learning outcomes

The laboratories were designed in accordance with the learning goals, ie. the microbiology laboratory was based on the learning of aseptic technique, which is essential for minimizing contamination and, on the other hand protecting the laboratory staff from infections. In the virus isolation and identification assignment each student uses their Avatar to navigate through the laboratory. Students are required to perform a certain task, eg. adding virus to a mixture of growth media and placing this into a centrifuge. The students are guided through tasks such as gowning for sterile chambers, washing and disinfecting hands, using a microscope, placing virus cultures into an incubator etc. The

focus of the chemistry laboratory is on safety in the chemistry laboratory, which students complete before the real-life practical class. This allows students to familiarize themselves with the practical laboratory and to become aware of potential hazards and prevention of such hazards. For both the virus and the chemistry laboratories, plenty of additional information is provided by links to teaching videos and other study material.

Conclusions

Lablife3D provides a viable alternative to traditional laboratory experimentation, it may be used as an adjunct to laboratory experimentation, as a testing platform for student to run virtual experiment and also for repeating practicals without any hazards, costs or preparations. For teachers, it provides an excellent option for designing learning experiences and for international networking. The Second Life world supports the development of communication and team work skills in addition to achieving the goals for motivation, independent work and learning-by-doing. Enhancing collaboration and communication is also in line with the desired learning outcomes for the engineering students. The Lablife3D project is in line with constructive alignment as the learning outcomes and contents are defined and learning and teaching activities have been selected.

LabLife3D: Teaching Biotechnology and Chemistry to Engineering Students by Using Second Life

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Practical skills are one of the core competencies in natural sciences, where skills and experience are gained through extensive laboratory experimentation. However, current laboratory courses at Aalto University are burdened by heavy expenses for modern and safe equipment, facilities and reagents. Students suffer from large class sizes and overlapping schedules with other courses. Although learning by doing is the ultimate goal of practical laboratory classes, it is evident that the current curriculum lacks the space and time for the learning experience to mature. Consequently, many students pass laboratory classes without developing a critical thought process of connecting theory with practice. LabLife3D helps to bridge the gap between theory and practice by supporting contact teaching with simulations and virtual experimentation using the Second Life platform.

LabLife3D engages students to experiment and critically evaluate the inherent behavior of biological or chemical material in a shared local space. It facilitates engagement by offering experimentation in a risk-free environment. Also the non-biotech/chemistry major students across Aalto University can participate in experimentation and contribute to their multidisciplinary knowledge of experimental work. This allows them to better understand the experimental work as a major activity of many commercial and design ventures engaged in life sciences.

The virtual laboratory LabLife3D has one section dedicated to cleanroom facilities and the other to chemistry. The students can discuss and reflect their work in the lobby. LabLife3D is housed in the Aalto Archipelago in Second Life virtual world and is freely accessible for visitors.

Keywords: Second Life, virtual laboratory, biotechnology, chemistry

1 Introduction

Engaged learning is 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. (Ramsden, 1988) Accordingly, "Learning should be seen as a qualitative change in a person's view of seeing, experiencing and understanding, conceptualizing something in the real world rather than a quantitative change in the amount of knowledge someone possesses" (Biggs, 1999). Goal setting, active participation taking responsibility and feedback should be shared by students and teacher alike. Significant learning (Fink, 2003) can only be built on mutual commitment and respect between learner and teacher.

Technology is a significant part in the learning of the millennial student (Gilbert, 2007). Incorporating virtual technologies enables the learning space to engage student and teacher in mutually enriching, active and learning centered interactions. Virtual technologies also help in adjusting the teacher-to-student ratio. Such technologies can be used to facilitate interaction and discussion in cyberspace. This practice should be seen where possible as an alternative, rather than as a replacement to face-to-face communication. (Daniel, 2008) Virtual worlds are usually a part of a larger learning environment, which is more than just a classroom. As stated by Wilson "A learning environment is a place or community where people can draw upon resources to make sense out of things and construct meaningful solutions to problems" (Wilson, 1996).

