LMN-Lab: AR elements for chemistry laboratory practices

Laure Charton
Chalmers University of Technology
Gothenburg, Sweden
laurec@student.chalmers.se

Nadia Cuotto
Chalmers University of Technology
Gothenburg, Sweden
cuotto@student.chalmers.se

Maja Jakobsson
Chalmers University of Technology
Gothenburg, Sweden
jamaja@student.chalmers.se

ABSTRACT
This paper presents LMN-Lab, an innovative system with Augmented Reality (AR) elements for performing chemistry lab practices in a safer manner. LMN-Lab offers students multiple possibilities to carry out dangerous chemistry experiments that are not currently included in high school curriculum in Sweden. The system focuses on solving problems of: lab accidents with hazardous chemicals, storage space for them, reducing chemical waste and reducing teacher's concern about student safety. The design process is described along with relevant methods that influenced the final concept. Challenges and questions raised while getting feedback from the future users (high school students) and other people who tried out the prototype are presented, mentioning the need of further research and usability tests to assure that some features, that will bring value to LMN-Lab system, are feasible and viable to implement.

Author Keywords
Chemistry laboratory practice; high school; mixed reality; hazardous chemical; mixed reality lab; virtual element.

ACM Classification Keywords
H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems.

INTRODUCTION
Mixed reality is a technology that combines real world objects with virtual elements. In recent years, mixed reality has been an interesting asset in education. It can be a really powerful tool to explain different phenomena to students [2], for example in science subjects. It is composed of augmented reality (virtual elements added to the physical world) and augmented virtuality (real elements added to the virtual environment).

This project was initiated with the purpose of using mixed reality technology to improve the learning experience in high school settings. The main partners were Kattegattgymnasiet, a high school in Halmstad, Sweden, and EON Reality, a software developer company specialized in virtual and augmented reality. The partners had high interests in the development of new educational applications using mixed reality. The aim of this paper is to present LMN-Lab, a system for making chemistry lab practices safer by using AR technology.

Paper presented at SIDeR 2016
Malmö University, Sweden

BACKGROUND
Studies have already been done in mixed reality for labs, some of which constitute interesting input to this project.

Related work
The Concord Consortium has looked further into the different aspects regarding real and virtual labs used in education [10]. They state that the virtual labs provide many possibilities, as they focus students' attention on concepts through visual and interactive simulations, but that these labs often lack of realism. Real labs, however, can provide a richer context and multi-sensory experiences, but fail to reveal the underlying concepts to the students. Combining the two environments, they investigate how the combination of real and virtual elements can promote deeper understanding, better learning, and help students build stronger mental associations of perceived facts and visualized concepts [10]. They studied two kinds of environments: one in which real-time data from a physical environment is used to control a virtual experiment, and the other one where physical and virtual experiments are studied in parallel [9]. They state some advantages of these environments: the possibility of visualizing abstract components or invisible processes in real time, and the opportunity to have virtual experiments. These can be adjusted to match results in the physical world, thus help students to understand different phenomena.

Chemistry laboratory practices
Performing chemistry labs in high schools can be a dangerous activity, for both students and teachers. According to Arbetsmiljöverket (AV), chemistry labs that could pose risks for the working environment, no matter if the labs are performed by students or only the teacher, should be risk assessed before implementation [1]. This means that some resources are needed to assess in each new laboratory practice.

Students learn by doing, and the knowledge they gain during laboratory practices stay longer in their memory, since it helps them to connect theory with the real world [2]. However, today's laboratory practices put high demands on safety and supervision and require storage for chemicals as well as procedures to handle the chemical waste. As mentioned, all practices need to be assessed before implementation, and even if the practices are considered safe enough to be performed by students, they may still include hazardous materials that risk to injure the students.

FROM IDEA TO CONCEPT

The design process began with an introduction to the context from the partners, followed by research to understand the problem and come up with ideas to solve it.

Defining the challenge

In the beginning of this project, one of the partners, Kattegattgymnasiet, presented issues within education that they would like to be addressed with mixed reality technology. We decided to design a solution to be used by high school students and we also defined the context of use to be inside classrooms.

From there, we started to brainstorm ideas to solve some of those problems mentioned by Kattegattgymnasiet's principal, as well as targeting other issues that we remembered from our time in high school. We wanted to focus on keeping students interested while also having fun. These ideas were combined with AR technology and presented to the different partners. The idea that seemed the most promising regarding active engagement, scalability and new experience was the one which uses virtual substances for chemistry lab practices.

Refining the idea

We went to Hvitfeldtska gymnasiet in Gothenburg in order to do user research by interviewing students who were taking natural science courses. The purpose was to better understand which challenges they faced with laboratory practices. In addition, we visited EON Reality to get some technology input on the idea, evaluating the feasibility to implement.

Furthermore, we looked into the chemistry curriculum to learn which content teachers address in high school [6]. The content that attracted our attention were: acid-base and redox reactions, the amount of substance concentration and reactions mechanisms. Combining these findings with videos of interesting chemical experiments, we built a basis of what we wanted to include in the concept.

The next step was to present a short description of our concept to Kattegattgymnasiet, on which chemistry students had the chance of giving feedback. They particularly liked that our concept would eliminate the need of chemicals, and that they could perform laboratory practices even outside the classroom. Some skepticism was also present, mostly because some of them did not understand how the concept could work.

