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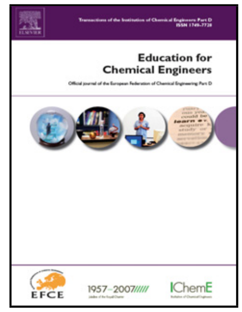


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**Learning Experiences from Digital Laboratory Safety Training**

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**Abstract**
We present a digital laboratory safety training platform called AALTOLAB which we have developed to address the need for more flexible and engaging ways to teach laboratory safety for chemical engineers. AALTOLAB consists of an interactive, web-based 360° virtual laboratory, integrated with a Moodle-based digital exam with automatic assessment. The modular platform offers different modules from general comprehensive laboratory training to more specialised modules. Students and staff can freely navigate in the laboratory rooms at any time and interact with different action points including interactive videos, slideshows, and minigames. Our technical solution allows teachers even with limited technological skills to easily modify the training materials in real time. The relationship of students' learning experiences and level of learning is also discussed. We believe that our safety training concept facilitates deep learning and students' engagement, thus improving safety culture in our laboratories.

**Keywords:** Laboratory safety; Virtual reality; Online learning; Digitalisation

## 1. Introduction

Safe laboratory practices are a key part of a chemist's professional portfolio, and traditionally in higher education they are taught gradually in different laboratory courses during the whole study curriculum. It is also very common that universities demand a general laboratory safety training in order to ensure a certain level of knowledge already before starting to work in any laboratory premises. Recently, more in-depth approaches have also been reported, which include for example follow-up revisions in the upcoming years (Loughlin and Crosswell, 2020) or fostering safety culture via the ongoing safety discussions later on (Thomsen and Borre-Gude, 2020).

Such a multi-step model has proved rather functional, but in order to ensure a wide-spread safety culture,  there is plenty of room for development: a number of high-profile laboratory accidents at academic laboratories in the past decade emphasize the need even for more effective and rigorous laboratory safety training (Yang et al., 2019; Ménard and Trant, 2020). There are also some clear disadvantages to the (most) traditional approach to laboratory safety education, for example lecture-based teaching of laboratory safety can feel too separated from the real laboratory environment, and as the laboratory courses themselves are typically designed to be extremely safe, students' attitude towards the safety issues is diluted to mere nuisance rather than the core knowledge of their professionalism (Ménard and Trant, 2020). Moreover, from the practical point of view, laboratory-related teaching sessions are also very much tied down to the time and place - which can be a limiting factor for a student's study progress, and any exceptional situations such as student sick leaves may easily increase teachers' workload. This can result in a vicious circle further enhancing students annoyance towards the topic and burdening teaching staff enormously.

One very timely strategy to address the above challenges in laboratory safety training is to harness virtual laboratories in education (Glassey and Magalhães, 2020). We have witnessed a great bloom of virtual laboratories in past years and their pros and cons have been reviewed for example by de Jong et al. (2013) and Potkonjak et al. (2016). A major advantage of virtual laboratories is that they save costs as the activities can be repeated as many times and by as many persons as necessary without notable extra costs. Such flexibility and availability of virtual platforms can also enhance the autonomy of students (Granjo and Rasteiro, 2020). Furthermore, virtual laboratories allow the students to observe and create scenarios that are unachievable or very dangerous in real life. Related to this, well-implemented gamified laboratory simulations can motivate students and improve learning outcomes compared with traditional teaching methods. (Bonde et al, 2014). Another very promising finding is that virtual laboratories or virtual field trips can strongly support the corresponding real-world activities when the students can first prepare in a virtual setting (Saifan, 2019; Saifan, 2020). The cons of virtual laboratories are that creating and using immersive 3D virtual laboratories requires significant financial resources and it still does not remove the need for real-life laboratory training. Additional risk is that a virtual laboratory setting may lead to a crooked student attitude, in other words to a lack of seriousness and carefulness.