It is suggested in literature, that virtual worlds in education lead to increased engagement (Palomäki, 2009). Brain activity has been measured for tasks performed in real as well as in virtual reality environments (Mikropoulos, 2001). His findings demonstrated subject being more attentive, responsive, and utilized less mental effort in the virtual world, showing that knowledge transfer of information gained in one world to the other world is possible. Moreover, students are more engaged in learning tasks and 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, being more interactive and experiential (Richter, Anderson-Inman, & Frisbee, 2007). 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. When using virtual worlds, engagement experiences are present and the enthusiasm for learning can increase (Foster, 2007a). 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). Moreover, the benefits of Second Life include providing "a social laboratory where role-playing, simulations, exploration, and experimentation can be tried out in a relatively risk-free environment" (Graves, 2008). From these reasons the Second Life virtual world was selected to be the platform for LabLife3D.

1.1 LabLife3D environment

LabLife3D is a simulated laboratory environment build inside the Second Life virtual world. During the planning and implementation process subject experts were consulted to realistically model a physical laboratory to the virtual world. Photographs from laboratory equipment were used to build realistic models inside LabLife3D. The laboratory building includes an organic chemistry laboratory, clean room facilities, and a lobby to be used as a discussion place for students. Students can walk inside the laboratory premises, and get to know laboratory equipment and procedures. They can chat via text, or have conversations in a Skype-like manner using a headset. They can perform step-by-step pre-coded laboratory experiments. Two such experiments are currently built into the system. Figure 1 shows a general view inside the simulated laboratory.



Figure 1. LabLife3D premises and a view to the organic laboratory.

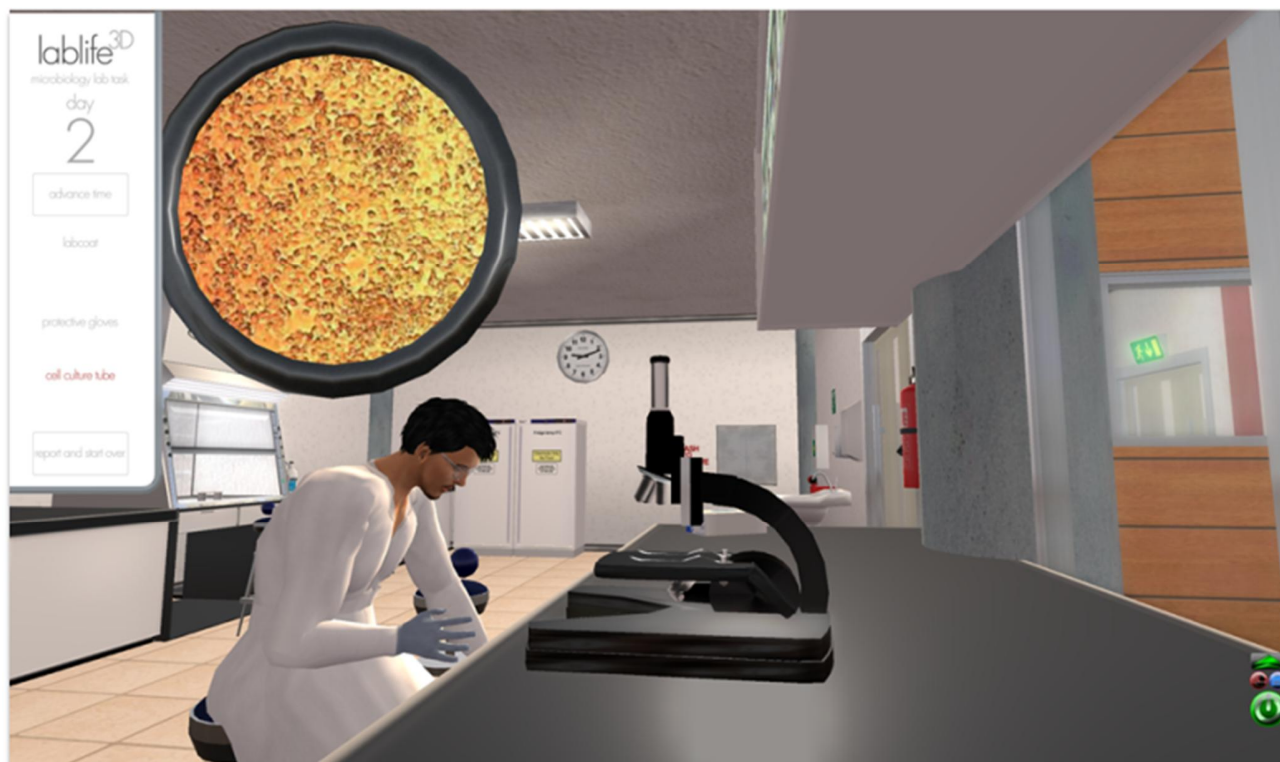


Figure 2. A snapshot from a virus identification scenario conducted inside the clean room zone. The student is using a microscope to examine a sample after a growth period of two days. The round image in the upper left quarter shows the image from the microscope.

