

Virtual Labstore: A Tool to Facilitate Inquiry-based Laboratory Research Education

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Abstract

In our biomedical educational program, students follow research courses. Traditionally, students receive research questions and pre-determined, teacher-prepared lists of laboratory materials to use. Currently, we aim to increase our research courses' inquiry level towards a more open inquiry by omitting these teacher-prepared lists. Additionally, we want to enhance the flexibility of student-teacher interactions during research courses. Therefore, Virtual Labstore was developed. This is an online 3D laboratory stockroom in which students are able to browse all the laboratory materials present in our university and buy materials for their experiments within the limits of pre-determined financial budgets. Furthermore, several online communication tools were made available to facilitate remote student-teacher interaction. Although several students initially experienced internet-connection related problems and lacked overview of the virtual workspace itself, students indicated during focus group sessions that using Virtual Labstore instead of teacher-prepared lists stimulated thinking about how to perform their experiments. Additionally, they acknowledged the value of being able to look for materials and communicate with their teacher independently of physical location. In conclusion, Virtual Labstore positively affected students' perceptions on learning about experimental design and increased student-teacher interaction flexibility. However, Wi-Fi-stability should be checked, and time should be allocated for student-training before use.

Keywords: second life, 3D virtual learning environment, inquiry-based learning, warehouse, store, shop, laboratory education, research education, distance education

Introduction

In the undergraduate educational program 'Biology and Medical Laboratory Research' of the University of Applied Sciences Leiden (The Netherlands), students are trained to become biomedical laboratory research technicians with a Bachelor of Science (B.Sc.) qualification. This program consists of several educational tracks, including a 'research track' in which research skills are taught, and a 'technical track', in which laboratory techniques are taught. Currently, we wish to implement inquiry-based research courses into our research track to stimulate scientific thinking and process skills.

Inquiry-based research courses focus on formulating the research question and hypothesis, developing the experimental procedures, performing laboratory experiments to collect data, and critically evaluating obtained results (French & Russell, 2006). Different levels of inquiry can be distinguished, based on who provides the problem, who provides the experimental procedures, whether the solution or outcome is known and the extent of the instructor's

involvement (Johnson, 2009; Herron, 1971). Generally, when the research question and the experimental procedures are provided by the teacher, the inquiry is categorized as structured. Presently, our aim is to implement more open inquiry-based research courses, in which the research question is still provided by the teacher, but the procedures are devised and performed by the students and the outcome is unknown. This situation mimics the situation in the work field for which our students are trained.

In our previous research courses, students received a research question and a pre-determined teacher-prepared list of selected laboratory materials which could be used to perform the experiments. Since these materials lists were presented at the beginning of the research course, we believe that the students' line of thinking was already directed towards the 'right' experimental approach. Hence, this type of inquiry would be classified as somewhere between structured and guided inquiry (Johnson, 2009). Our aim is to expose our students to a more open inquiry-based research experience in which

they develop their own experimental procedures. To do this we discarded the teacher-prepared materials lists and replaced them with an online warehouse system that displays the complete collection of laboratory materials available in our university. This online laboratory warehouse system enabled the students to select their own materials for their projects, and the selected materials were easily accessed by the teacher afterwards. Moreover, in order to mimic a real laboratory situation and raise cost awareness of our students, the products were price-tagged (Brown, 2006).

During the research courses, students discuss their research projects with their teachers in scheduled class meetings. Many of our students do not live in the vicinity of our university and often work on the preparation part of their research projects off-campus. Therefore, we additionally aimed to increase the flexibility of student-teacher interactions throughout the research courses by removing the need for a physical class space. This was achieved by implementing extra online sessions in addition to our scheduled face-to-face meetings in which students were able to discuss their projects with the teacher.

To integrate the warehouse system with an online communication platform, we developed Virtual Labstore. This is a three-dimensional (3D) virtual learning environment (3DVLE) in which avatars can interact with the laboratory warehouse system and communicate with others using both audio and text-based applications. Although the warehouse system could be constructed with Microsoft Excel or Access and shared with Learning Management Systems (LMSs) such as Blackboard, 3D platforms, such as Second Life or Active Worlds (Hew & Cheung, 2010), are known to have positive effects on students' appreciation of the learning environment (Tapsis et al., 2012). Over the years, many different 3DVLEs have become available and the majority of these 3DVLEs were designed as a) tools for learning support, b) simulation environments, c) social interaction environments and d) game environments (Reisoğlu et al., 2017). Furthermore, different 3DVLEs employ diverse learning strategies and have been used for a wide range of topics such as language learning, science, health science, the field of business and computer science (Reisoğlu et al., 2017). 3DVLEs that are situated in a laboratory setting generally consist of interactive simulations. Examples include Labster (Bonde et al., 2014), the Second World Immersive Future Teaching (SWIFT) project (Rudman

et al., 2010 and Rueda et al., 2018) and Earthlab Education Island (Vrellis et al., 2016). In Labster, pre-defined virtual laboratory exercises can be performed in which students also have to answer questions and receive immediate feedback throughout the exercises. In the SWIFT project, a genetic testing lab is simulated, and students can communicate with each other and teachers to facilitate discussion about the assignment. The Earthlab Education Island was used to combine a problem-based learning strategy with a laboratory simulation about the laws of reflection and trigonometry. However, although several 3DVLEs are available in which interactive laboratories are simulated and communication between users is possible, no 3DVLE has been available that simulates an interactive laboratory warehouse system which can be used to prepare real-world laboratory experiments. Hence, the newly developed Virtual Labstore constitutes a unique addition to currently existing 3DVLEs.