In their pioneering article, Makransky et al. (2019) studied the connection between different virtual learning methods and learning results. Their main finding could be presented as follows: Immersion ≠ Learning. The study showed that the high-level immersion enabled by a virtual reality (VR) headset supports learning, but overloads the students' brains. This leads to a decreased focus on the actual topic, resulting in inferior learning results compared to a setting where a student uses the 3D materials from a conventional PC screen with a mouse and a keyboard. However, this result does not directly confirm that increased immersion always has negative outcomes. Some studies have also found opposite results (Alhalabi, 2016; Passig, Tzuriel, & Eshel-Kedmi, 2016; Webster, 2016). It is quite possible that the mere novelty of using a VR headset might be the reason for the brain overload, not the immersion itself.

A recent study by Pekdağ (2020) suggests that video-instructing can be more effective than traditional safety instructions, at least when studying the student performance in the safety exam afterwards. However, Pekdağ (2020) also emphasizes that mental overload is one of the critical factors in video-based instructions as too detailed videos resulted in confusion over different safety rules.

To tackle some of the challenges related to both laboratory safety training and novel virtual-reality based learning environments, we have developed a digital laboratory safety training platform called AALTOLAB. The target audience is all students and staff of the Aalto University School of Chemical Engineering. In this short communication, we report the technical solution of a modular laboratory safety training platform, with each module designed to provide more specialised knowledge. Furthermore, we also discuss the preliminary results of the relationship between students' learning experiences and level of learning.

## 2. AALTOLAB digital safety training platform

AALTOLAB is a digital laboratory safety training platform developed at Aalto University (Finland). Currently, the platform consists of three modules. A comprehensive general laboratory safety training module is obligatory for anyone who wants to work in our laboratories. Thus, the population entering the general training module is very diverse. The main target audience is our BSc, MSc, and PhD level students majoring in chemical engineering, chemistry, biosciences, wood chemistry, and materials science, but we also get students majoring in other fields such as electrical engineering or art and design, who typically participate in different laboratory-based workshops and multidisciplinary project courses. Additionally, all our staff - from technical support to professors - are expected to successfully complete this general training module.

More specialised modules can be undertaken when the students or researchers progress in their studies and research. Therefore, we have created an additional module for our staff, including topics like how to plan experiments and carry out risk assessments related to experiments. Also, a specialised module has been developed for working in cleanrooms, which only well-trained staff and students can enter. Future extensions currently under work include Biosafety and Radiation Safety modules

After the general laboratory safety training module and the more advanced staff module were completed in spring 2020, all academic and technical staff of the Aalto School of Chemical Engineering were required to complete them. In the following discussion, all participants of the safety training are referred here as students, even though their status varies from undergraduate students and to staff members. The AALTOLAB modules are open at any time and anyone can visit them whenever it suits them best. All training materials are licensed under Creative Commons Attribution ShareAlike 4.0 license (CC BY-SA 4.0), which means that they can be freely used, copied, and redistributed in any medium or format. We encourage everyone to make use of them if applicable, links to the material are available in the Supplementary materials.

Each module of the AALTOLAB safety training platform consists of two components: 360° Virtual Laboratory Space and an integrated, Moodle-based digital safety exam. In the following, we discuss the implementation of these components.

**2.1 Implementation of 360° Virtual Laboratory Space**

The 360° Virtual Laboratory Space can be accessed with any modern web browser and is based on 360° panorama pictures from our actual student laboratories (Figure 1 and http://lab.aalto.fi). The virtual environment has been created using 3DVista program package (https://www.3dvista.com/). From 3DVista, the virtual environment can be exported as a collection of HTML5 and JavaScript source files that can be uploaded at any server that can be accessed with a web browser. The virtual environment is compatible both with desktop and mobile devices, as long as the device supports HTML5 and JavaScript.

Students can freely navigate in the different laboratory rooms by using a mouse or a touchscreen. The virtual environment contains action points, with which the students interact to study topics related to laboratory safety. The action points include slideshows, photos, interactive educational videos with questions, and minigames (Figure 2). The action points have been implemented with H5P (https://h5p.org/), which is a free and open technology to create and share interactive HTML5 content.