2 Aims and objectives

The approach used in course planning was to promote constructive alignment learning and principles for good teaching (Biggs, 1999; Ramsden, 1992) (Figure 3). Such practices must draw on empirical evidence that integrates sound pedagogy with identified learner traits and learning styles. Learning styles reflect the different approaches to learning that individual students have. These individual approaches were accounted and integrated into the instructional design, teaching practices, feedback, and assessment.

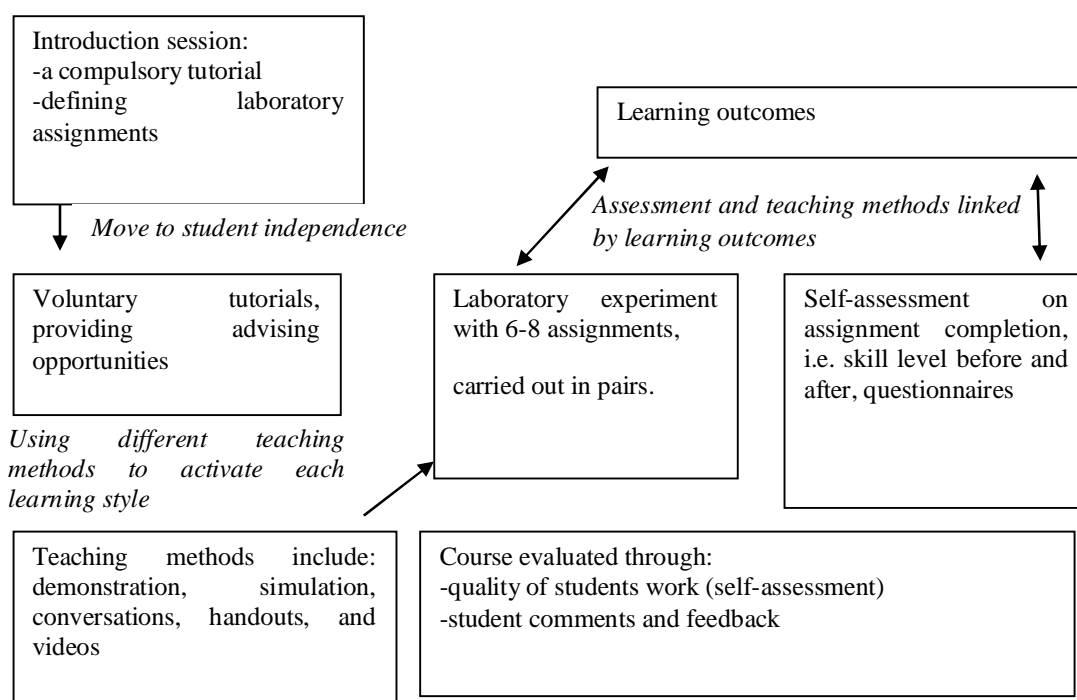


Figure 3. Course design as adapted to learning frameworks.

The project began with definition of 1) Team administrative details and 2) Content and learning related details. Administrative details comprised the definition of the roles of the project team and signing of agreements for IPR between the team and the university. Content and learning related details were implemented by initial visits to other Second Life learning platforms, planning and building of the laboratories for microbiology and chemistry, and designing the “laboratory classes” to be implemented in the Second Life environment.

2.1 Project team roles

The planning team consisted of nine individuals for whom specific roles were assigned according to the previously developed role outline (Palomäki, 2009), (Table 1).