Virtual Labstore contains the complete collection of reagents and hardware present in our university, including product information and price-tags. Students can walk around freely in Virtual Labstore using an avatar and order the materials they need. Furthermore, a financial budget is assigned to each student group, which limits the amount of materials they can collect to perform their research. The limit of the financial budget is pre-determined by the teacher.

Additionally, Virtual Labstore provides a virtual communication platform in which students can interact with their teacher, independently of physical location. It contains both verbal and non-verbal communication tools as well as teaching applications such as blackboard and PowerPoint screens.

Virtual Labstore was implemented in a second-year research course in which students had to show whether apoptosis was induced in Jurkat cells after treatment with the cytostatic etoposide. Afterwards, several students were interviewed in two separate focus groups. Our key objective was to get an initial impression of how students experience 1) designing experiments with Virtual Labstore and 2) communication with the teacher in Virtual Labstore. For that purpose, we chose to perform a limited qualitative study with student focus groups since these have the advantage that students are able to follow up on each other's ideas and opinions through facilitated discussion (Leung, 2009).

Methods

Using Virtual Labstore

Prior to the research course, the Virtual Labstore environment was developed by the Spanish company 'The Education District' (Virtway). The system works with three different websites. The first site is the Virtual Labstore space itself in which students and teachers can walk around and collect materials they need. The second website is the back-end site in which users are added, students and teachers are assigned to classes and information about materials is imported into the system. The third website is the management site in which the virtual space itself is managed. We positioned all the materials in the virtual space and included protocols, tutorials and a blackboard screen using this site. This was simply done by adding links to available internet websites.

For each class (16-18 students), a clone of the Virtual Labstore space was generated in the management site and students were assigned. These clones were only accessible for the students of the assigned classes. All the students obtained accounts for Virtual Labstore. Each student research group, consisting of two students, received a virtual financial budget of €10.000 (approximately 11,000 USD) which could be used to collect the materials they needed for their research project.

At the beginning of the research course, a short demonstration of Virtual Labstore was given to the students during a kick-off lecture. Additionally, students received a manual which gave a description on how to use Virtual Labstore. Similarly, the teachers involved also received a short demonstration and a manual describing the tool.

The students worked in pairs and assigned to assess whether the cytostatic etoposide is able to induce apoptosis in Jurkat cells. For this purpose, they had to develop a working plan in which they outlined the experimental procedures they wanted to perform. This working plan was assessed by the teacher and provided with feedback. Students were given the opportunity to ask questions and discuss matters related to the research assignment during both in-class sessions and virtual sessions. One of these virtual sessions was held outside regular office hours. Working plans that were finished were sent to the teacher via email. Additionally, students finalized their purchase of materials in the Virtual Labstore by pressing 'check out'. Immediately afterwards, the teacher automatically received an email with the ordered materials. Based on the working plans and

purchases made in the Virtual Labstore, the teacher decided whether students were allowed to perform their experiments in the laboratory. In case of an insufficient working plan, students could send in an approved version and make new purchases in the Virtual Labstore. After the experiments were performed and the results were analyzed, students wrote a research report which was graded by the teacher.

The different functionalities of Virtual Labstore are displayed in Figures 1 to 13.

Evaluation of Virtual Labstore

On completion of the research course, two separate focus groups were organized. In total, 8 students were randomly selected for participation in one of these focus groups.

Questions were asked about the use of Virtual Labstore with regard to a) the materials students needed for their research projects, b) the possibility of asking questions virtually, c) the visibility of costs of the materials and a predetermined financial budget and d) the overall added value when working on a research question and developing a working plan. The focus groups were audio recorded and afterwards the transcribed text was analyzed according to the procedures of qualitative content analysis described by Erlingsson and Brysiewicz (Erlingsson & Brysiewicz, 2017). In short, meaning units were extracted from the transcribed texts and labeled with descriptive codes. Codes describing the same issue were further grouped into categories. This analysis was performed by two individuals independently of each other. Subsequently, the categories were compared, and consensus was reached on the final categories.

Additionally, a short evaluation session was held with the teachers that were involved. Questions were asked about the advantaged and disadvantages of working with Virtual Labstore to develop the working plan. The answers were written down by the researcher and similarly analyzed as described above.

Results

After performing qualitative content analysis, 8 categories emerged from the students' answers.

Category 1: Experienced added value of using Virtual Labstore instead of teacher-defined lists

According to the students, using Virtual Labstore instead of teacher-prepared lists stimulated their thinking about which materials were needed for what

purpose and enhanced their preparation. Students noted that when teacher-defined materials lists were available, as was the case in previous research courses, they knew they needed all the materials in these lists. In their opinion, this simplified the research assignment. When using the Virtual Labstore instead, students indicated that since they had to select their materials themselves, they really had to think more independently about how they were going to address the research question and perform the experiments. They indicated that this made them better prepared for the laboratory work afterwards.