*Figure 1. An example view of the AALTOLAB 360° Virtual Laboratory Space.*

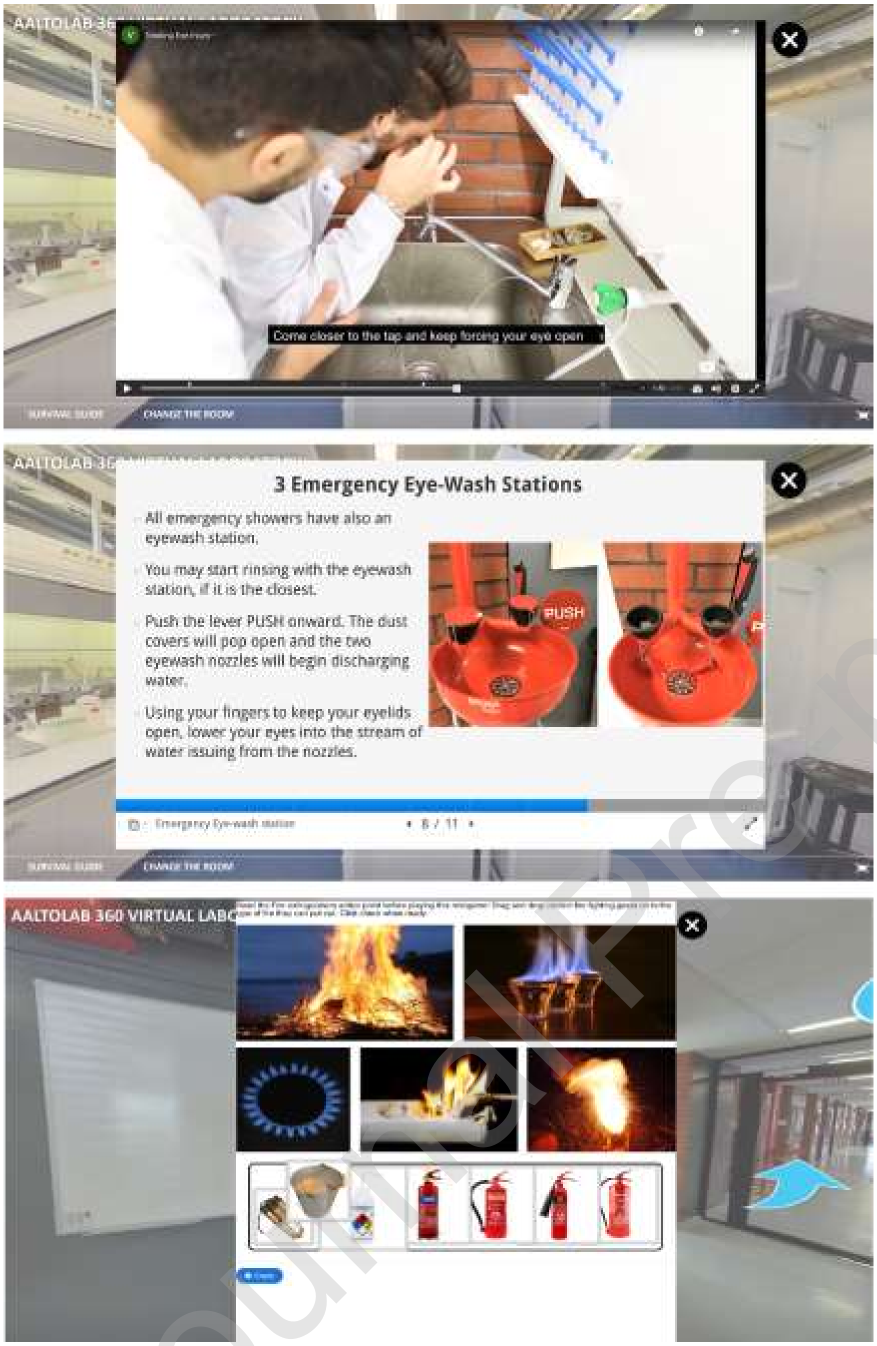



*Figure 2. Examples of action points in the AALTOLAB* 360° *Virtual Laboratory Space: interactive videos (top), slideshows (middle), and minigames (bottom).*