Table 1. Roles, expertise and responsibilities of the team. Based on (Palomäki, 2009). (* and ** = the same individual with two roles)

Role	Background	Responsibility
Project coordinator	Professor* (Microbiology)	Contract negotiations, copyright issues, guiding meetings, team communication, schedules, budgeting, and project monitoring.
Content experts, Instructors	3 Ph.D. students** (Microbiology) 1 Postdoc (Organic chemistry) 1 Professor (Organic chemistry) 1 Professor* (Microbiology)	Content expert: Providing opinion, experience, and expertise about the topic of the course. Content scriptwriting, i.e., producing learning material, exercises, the syllabus, teaching solutions, and planning the study processes Instructors: Based on experiences, the person in the role of the content expert is the best choice for the course instructor, i.e., the teacher. They have the responsibility of instruction and guiding students inside the virtual world. Earlier experience about virtual worlds is not necessary needed.
Web didactic expert	2 Pedagogical experts (Education development)	Planning the educational activities in Internet and virtual world. Expertise in university pedagogy, tools and learning processes.
Web didactic expert and www-producer	1 Ph.D. student (Work psychology) Virtual worlds and as learning environments 1 Student	Works in the role of production scriptwriter. Building the virtual world solutions with the developer according to the production script. Planning of visual layout and final implementation solution for the tools and environment. Structure and functional requirements of the course. Updates and changes to the learning environment during the course.
Developer and graphic designer	Outside expert	Developer plans and implements the needed solutions according to the production script. Previous expertise of creating virtual learning environments is needed. Makes updates and changes to the learning environment during the course.
IT support	University	Providing IT support and access.
Secretary	1 Ph.D. student** Microbiology	Manages team planning schedules, meetings and announces course news and collaborates with university planning officer.

2.2 Implementation of LabLife3D

At the start of the project the university had limited impact on the building process of the LabLife3D as it had no existing practices present for using Second Life. However, the university owned an archipelago, i.e. an area inside the virtual world, which the LabLife3D project decided to use. At the beginning of the planning phase, virtual worlds and their use in education were introduced to the project team. The project team had little or no previous experience of virtual worlds and it was therefore important to first increase their understanding of virtual worlds. Members of the team were then able to present ideas of possible scenarios which may be reasonable to implement in the Second Life environment and plan on how to best utilize the advantages of

virtual worlds. After the introduction, the project team started planning the teaching scenarios. From here, rapid prototyping model was used. That is, the scenario and the virtual laboratory were developed in small cycles, so that the construction and the scenario planning created ideas and feedback for each other. At the same time lists with images of the equipment needed were created. An experienced Second Life developer was used in implementing the virtual world solutions. Using both the expertise of the content experts, the virtual world didactic expert and the developer, the scenarios were shaped to suite the virtual world and educational goals.

Before entering LabLife3D students and were designated into pairs, where an attempt was made to try to pair individuals with familiarity with virtual worlds (e.g. games) with those students with less experience. Prior to entering the LabLife3D laboratory customized their avatars in a mandatory introduction session (Figure 3). This session familiarized the students with technical details and the assignments to be done in the Second Life laboratory. In the initial phase of this project 10 students took part in the microbiology experiments and 10 students in the chemistry safety laboratory. The aim is to increase the number of students as the concept is sufficiently tested.

When entering the laboratory building the users were given an object that worked as a head-up-display (HUD) as a box on their screen. On the HUD there are buttons that can be used to control the scenarios and information about the scenario status and student actions are shown. The HUD transforms the Second Life experience into a game-like laboratory simulation, where the actions of the students are tracked. There are plans to integrate PIVOTE software (<http://www.pivote.info/>) to track the student actions and report them to the teacher after the session.

Two microbiology cases were designed for biotechnology majors, namely working with viruses and isolation of bacteria from process industry waters. The laboratories were designed in accordance with the learning goals, i.e. the microbiology laboratory was based on the learning of aseptic technique, which is essential for minimizing contamination and, on the other hand protecting the laboratory staff from infections. In the virus isolation and identification assignment each student uses their avatar to navigate through the laboratory. Students are required to perform a certain task, e.g. adding virus to a mixture of growth media and placing this into a centrifuge. The students are guided through tasks such as gowning for sterile chambers, washing and disinfecting hands, using a microscope, placing virus cultures into an incubator etc. Similar tasks are also performed for the second case with the aim of identification of contaminants from process industry waters. In order to extend this virtual laboratory – scale experience into reality, students are required to calculate the amount of disinfectant that would be needed for elimination of the contaminant by scaling their findings to the process scale in industry (Figure 3). Some tasks require specific hand movements or avatar navigation and are difficult to demonstrate properly in a virtual world. For those tasks, video clips are to be embedded in the laboratory displays. To promote learning and give students real-time feedback, students also receive a list of points to remember whilst working in the laboratory environment, and a questionnaire is filled in at the beginning and the end of the virtual laboratory session.