Category 2: Experienced added value of working virtually in Virtual Labstore.

Students acknowledged the benefits of being able to have virtual question sessions with the teacher and looking for materials in the Virtual Labstore. The fact that Virtual Labstore is accessible in every location with an internet connection eliminates the need to travel to a certain physical location. This allowed the students to be more flexible. However, some students mentioned that they preferred face to face communication due to lack of eye contact / non-verbal communication in the virtual space. Students also mentioned that they could get accustomed to communicating virtually.

Category 3: The teacher must take the lead during virtual question sessions.

During virtual question sessions, communicating in the virtual space could be difficult and chaotic; at certain moments, students were talking all at once because it was not clear who was going to talk first. However, students indicated that if the teacher took the lead during the virtual sessions, this problem was solved.

Category 4: Cost awareness and financial constraints

Students indicated that the price information made them more aware of the costs of laboratory work. This potentially provides a more realistic situation since there is a financial constraint on the experimental choices students can make. However, since the budget was very high, it did not constrain students' work.

Category 5: Improving Virtual Labstore by providing a better overview of the available materials.

Several students indicated that they lacked an overview of the Virtual Labstore. They had difficulties finding the materials and protocols they needed and were therefore hampered when making their

research working plans. A suggestion was made to provide information on the contents of the cupboards at the location of the cupboard itself.

Category 6: Several aspects of working in the Virtual Labstore space itself are unpractical.

Students experienced several difficulties which were related to working in the Virtual Labstore space itself. Sometimes, students blocked each other's view in front of the cupboards. Additionally, it is possible that different students have the same avatar, and although names can be put on top of the avatars, this is very unpractical. Finally, sometimes the information on the little jars in the cupboards was difficult to read.

Category 7: Increase 'ease of use' by providing training for students and teachers

Students complained about the difficulty of using the Virtual Labstore. They proposed several solutions for this problem, including tutorials and demonstration movies about Virtual Labstore and a guided tour in the Virtual Labstore. They also proposed additional training for the teachers involved.

Category 8: Technical issues

Students experienced several technical issues, most of which were related to suboptimal access to the internet. These included problems with accessing the Virtual Labstore, slow loading of the avatars and materials lists and downloading protocols. When using Apple computers, product information was not visible.

In addition to the two focus groups with students, a short evaluation session was held with the teachers that were involved.

Several advantages of using the Virtual Labstore were mentioned. According to one teacher, students asked more questions and seemed to be less afraid to ask 'stupid' questions since they did not seem to be hampered by peer pressure. Another teacher added that in her experience, their questions were more specific than before. For example, they asked things such as '*can I use this cell proliferation kit to demonstrate that apoptosis has occurred?*' instead of '*what exactly are we supposed to do?*'. Additionally, specific questions about the datasheets (spec sheets) that accompany the materials in the Virtual Labstore were asked. Teachers noted that the large number of materials available in Virtual Labstore called for a more thorough preparation by the students.

Disadvantages that were mentioned included 1) technical issues similar to those experienced by the students and 2) difficulties with finding materials in the Virtual Labstore and finding protocols for carrying out the experiments.

Discussion

To increase the level of inquiry of our research courses towards open inquiry, we developed Virtual Labstore. We circumvented the use of teacher-prepared lists of selected laboratory materials by creating a virtual warehouse containing all available laboratory materials in our university. Students received a research question, worked on their experimental designs and subsequently selected the necessary materials in Virtual Labstore, taking into account product and price information.

Our key objective was to assess how students experienced the replacement of the teacher-prepared lists of necessary materials with Virtual Labstore and how it affected their perception of designing experiments. The students indicated that they needed to think more independently during the experimental design phase which enhanced their preparation. According to the teachers, the students asked more specific questions about the research strategy as well as the protocols they found attached to the materials present in Virtual Labstore. These observations could indicate that the students demonstrated an increased sense of 'agency' in relation to the research project. Agency combined with mentorship has been described as a positive indicator for student project ownership and this has been associated with a positive research experience (Hanauer et al., 2012). The current findings are also in line with a previous report in which students felt they had to think and analyze more throughout a guided inquiry-based physics course (Parappilly et al., 2013).

Our secondary objective was to assess how students experienced the flexibility of student-teacher interactions through the use of virtual classrooms. Scheduled sessions with the teacher in Virtual Labstore enabled students to ask questions about their working plans. Students indicated that working independently of a physical location increased their flexibility. However, some students mentioned that they preferred face-to-face communication since eye contact and non-verbal communication were absent but that they could become accustomed to communicating virtually. One teacher observed that working in a virtual world lowers the strain of shyness, which is in line with a similar observation made by Pfeil et al. (2009). Hence, we conclude that

using Virtual Labstore for virtual educational sessions is a useful tool to increase the flexibility of our educational program.