The H5P activities of the 360° Virtual Laboratory Space actually reside in a Moodle Learning Management System (https://moodle.com/) and from there they are embedded to the virtual environment created with 3DVista. The H5P activities could also be embedded from other platforms such as H5P cloud service (https://h5p.com/), but we chose Moodle as it is readily available at Aalto University and we will anyway be using it for the digital safety exam (see below). The overall architecture of AALTOLAB is illustrated in Figure 3 and the main purpose of this approach  is to enable easy editing of the laboratory safety training material. The laboratory safety teachers do not have to worry about the 360° virtual environment or 3DVista as they only need to login to our Moodle and edit the H5P activities with the very accessible user interface provided by H5P. For example, for editing the slideshow-type information points, the teacher does not need to know any aspects related to HTML, JavaScript, or 360° panoramas. The H5P-based content management approach has already proven to be very agile during translation of the 360° Virtual Laboratory Space into other languages. The video materials created for the 360° Virtual Laboratory Space have also been used in BSc-level, compulsory Swedish language course for chemical engineering students, where the students who have completed the safety training have then made their own safety videos in Swedish, in order to further nurture the safety culture and utilise collaborative learning principles (McGarry et al., 2013).

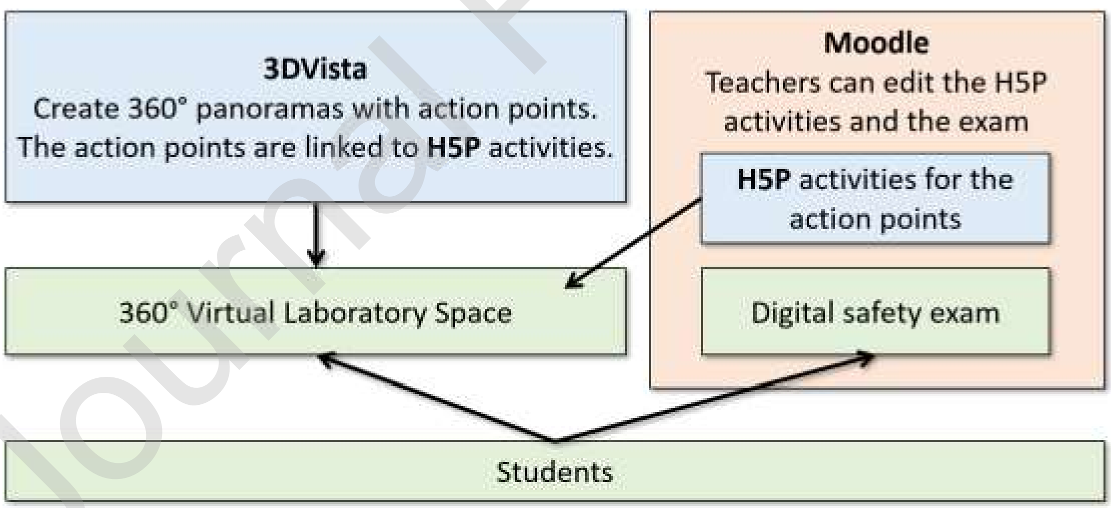



*Figure 3. Architecture of the AALTOLAB Laboratory safety training platform.*

**2.2 Implementation of integrated Moodle-based digital safety exam**

We assess the learning of the students with an integrated Moodle-based digital safety exam, which is in practice an automatically assessed Moodle Quiz (Figure 4). The exam includes a variety of different question types such as multiple choice questions and drag-and-drop questions. The only limitation for the question types is that there must be a method to grade them automatically. We have chosen this approach to increase the flexibility and scalability of the digital exam and versatile use of different question types ensures that the exam still assesses learning in a rigorous way. Students can take the exam as many times as they want, and an automated feedback is provided for each question. The exams are designed in such a way that a brute-force trial and error approach cannot be utilised: each exam attempt consists of about 30 questions which are randomly selected from a question bank of over 120 questions. The questions have been carefully formatted so that searching answers with search engines is less efficient than using the study materials in the 360° Virtual Laboratory Space. This is achieved with specific question deployment, such as "How do you act in situation X?" or "If you do Y, what should you do next?"