The focus of the chemistry laboratory is on safety in the chemistry laboratory, which chemistry major students complete before the real-life practical class. This allows students to familiarize themselves with the practical laboratory and to become aware of potential hazards and prevention of such hazards. The learning process was been divided in two separate cases. In the first case, students have open access to the laboratory where they can familiarize themselves with different equipment and laboratory hardware. The only safety requirement in this mode is the use of lab coats and goggles. Additional information is provided by links to teaching videos and other study material. In the second case, students are required to perform a simple organic reaction and the performance is evaluated with an end report. To pass the test students must take into account sufficient number of safety features; protective clothing, correct cleaning of chemical spills etc. Students are encouraged perform this task in addition to already existing mandatory online safety examination that is usually taken before the first real-life laboratory course.

3 Discussion

Student feedback suggested that the Second Life environment supports the development of communication and team work skills in addition to achieving the goals for motivation, independent work and learning-by-doing. Enhancing collaboration and communication is also in line with the desired learning outcomes for the

engineering students and extends also to the ability to interact with individuals located around the world (Barab et al., 2000). If time is given for students to customize their avatars to look like themselves, it can help to enhance on-line communication (Foster, 2007b).

Working with viruses, as facilitated in Second Life, provides the student with unique opportunity to familiarize with techniques related specifically with isolation and handling of viruses. Due to biological risk, high costs of virus laboratory designs, and restricted time in the curriculum, engineering students at our university do not have any other opportunity to familiarize themselves with viral methodology. The implementation of instruction on the safety in the chemistry laboratory has very practical justifications, as this knowledge is essential to all laboratory instrumentation in the life sciences and therefore includes a major student load. Evidently, students must also practice the actual laboratory skills in the real environment. Safety issues are of crucial importance to the safety of students and faculty as well as to the correct implementation of experimental work and consequently to the quality of scientific research data. In addition, at the end of the project we evaluated whether we had set the correct goals and where these goals relevant. This included feedback both from the students and their performance as well as self-assessment by the project team.

4 Conclusions

The first year pilot of the project met the objectives set. The emphasis of the first year was to investigate on how the teaching and learning activities in Second Life can support reaching the desired learning outcomes. The student feedback suggested advantages when compared to traditional teaching methods. This means the continuation of the project seems to be justified. Further topics for studies include the usage of the developed environment in other areas such as language training, and studying the change process related to the implementation of a new study and teaching method.

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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 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 Disadvantages 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, Nah & Siau 2008; Holmberg & 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, Wright & Hartman 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, Anderson-Inman & Frisbee 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 & 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

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	<i>same as above</i>
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

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 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

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.

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 & Natsis 2010, and Strangman, Hall & Meyer 2003). Although some of the studies relate to simulated laboratories (e.g. the 2D laboratory of Josephsen & 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 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).



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

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 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



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

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 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!

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%

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).

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, Du, Holgaard & Jensen 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

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%

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 & 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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Multidisciplinary Learning Affordances of a Science-Based Virtual World Environment

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INTRODUCTION

The concept of learning affordances has become increasingly used since Gibson [1] used the term to refer to the functional properties that determine the possible utility of an object or an environment.

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According to Greeno [2] “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. Educators claim that authentic learning is the most desirable way to achieve, deeper, more complex, and contextual understanding of particular disciplinary areas [3]. 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, an increasing number of educators are turning to Virtual World (VW) environments, where simulations and learning-by-doing can be facilitated within disciplinary and professional contexts [3]. 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 [5]. Second Life (SL) 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 [6]. Interaction in SL takes place through an Avatar and SL includes communication tools such as text and voice chats, instant messaging and sounds can be imported into SL, and audio and videos can be streamed into SL. Rosenbaum, et al. [7] have pointed out, that technology plays an important role in facilitating integration of the skills needed for living in a technology-centric environment and mediating authentic learning experiences by creation of communities of practice around the tools used by disciplinary experts. Consequently, development of future learning spaces calls for leveraging the affordances of advanced digitalized technologies for improved learning outcomes.