In order to raise cost awareness of our students, all the materials were realistically price-tagged, and student research groups received a financial budget. Students appreciated the price information but noticed that the provided financial budget was unrealistically high. For this study, we did not wish to hamper students' work by providing a budget that was too small. Therefore, we chose a high budget that would not limit students' purchases. However, by monitoring the current purchases of the students, we obtained indications for a more realistic budget which we can use in the future. Preliminary calculations have estimated this realistic budget to be a couple of hundred euro's (similar amount in USD) for the current research course. We believe that providing students with a realistic financial budget could be very helpful when working in a more open inquiry setting since it may facilitate self-regulation of the magnitude of students' projects. In the future, it would be interesting to compare the current student learning experiences with those of students who obtained a realistic budget.

Throughout the Virtual Labstore sessions, several aspects of the virtual space itself, including overcrowding, were experienced as unpractical by the students. In the real world, students perceive insufficient working space in the laboratory as a deficiency in the learning environment (Sandström et al., 2013). Generally, an uncomfortable physical learning space which hampers performing tasks has a negative effect on learning (Sjöblom et al., 2016) and this might also be true for virtual learning spaces. Winkelmann et al. (2017) reported that using virtual laboratory environments is regarded as helpful when space and equipment are limited in the real-world laboratory. We therefore believe that we should take advantage of the fact that in virtual learning spaces, practical issues such as overcrowding can easily be resolved. In the future, overcrowding may be prevented by having less students entering at the same time. One way to achieve this is by creating separate clones for each student pair. Additionally, the email addresses of the students are currently displayed on top of their avatars as a means to identify the avatars. However, these long email addresses hampered avatar identification when more students were closely together in the virtual space. Virtual Labstore uses the login names of the students as identification names for the avatars. Since we were

using Virtual Labstore with more than 100 students, it seemed most practical to use students' email addresses as login names because these were readily available. However, to better facilitate the identification of the avatars, we are planning to create short login names for the students in the future. Interestingly, using a personal avatar increased students' sense of telepresence and copresence throughout an English as Foreign Language course performed in Active Worlds (Peterson, 2006). Hence, we are currently also thinking of developing and implementing the ability to customize avatars in order to better facilitate student identification and to further enhance students' learning experience.

Students indicated that they had difficulties using Virtual Labstore for the first time and finding their way inside the virtual space. One student suggested providing content information near the cupboards. This content information was already available when clicking on the signs above the cupboards but apparently this was not noticed by all the students. In order to improve ease of use of Virtual Labstore, students indicated that they needed more and better instruction on how to use Virtual Labstore. This is in line with previous reports (Pfeil et al., 2009; Salmon et al., 2010) in which the importance of investing enough time in getting students and tutors started with the virtual system was mentioned. In the current research course, a short introduction was given to the students during a kick off meeting in which other information about the course was given as well. Additionally, an online manual about the virtual platform was provided. Clearly, this was not sufficient for many of the students to be able to use the platform efficiently. Therefore, we plan to organize several dedicated meetings about the platform in the future, including a demonstration of a pre-recorded virtual tour and a tutorial with exercises about the different functionalities that are present in this virtual world. Besides training the tutors in how to use the virtual space, Pfeil et al. (2009) also emphasized the importance of training tutors in how to teach and moderate teaching sessions in the virtual space. For example, our students reported that the teacher has to take the lead to facilitate a structured virtual class meeting. Hence, before using Virtual Labstore in the future, a training program for both students and teachers should be developed and time should be invested to execute and evaluate this program.

Several technical problems were encountered by

some students, including loading elements of the Virtual Labstore and loading the Virtual Labstore environment itself. These problems were mainly related to a hampered connection to the internet. Most likely this was caused by low Wi-Fi stability and not so much by low internet speed (personal communication with The Education District, Virtway). Warburton (2009) already mentioned technical issues in 2009 which can cause 'lags' that occur when too many objects within a single location cause slow loading. These lags can lead to a frustrating experience and pose a barrier to successfully implementing a virtual world. Therefore, in order to have a positive Virtual Labstore experience, a good internet connection is crucial and when Wi-Fi stability is low, a wired Ethernet connection might be used as an alternative instead. Thus, facilitating a proper internet connection needs to be taken into account when students access Virtual Labstore both at home and on campus.

At present, our educational program consists of several educational tracks. The research courses are part of the research track which focuses on teaching research skills. Our technical track includes educational courses about laboratory techniques. As mentioned before, there are other 3DVLEs that simulate laboratory environments, such as Labster (Bonde et al., 2014). Labster is a platform in which pre-defined virtual laboratory exercises are simulated and in which students are allowed to make mistakes. In our opinion, this is a very interesting tool for learning how to perform laboratory experiments and it could be very helpful in our technical track to prepare our students for real-world experiments. In the future, we therefore aim to use Virtual Labstore and Labster separately for our research and technical tracks respectively.

In conclusion, Virtual Labstore is a promising tool which can facilitate a more open inquiry-based laboratory research course and increase the flexibility of student-teacher interactions. Virtual Labstore can easily be adjusted by teachers with new laboratory techniques, protocols and tutorials. Challenges that need to be addressed in the future are the development of a training program for both students and teachers. Finally, the current study indicated that using Virtual Labstore enhanced students' perception of their own thinking about experimental design. However, future studies are needed to evaluate whether students' actual ability to design experiments also increases by using Virtual Labstore.