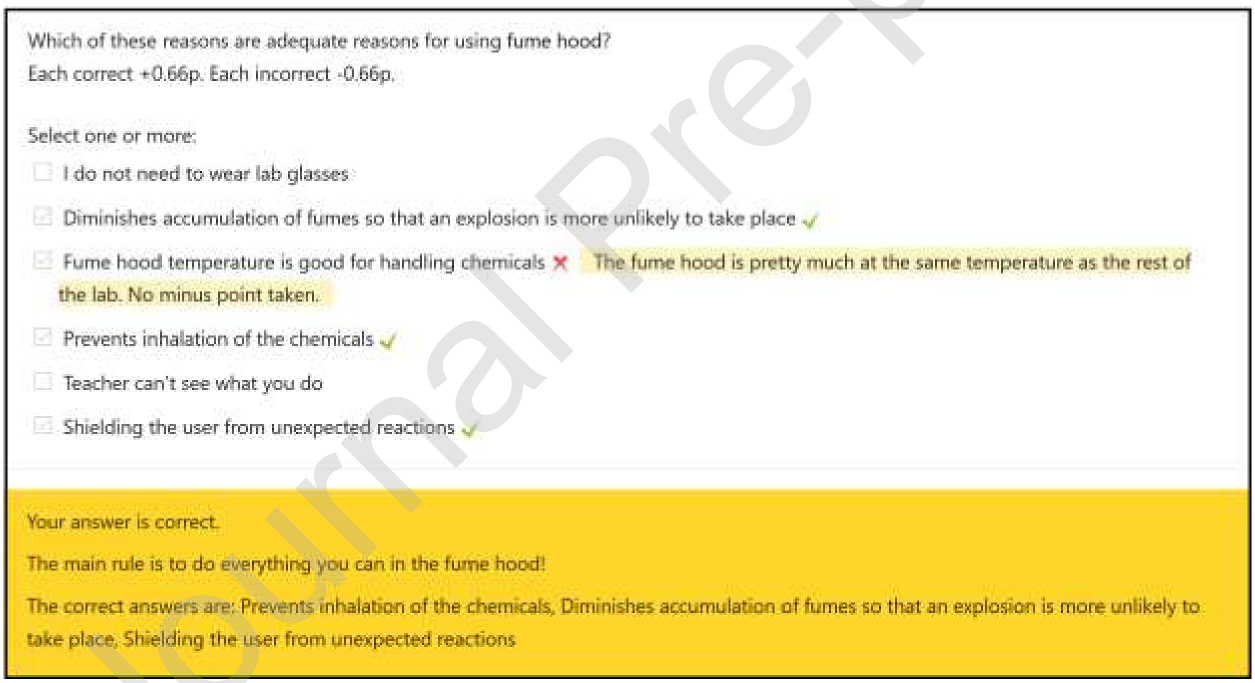



*Figure 4. An example of a question and related feedback in the laboratory safety exam.*

In order to avoid the wrong idea of laboratory safety being a list of small details which need to be memorized, students are strongly advised to keep the 360° Virtual Laboratory Space open when they are taking the exam. The main topics in our general laboratory safety training module (called Common Module) are listed in Table 1. A specialised module for our staff (called

Staff Module) includes more detailed information, necessary for working as an independent and responsible researcher.