1 APPROACH AND METHODS

1.1 Research questions and hypotheses

The overall objective of the studies presented in this paper, is to show how the enablers to learning in 3D virtual worlds could be identified and further used in pedagogically sound ways. The study sets out to answer three research questions:

1. What are the affordances of virtual worlds that facilitate authentic learning in a science-based laboratory simulation and how can these best be leveraged ?
2. What do students perceive to be the barriers and enablers to learning in such a virtual world environment ?
3. What type of support (from the teacher or embedded in the environment) promotes authentic learning in virtual world environments ?

1.2 Study design

Design-based research methodology was used, which is a blend of empirical research with the theory – based design of learning environments. The method focuses on the systematic investigation of innovations designed to improve educational practice through an iterative process of design, development, implementation and analysis in real-world settings [8], and followed the framework outlined in *Fig.1*. A major strength of design-based research lies in its adaptability to adjust the intervention based on ongoing findings from participants.

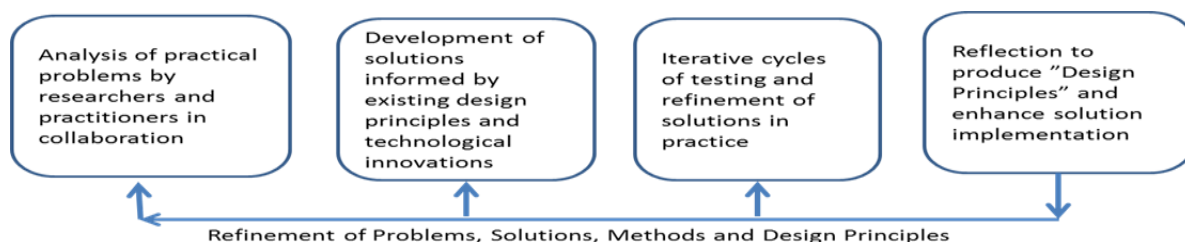


Fig.1. Predictive and design-based research approaches in educational technology research [9].

1.3 Laboratory experiments in Second Life: Lablife3D

To date, we have designed five laboratory experiments into SL <https://sites.google.com/site/lablife3d/>, namely 1) a virus isolation simulation, 2) a molecular biology experimentation, 3) an organic chemistry laboratory safety tutorial, 4) a decarboxylation experiment and 5) a vacuum distillation experiment [10]. For the present study we used the organic chemistry decarboxylation experiments and the molecular biology experiments to study student and teacher responses. The organic chemistry simulation [11] is not a strict laboratory practice exercise (*Fig.2*). 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 simulation is controlled by clicking with the computer cursor on the chemical containers and instruments, such as the synthesis station and a balance, in the laboratory 3D space [10]. The primary learning outcome of the molecular biology simulation [12] is to give the student the opportunity to learn the process of identifying a virus from a human cell sample (*Fig. 3*). The virus that is studied is an enterovirus, which students will identify in accordance to standard scientific methodology, based on a specific enterovirus protein known as VP1.



Fig.2. Screenshot: The organic chemistry simulation on decarboxylation reactions



Fig. 3. Screenshot: The molecular biology experiment.

1.4 Student feedback and development of learning analytics

Two types of forms were used to perfect the collection of student feedback, of which the first was based on a qualitative assessment student perceptions of what they had achieved. However, during the study it became evident that the data was difficult to interpret, and a Likert scale was subsequently used [10]. So far feedback has been collected from 39 students. Piloting different means for collecting feedback was an important part of the study, as it was also used to formulate the teacher interview questions as well as to create an approach for the use of learning analytics to assess student performance in the SL world. Siemens and Long [13] have described big data or learning analytics to be “the most dramatic factor shaping the future of higher education” providing researchers and educators with more quantitative data on what is happening in the learning process. Consequently, one of our current aims is to develop quantitative tools for the assessment of learning in VWs. For this purpose, we have studied the molecular biology exercise in order to elucidate 1) how does the learning process proceed during the VW exercise and what are the critical learning event, enablers and barriers ?, 2) what kind of quantitative data can be collected during this process and what indicators from this data can be used to quantify or describe the learning and 3) how can this data be used to enhance learning in VWs or even other real-world learning events ? The data for this part of the study is still based on a small sample, however, this represents a piloting phase of the project [14].