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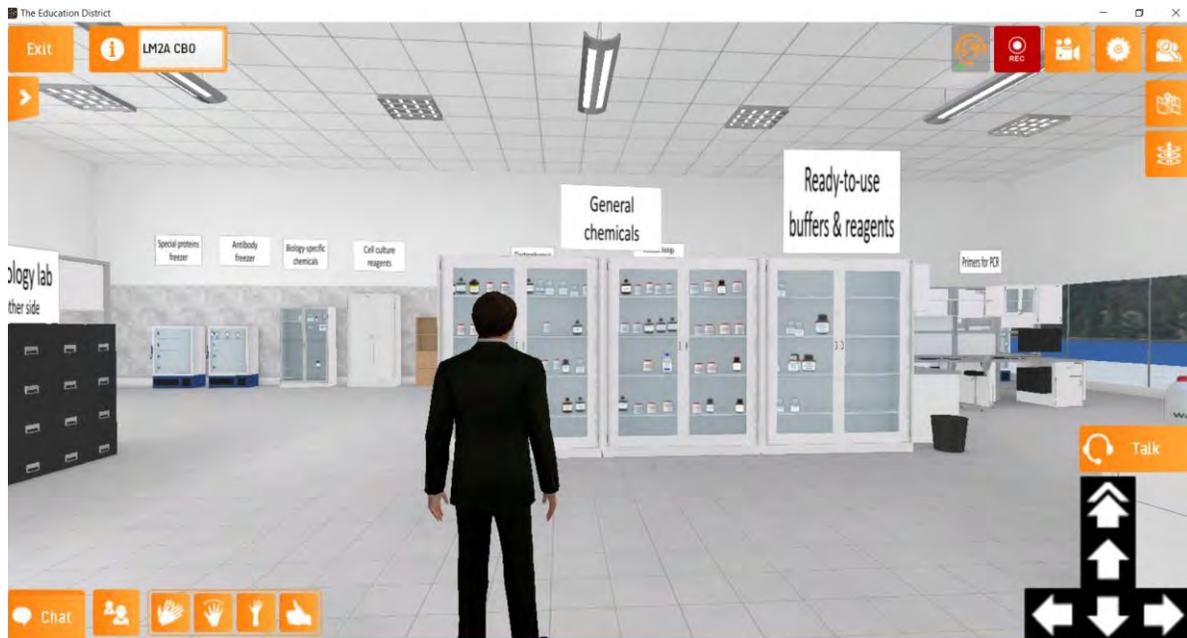
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Appendix

Figure 1.

General overview of Virtual Labstore.



The arrow buttons are used for walking through the virtual space. Talk and chat buttons are present for communication. Additionally, hand gesture buttons are available and optionally, a recording button can be added as well.

Figure 2.

Close-up of the General Chemicals cupboard.