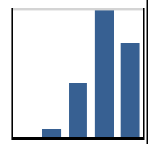
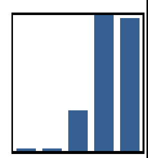
*Table 1. Topics in the Common (general) and Staff laboratory safety training modules of AALTOLAB. In total, the general and staff training modules include about 40 and about 10 action points, respectively.*

| **Main topics in the general laboratory safety training module** |
|---|
| Where do I find information about chemicals (chemical safety data sheets and hazard pictograms)? |
| What type of personal protection equipment should I choose in different cases (typical for teaching laboratories)? |
| What to do with chemical waste? Our training does not include full waste management plans. |
| What to do in case of fire / chemical splash into the eye / small wounds and cuts / chemical spillage on the floor / broken glassware? Our training does **not** substitute a true first-aid training. |
| How to evaluate possible risks? Risk assessment is done at a very simplistic level and students are not expected to write full risk assessment reports. |
| **Main topics in the staff training module** |
| Risk assessment |
| Incident reporting |
| Waste management |
| Infrastructure booking |
| Ordering chemicals |

**3. Students' Learning Experiences**

At the end of the digital exam, students were asked to answer three voluntary feedback questions which were assessed in a five-point Likert scale as presented in Table 2. The three questions and corresponding answer distribution collected from the feedback given by the staff members who had completed the general and staff safety training modules are presented in Table 2. Only one set of feedback answers from every student was taken into account, even if they completed the quiz several times to achieve a better overall score.

*Table 2. Feedback questions and students' answer distribution* (N = 221).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **My general opinion for the digital course materials is ....** | **I hated it = 1** | **I did not like it = 2** | **It was ok = 3** | **I liked it = 4** | **I liked it very much = 5** | **Column chart** | **Mode** |
| | 1 % | 3 % | 24 % | 38 % | 34 % |  | 4 |
| **My general evaluation for Digital Exam is ....** | **Very bad = 1** | **Bad = 2** | **Ok = 3** | **Good = 4** | **Very good = 5** | **Column chart** | **Mode** |
| | 0 % | 3 % | 19 % | 44 % | 33 % |  | 4 |
| **I think that 360° virtual space is a fun and efficient way to present the lab safety course materials for students?** | **Strongly disagree = 1** | **Disagree = 2** | **Neutral = 3** | **Agree = 4** | **Strongly agree = 5** | **Column chart** | **Mode** |
| | 1 % | 1 % | 13 % | 43 % | 42 % |  | 4 |

Students were also allowed to give open feedback in written form. The question was formed as follows: *"If you have any comments, positive or negative, regarding the course, please write them here."*. There were two major themes which recurred in the open feedback:

***1. Humor.*** One of the most liked features in the exam was the overall mood and atmosphere created by the materials and exam questions. For example, we had included some absurdly wrong answer options in the exam question: for the question *"Unknown chemical has gotten into your eye. What should you do first?"*, one invalid answer was *"Remove contaminated eye ball"*.

Even though laboratory safety is a serious topic, we felt that using humor was justifiable as the topic has been historically considered as one of the most boring topics by our students. According to Berlyne (1972), humor increases psychological arousal and consequently attention and interest. We got indirect proof that our approach worked as some of the students reported that they had repeated the exam even after finishing the course. The incongruity of using humor was also discovered: even though most of the students liked the humor according to the feedback, some students reported that the humor was childish and stupid. It is extremely hard to create humor that strikes funny for all personalities.

***2. Navigation and finding information.*** On average, the feedback for studying in the 360° virtual space was good. A fundamental problem with the 360° virtual space was that many students felt that it was hard to keep track of which virtual laboratory rooms they had visited and which teaching topics they had studied in the 360° virtual space. This problem also was repeated in the exam where many students perceived that it was tedious to find the correct information in the 360° virtual space. However, from a learning point of view it can be argued that this forces students to re-read materials, which could lead to better recall of information. However, it is unclear how much the students read the material again when searching for the right info or did they mainly skim through the titles of the active points. Therefore we added a feature which allowed the student to track which points in which rooms have been opened in the 360° virtual space.

## 4. Evaluation of Learning and Its Relation to Learning Experience

The exam was graded on a scale of 0 % - 100 %. A total score of 75 % is needed to pass the exam. As presented in Table 3, it appears that students' assessment of digital laboratory safety material and studying it in virtual 360° space grew steadily when students achieved higher scores from the exam. The data used in the table is the same which was used for Table 2. According to Table 3, there seems to be a positive correlation between the students' success in exams and their feedback of digital learning. The results suggest that when students enjoy studying in a virtual laboratory also the learning results are enhanced. However, further research on the topic is needed.