The quantitative data is based on the automatic monitoring of the time spent and the number of user interactions taken by student whilst performing the tasks in the molecular biology laboratory. By user interactions we refer to the clicks made by student (ie. via computer mouse or other controls) whilst carrying out a given exercise in the VW. Nine students took part in the study and three of these were also interviewed as a focus group.

1.5 Teacher interviews

Eighteen individuals participated in the teacher interviews, for which the molecular biology laboratory exercise was used as a demo. Two of these individuals were later considered to represent more administrative staff, and therefore the final data is based on 16 interviews. 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.

2 RESULTS AND DISCUSSION

2.1 Student experiences

Both the organic chemistry experiment on decarboxylation and the molecular biology experiment have been assessed as course exercises by groups of first- to third-year students [10]. Organic chemistry exercises were performed in four groups total (two time slots, both with two simultaneous groups) on Mondays and Fridays. The students in Monday groups found the experiment was reasonably interesting and was in line with their previous studies to some extent and felt that they also learned some scientific content. However, it was evident that the students felt that the exercise could be completed by clicking through, without really putting much effort into the scientific contents. In contrast, students in the Friday groups, were more critical. Half of the students did not think that the exercise was very interesting and did not feel that they had learned anything new. They also admitted that they had just used the easiest route to get to the end of the experiment by haphazard clicking. Notes made by two independent observers support these differences. Some explanations for these differences were a) previous experience with virtual worlds and IT skills in general (both better Monday), and b) age (in Friday, freshmen only). We also admit that Fridays may not be the best day to conduct these types of studies. Students in all groups (97%) all emphasized that they felt that face-to-face interaction with the teacher is very important [10].

Based on the experiences gained on the organic chemistry exercise and the student feedback, we designed a new feedback form 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 with final comparison to the NIH database BLAST, which is commonly used in real-life comparison of virus sequences. Overall, the student response from the molecular biology experiment was positive [15,16]. Students stated that they had understood the assignment and a clear majority felt that they had learned something new. The difficulty level was considered appropriate. 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.

2.2 Towards using learning analytics

Preliminary identification of barriers and enablers to learning was performed in line with the framework of Warburton et al.[17]. based on the student interviews as part of piloting the use of learning analytics. Enablers of learning included the contextualization of abstract information, exposure to authentic content and culture, experiencing immersive environments without physical barriers. On the other hand, barriers were also evident, namely technical problems relating to actions in the VW. In addition, it was stated that cultural or professional conduct may become distorted as making a mistake does not lead to a consequence. Moreover, collaboration and interaction may be hindered by pressure caused by the faster advancement of others during a joint demo session and time needed to have the Avatar and the environment functional. As we believe that more quantitative data will be needed in the future, we also explored various routes for the possible application of learning analytics. In order to develop more quantitative tools for assessment of student progress, the total number of user interactions, ie. “clicks” were collected, this also included clicks at an individual working station, clicks made for starting the experiment, mistakenly made clicks and extra or unnecessary clicks. It was evident that students tried 1-3 times to restart the experiment, after which the numbers of clicks varied between 44 and 96 and the time used between 21 and 47 minutes. However, the number of clicks did not correlate with arriving at the correct solution to the exercise. On the other hand, even though the sample size was small, there was a minor tendency for students who tried 2 or 3 times to start the experiment to either not arrive at the right answer or then possibly only come close to the right answer [14]. These data are preliminary testing for the development of methods for the use of learning analytics, which will require large sample sizes.