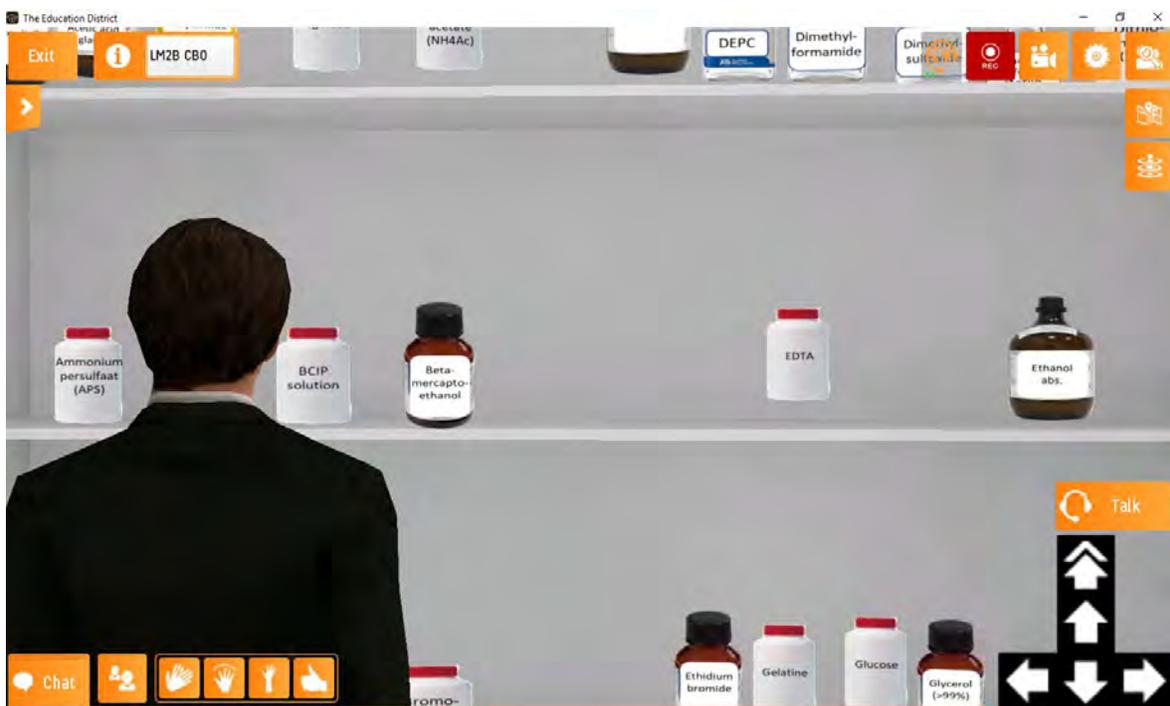
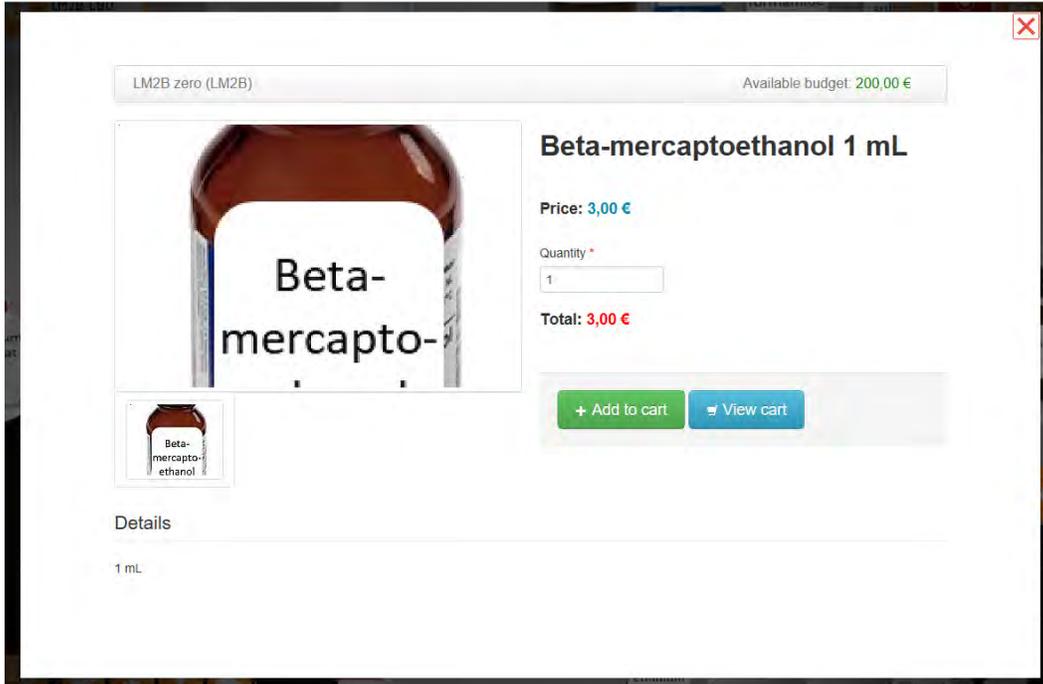


Figure 3.

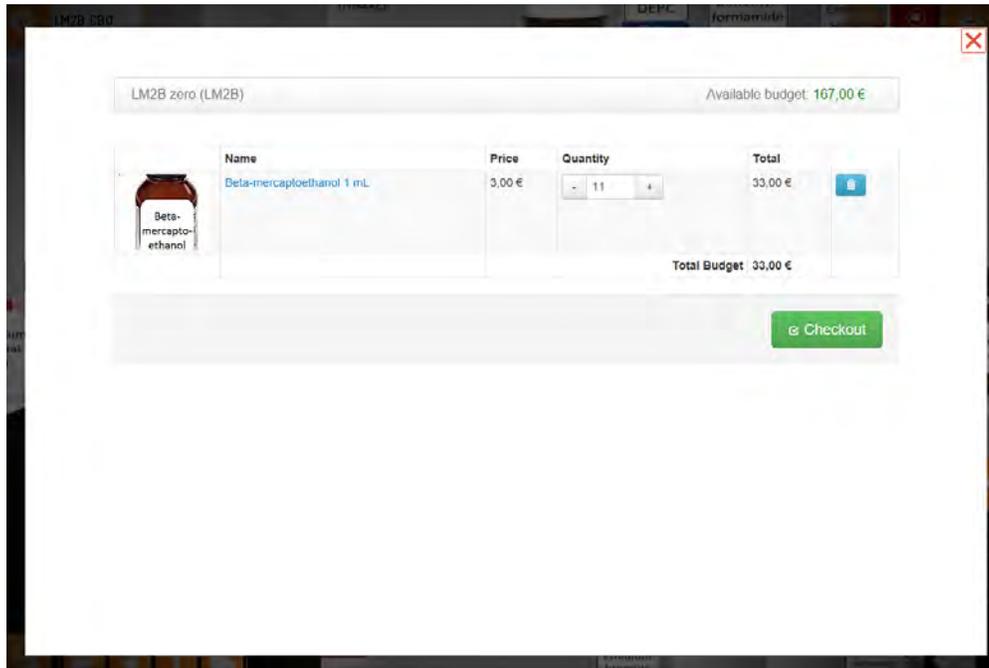
Product buying functionality.



After clicking on the beta-mercapto-ethanol bottle in Figure 2, the current screen is displayed. Price information and details of the product are depicted. In the upper right, the available financial budget can be seen. The product can be bought by clicking on the 'add to cart' button.

Figure 4.