*Table 3. The relation between the exam grade and the feedback from the students. The numerical scale for each question is explained in Table 2. The results obtained at a five-point Likert scale are classified in intervals similarly to a recent study on virtual platform on chemical engineering (Granjo and Rasteiro, 2020)*

| **Student's exam score (%)** | **My general opinion for the digital course materials is ....** | | | | **My general evaluation for the Digital Exam is ....** | | | | **I think that 360° virtual space is a fun and efficient way to present the lab safety course materials for students?** | | | | **N** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mode** | **<3 (%)** | **3 (%)** | **>3 (%)** | **Mode** | **<3 (%)** | **3 (%)** | **>3 (%)** | **Mode** | **<3 (%)** | **3 (%)** | **>3 (%)** | |
| **100-90** | **4** | 3 | 15 | 82 | **4** | 3 | 10 | 88 | **5** | 3 | 10 | 87 | **105** |
| **90-80** | **3** | 3 | 33 | 63 | **4 & 5** | 2 | 25 | 73 | **4** | 2 | 11 | 87 | **93** |
| **80-75** | **3** | 13 | 35 | 52 | **3** | 9 | 39 | 52 | **3 & 4** | 0 | 35 | 65 | **23** |
| **Any** | **4** | 4 | 25 | 71 | **4** | 3 | 19 | 78 | **4** | 2 | 13 | 85 | **221** |

## 5. Discussion

The teaching philosophy of AALTOLAB Laboratory safety training platform is not to teach small details to be memorised by heart but to encourage students to think about safe laboratory practices and help them to realize that safety is an inseparable part of all laboratory activities that concerns students and staff alike. This philosophy is translated to reality with the following practical decisions. First, students and staff alike start learning laboratory safety issues in the same 360° Virtual Laboratory Space and take the same digital exam, providing the same starting point both for students and staff and highlighting that laboratory safety is a common goal for everyone. As Stuart and McEwen (2016) point out, academic laboratory settings include many different players (e.g. students, teachers, researchers, technical staff, professors, etc.) and each of them can have different set of vocabulary and way to approach possible safety issues. Therefore, it is of paramount importance to have a unified basis from the inception, both for students and staff members. Moreover, experience in a certain field of chemistry does not necessarily equal to safe laboratory practices, and safe laboratory practices develop just like any other field of chemical research.

Secondly, the compulsory Laboratory Safety Course that students have in their study curriculum and they obtain by completing the AALTOLAB safety training is actually 0 ECTS, as laboratory safety is such a core knowledge of a chemist that it is not learnt for credits or diplomas, but for the continuous, life-long personal development as a high-quality professional. This is purely a decision made based on our values as teachers, as we believe this message is a critical part of a safety culture.

Thirdly, the students are recommended to keep 360° Virtual Laboratory Space (which contains all information) open at the same time as they take the exam, and there is no limitation to time or number of attempts in the exam; actually, a student can even log off and log back on later to continue the exam. Even though there are contradicting reports of online examination and exam anxiety (Stowell, 2010; Karaman, 2011), we believe that non-limitation in time and attempts engages students better with the topics as indicated by Karaman's (2011) study of flexible online exams. High engagement could also be seen in our course as many students did retake the exam several times. There were, however, clearly different motivations to do so: some students did it simply to be able to pass, some reported they did it for fun, and some clearly had a competitive and more ambitious edge as even though they passed the exam at first try, they repeated it until they received nearly 100 % correct answers. Therefore, we believe that the possibility to retake the exam numerous times without time limitation is helping deep learning and student engagement. While the students are free to explore our virtual laboratory space in any order they like, the methodology developed here is also suited for more linear laboratory exercises, where the students have to accomplish a certain task. Further developments in this area open up major possibilities to complement, support, and extend hands-on laboratory work (Domínguez, 2018; Ramírez, 2020; Seifan, 2020).