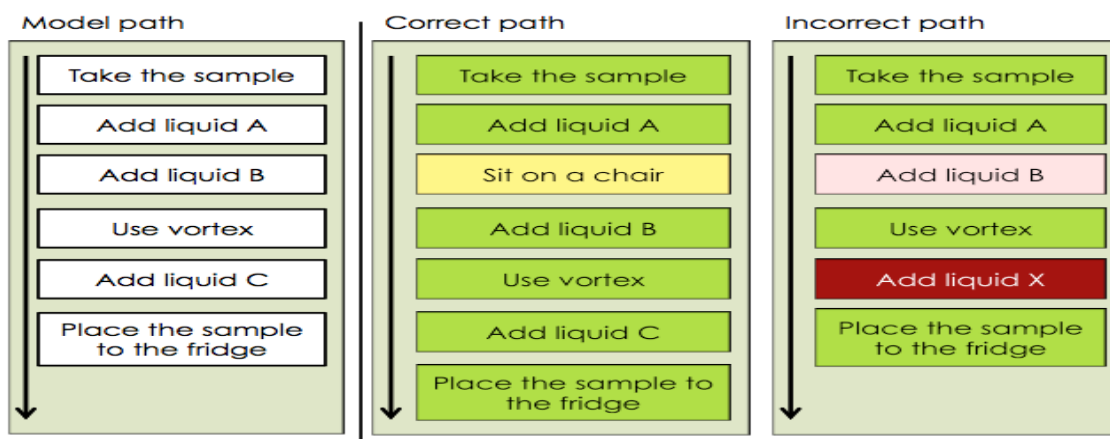


Fig 4. : Model for data analysis: Visualizing different paths the students take during a virtual laboratory exercise [14].

Based on this preliminary data we are currently working on a model for collection and analysis of quantitative data for future experiments (Fig. 4). The data consists of students' actions e.g. clicks and events triggered by the clicks, time tags of all the actions, compositions of the substances used, and needed actions. In the model for data analysis the students' actions will be compared to the “model path” which indicates the correct step-by-step completion of the exercise. Students' actions can be color-coded in order to better understand the difficulties during the exercise. Green boxes represent correct clicks, red boxes stand for incorrect clicks, and yellow boxes are clicks which do not rule out completing the exercise but will not help completing it either. Light red boxes indicate clicks which were supposed to take place, but weren't performed by the student. This approach is most suitable for the measurement of affordances and barriers in learning scientific facts and data, which typically are “right” or “wrong”, although this is not exclusive.

2.3 Teacher experiences

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. On the other hand, 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 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 (eg. chats, Facebook, Twitter etc.). However, 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, ie. 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.

3 CONCLUSIONS

The aim of our work is to generate virtual word learning environments which enhance learning. To do so, we have identified a number of enablers and barriers for learning, which at this point are mainly applicable to Second Life. Students clearly have the ability to complete exercises in a virtual world, regardless of lack of prior experience. Technical issues that appeared to be a hindrance are e.g. moving the Avatar around in a laboratory, obtaining the instructions of how to implement some

movement and teleport the Avatar into the laboratory. These issues are very specific to SL, however, they are to be expected to occur also in any other immersive world, where the individual takes on a virtual representation. Such difficulties may be hard to obliterate completely and it is therefore very important that students can familiarize themselves with the control tools of the VW prior to the teaching or learning event. On the other hand, our data shows that students do learn scientific contents and methodology in laboratory experimentations in SL and therefore, as suggested by Strangman [18] content area knowledge and conceptual change could be expected to be an outcome of the virtual world experiments that we have designed. Work on development of quantitative tools in terms of application of learning analytics is progressing and seems promising. However, the world of learning analytics is a complex area, where larger groups of students need to be studied. Currently, we have an excellent setup for data collection, with some preliminary data, which we will expand to a larger group of students. Collecting the information on how long and where students are likely to get “stuck” will allow us to have quantitative proof on how each phase or part of an experiment is approached by the student.

The most evident difference between student and teacher attitudes towards the use of VWs such as Second Life in teaching and learning stems from the teacher perception that they are less qualified to engage in new digital technologies. As the digitalization of learning and teaching is inevitable, this calls for a paradigm shift in teacher education. Moreover, it is important that new digital tools in teaching and learning are aligned with relevant context, the learning goals and desired outcomes are clearly defined, and the use of the digital technologies can be practiced in advance for the users to familiarize themselves with the technical requirements in advance. As use of digital teaching and learning tools require rather similar approaches, build up in confidence will assist the teacher and the students to eventually become comfortable with virtual learning environments. Based on our studies, both teachers and students have a positive attitude towards learning and teaching in VW learning spaces.

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