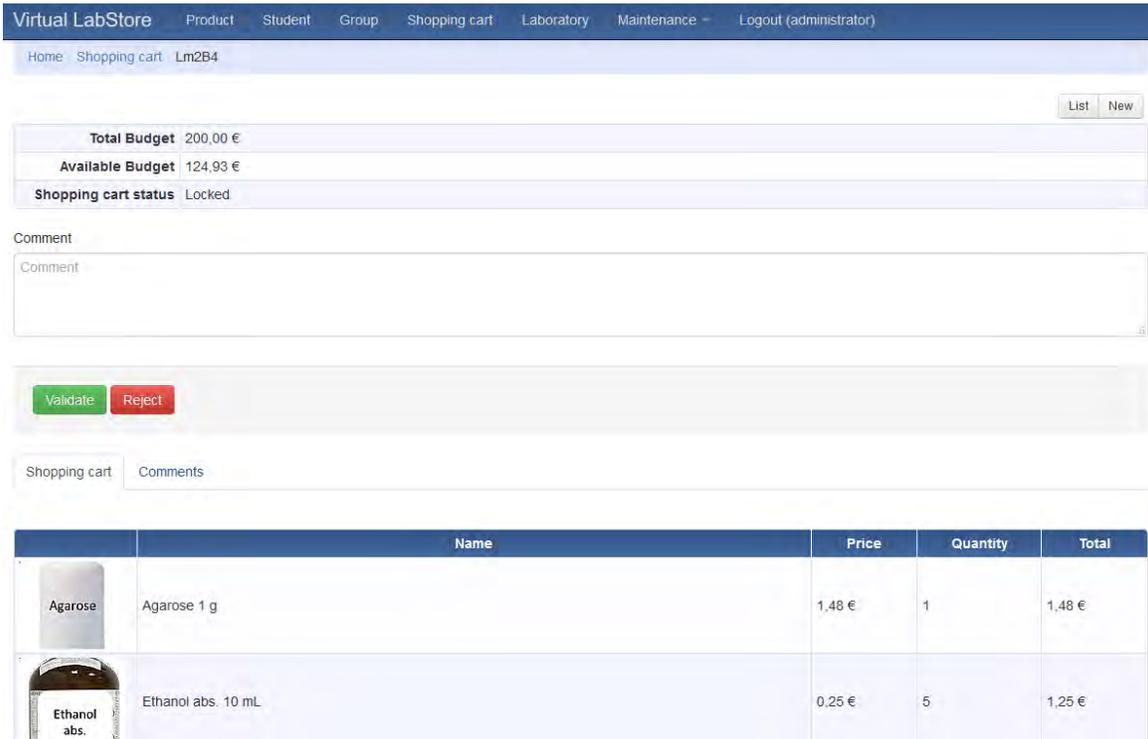
Product buying functionality.



After ordering 11 bottles of beta-mercapto-ethanol in Figure 3, the 'view cart button' was pressed and the current screen is depicted in which all the ordered items are listed.

Figure 5.

List of the ordered materials the teacher receives after student pressed the 'checkout' button in Figure 4.



Virtual LabStore Product Student Group Shopping cart Laboratory Maintenance Logout (administrator)

Home Shopping cart Lm2B4

List New

Total Budget 200,00 €

Available Budget 124,93 €

Shopping cart status Locked

Comment

Comment

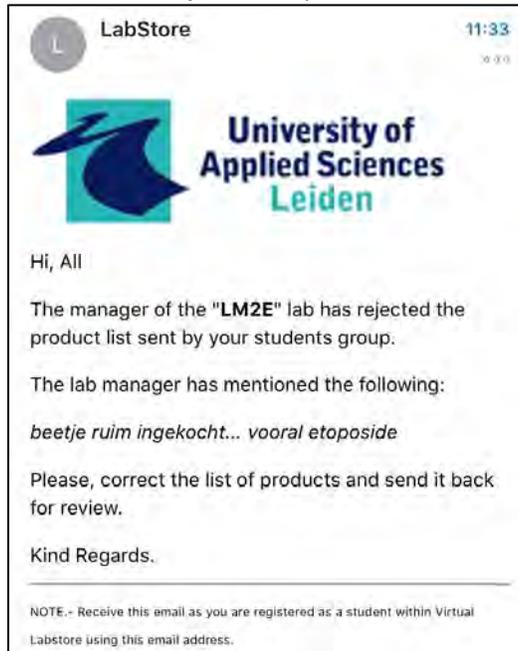
Validate Reject

Shopping cart Comments

	Name	Price	Quantity	Total
	Agarose 1 g	1,48 €	1	1,48 €
	Ethanol abs. 10 mL	0,25 €	5	1,25 €

Figure 6.

Message received by students after teacher has rejected the product list.



LabStore 11:33

 University of Applied Sciences Leiden

Hi, All

The manager of the "LM2E" lab has rejected the product list sent by your students group.

The lab manager has mentioned the following:

beetje ruim ingekocht... vooral etoposide

Please, correct the list of products and send it back for review.