The goal of the students' laboratory safety training is to give students a basic knowledge of laboratory safety issues and to inspire them to find more information and encourage them to ask help if needed. Many action points lead to an answer "if you do not know, do not guess but ask for help". We believe that AALTOLAB safety training platform also helps both students and staff to maintain high-level safety standards in our laboratories since it is convenient to look over the material again if something is forgotten.

Based on our experience, a 360° virtual laboratory environment enables efficient and engaging implementation of laboratory safety training. Modern learning technologies allow embedding the safety materials to the 360° virtual environment in such a way that persons with limited technological skills can easily modify and update the training materials in real time. In Table 4, we summarise the main pros and cons of using our virtual laboratory platform for safety training. Although saving time and cost after initial investment of resources is an advantage we appreciate, the more valuable advantage is that students' feedback suggests that our new approach to safety training increases student engagement and motivation, leading to enhanced learning results.

*Table 4. Main advantages and drawbacks of AALTOLAB for laboratory safety training.*

| | **Pros / advantages** | **Cons / drawbacks** |
|---|---|---|
| Teacher's point of view | **Time and cost savings:**<br>● Digital exam is graded automatically; no need of supervising and making the exam many times a year<br>● Unlimited users; hundreds of students can participate; no lecture hall size limitations or lectures many times a year<br><br>**Development of the content:**<br>● Modifying and updating existing material by using Moodle is easy<br>● Material can be directed for different target groups and for different types of learners<br>● By using educational videos real life situations can be presented | ● At the beginning development of the platform requires time and resources<br>● Real life training is still necessary; some things need to be explained in more detailed way in the laboratory<br>● Shooting and editing videos takes time<br>● It is hard to emphasize the most important safety guidelines so that they are not overwhelmed by less important information<br>● No way to verify who really did the exam (i.e. student can let his friend or anyone else to do the exam with his log in credentials) |

| | | |
|---|---|---|
| Student's point of view | **Flexibility:**<br>● Exam can be done at any time of the day and at any time of the academic year<br>● Exam can be done numerous times without time limitation<br>**Learning experience:**<br>● Seeing actual laboratories and equipment and situations in them helps students to better visualize safety issues in the laboratory<br>● Interactive material, e.g. short and sometimes funny videos and minigames, make studying more entertaining and motivates students; more active learning compared to passive lecture<br>● It is easy to look over the material again if something is forgotten<br>● Automated feedback is provided after each question in exam; it is okay to make mistakes and learning takes place also in the exam | ● Lack of personal contact with fellow students and teacher<br>● There is a possibility to misunderstand and not be able to ask from teacher<br>● 360° virtual environment may be confusing for some students |

**6. Conclusions**

Web-based 360° virtual environment enables efficient and interesting implementation of laboratory safety training for chemical engineering students. Course feedback suggests that it increases student engagement and motivation, leading to enhanced learning results. Modern technologies allow linking course materials to 360° space so that persons with limited technological skills can easily modify and update them in real time. Virtual laboratory platform also allows easy way to develop materials for different target groups and to consider different types of learners.

From the students' perspective, one of the advantages of online safety training is that they can study and learn at their own pace and when they have time to do it. However, to enable independent studying, the study material needs to be carefully designed. Also, the use of a virtual laboratory environment should be as user-friendly as possible. It is advisable to put a lot of effort in the 360° space design so that navigation in it is clear. No other major problems were encountered relating to the student's learning experience in 360° Virtual Laboratory Space.

Based on our good experiences of the AALTOLAB laboratory safety training platform, we are aiming to introduce 360° virtual environments and integrated digital exams to other types of laboratories at our campus. The platform and most of the basic laboratory safety training materials are ready which makes the solution highly scalable. This allows us to create tailored versions of the course with little extra effort.

## Supplementary materials

AALTOLAB 360° Virtual Spaces are available at http://lab.aalto.fi/ and AALTOLAB Youtube channel is available at https://www.youtube.com/channel/UCSSoZDoHuWPONeoWLw993Og

## Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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