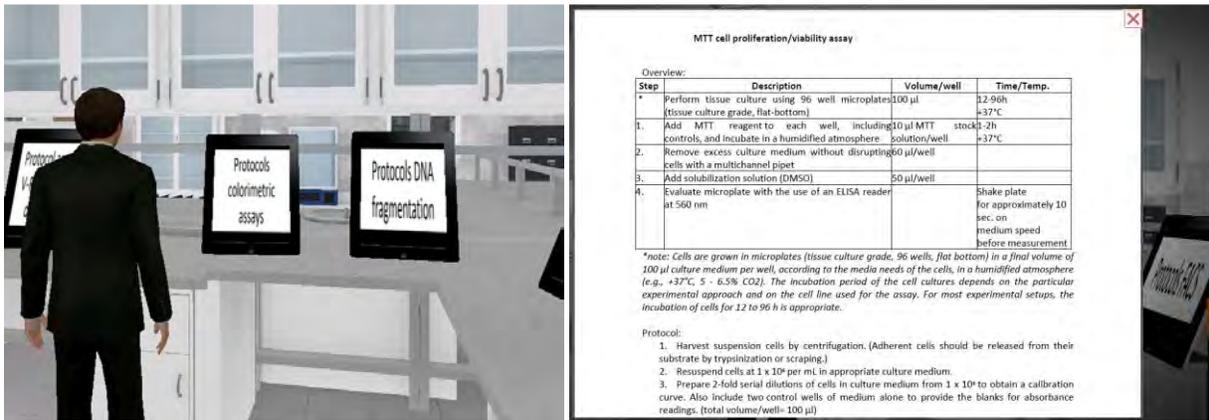
Kind Regards.

NOTE.- Receive this email as you are registered as a student within Virtual Labstore using this email address.

After the teacher has pressed the 'reject' button in Figure 5, the message depicted in this figure is sent to the students via email. The Dutch sentence '*beetje ruim ingekocht, vooral etoposide*' translates as '*you bought a lot of etoposide*'.

Figure 9.

Protocols can be added to the Virtual Labstore.



Protocols can be added to the Virtual Labstore by adding them manually or by inserting internet website links into the management site.

Figure 10.

An example of an inserted internet connection.

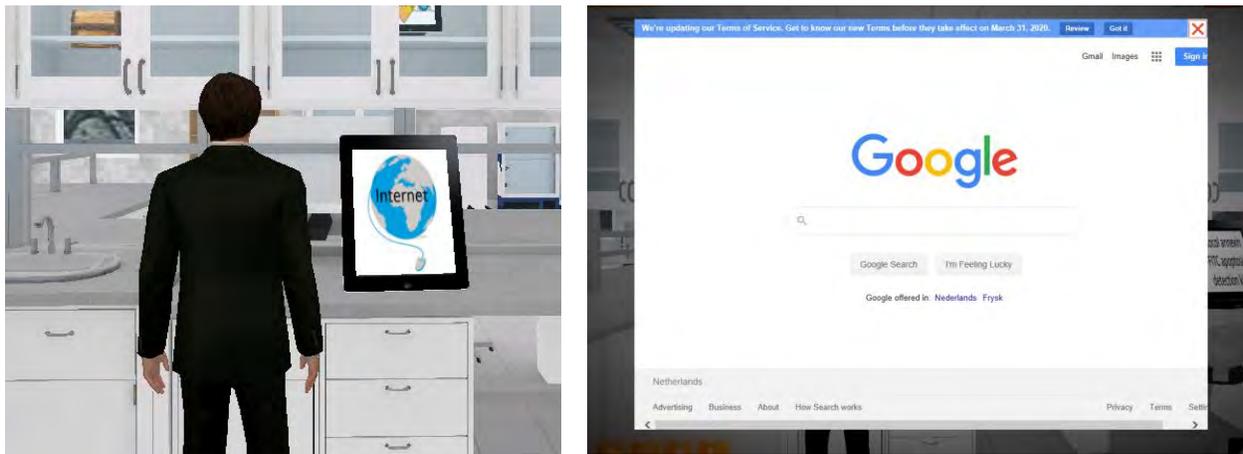


Figure 11.
Managing products in the back-end site.

Name	Price	Deactivated	
Acetic acid glacial (azijnzuur) 1 mL	0,04 €	No	
Acrylamide (30%) / bis (29:1) 1 mL	0,50 €	No	
Agarose 1 g	1,48 €	No	
Ammonium acetate 10 g	0,13 €	No	
Ammonium persulfaat (APS) 100 mg	0,13 €	No	
Ammonium sulfate 10 g	2,85 €	No	
BCIP (5-bromo-4-chloro-3-indotyl-phosphate, Boehringer-Mannheim) solution 50 mg	58,50 €	No	
Beta-mercaptoethanol 1 mL	3,00 €	No	
Boric acid 1 g	0,06 €	No	
Bovine serum albumin (BSA) 10 mg	0,80 €	No	

New products are added by pressing the '+New' button.

Figure 12.
Managing products in the back-end site.

Virtual LabStore Product Student Group Shopping cart Laboratory Maintenance Logout (administrator)

Home Product Acrylamide (30%) / bis (29:1) 1 mL Update

Product images

Details

Name * Acrylamide (30%) / bis (29:1) 1 mL

Description **A Normal text** Black **Bold** *Italic* Underline

1 mL

Products can be adjusted and descriptions can be added.