RESULTS

The results derived from this project consist mainly of the concept itself, but also of prototypes as well as impressions and feedback it got throughout the project.

LMN-Lab

Since laboratory practices are important for the students' learning experience, we chose to focus on how that experience can be improved. By using virtual elements instead of real ones, students will be able to participate in dangerous or uncommon chemistry lab practices. Our concept, LMN-Lab, is an AR system where dangerous chemistry laboratory practices can be performed safely. The system consists of a screen and a Kinect device that can track and analyze motions, hands and objects in real time, see figure 1.

Doing a lab with this system seems exactly like performing a traditional lab, except that the student will have a screen between herself and her hands. In order to keep the experience realistic, students will use real chemical glassware, which gives them the haptic sensation that they are performing a real laboratory practice. The Kinect technology tracks the lab participant's hands and glassware, which are displayed on the screen as if they were seen through a window. However, instead of having real chemical components, LMN-Lab recognizes the glassware and displays components inside of them virtually on the screen. When triggering a chemical reaction (e.g. mixing components), the visualization of the chemical effect (smoke, color, etc.) is displayed. The system can also show lab practice instructions and other relevant information to help students understand the content of the lab, e.g. chemical equation of the reaction.

Figure 1: LMN-Lab: AR system for dangerous chemistry lab practice.

The desired experience is to somehow represent the lab safety cabinet used for performing hazardous experiments. Having actual cabinets for all students would be too costly and bulky, but they do mediate the feeling of handling dangerous components. We want students to understand the importance of safety measures and caution while handling chemicals, even if we only portray them virtually.

LMN-Lab offers learning by doing in a safer environment, for both students and teachers, since components are virtual instead of being real chemicals. This also implies that there is no chemical waste, and less need for storing chemical substances. This constitutes an improvement for the sustainable design research field, which is already progressing in the challenge of waste reduction in various the areas such as nutrition [4, 5, 7], clothing [7] and chemical recycling [5] to mention but a few. LMN-Lab aims to allow teachers to focus more on the content of the lab practices, rather than worrying about students getting injured with hazardous chemicals. It also offers unlimited chemistry components and practices, providing students a broader access to more experiments that are not included in today's course curriculum. Furthermore, LMN-Lab aims to be scalable to other lab practices or science courses.

Prototypes

An important aspect of the concept is that users will manipulate equipment located behind a screen. How would it feel for students to interact with real glassware from the other side of a screen? Several prototypes were created to evaluate and get feedback on the concept itself, as well as on the feeling of using it.

Physical Prototype

A black box with a screen and plexiglass with drilled holes (for arms) was built to represent a lab safety cabinet, where real beakers were placed inside (see figure 2). The box had several chemistry warning symbols, such as corrosive, explosion risk and so on, to warn users that hazardous materials were implied. This setting was thought through to make users curious to know what was placed inside of it and also to be warned that whatever it is, is dangerous and delicate.

Figure 2: LMN-Lab Physical Prototype

Digital Prototype

The purpose of the digital prototype was to have a base for explaining our concept and how the visualization of the components would work, rather than having people guess how it would look. It was also intended to enable us to test the idea before trying to implement Kinect technology. This prototype worked jointly with the physical prototype, where one of the real beakers had a marker on top of it. Once the marker was tracked by a webcam, the screen would display a semi-transparent cylinder in the beaker, representing a chemical component. The cylinder was a 3D model created with CATIA V5 software and the tracking and visualization was realized using EON Reality software.

Video Prototype

In combination with the physical and digital prototypes, we made a video prototype [3]. The aim was to convey our concept by showing some of the features and possibilities that LMN-Lab offers.

Evaluation

We evaluated our concept through user testing, both in the intended high school context and during an exhibition about mixed reality in education.

Field Testing

In order to assess how the users would interact with a screen between them and the equipment they were to manipulate, we visited Kattegattgymnasiet and had some students and teachers from chemistry class test the basic idea. There were three teachers, two teacher assistants and approximately fifteen students between 16-17 years old present. An introduction to the concept was presented to all of them, and afterwards five participants got to try out a low fidelity prototype. This prototype consisted of a laptop and real glassware, where the participants manipulated the beakers by seeing their actions through the laptop screen, and were told to express out loud what they were experiencing. This served as a pilot test of the digital prototype. We noticed that students seemed to have an easier time manipulating the beakers than the teachers, something that might have to do with technology expertise.

In addition to the user testing, we interviewed a chemistry teacher and the high school principal (who taught natural sciences) for further evaluation of our concept. Some interesting feedback was that LMN-Lab would reduce the preparation time of lab practices for the teachers (mixing chemicals, preparing different concentrations, etc.). Furthermore, they believed that the possibility to perform more exciting experiments in class could make students more interested in the chemistry subject.

The exhibition

We ended the project by presenting our concept and prototypes during an exhibition in which university students, designers and teachers were present. During the exhibition, users had to wear gloves, glasses and a white coat, as well as read lab instructions in paper format, in order to lead them into the mindset that they were going to perform a real chemistry lab practice and handle hazardous chemicals.

An overall positive feedback was received during the demonstration. We noticed that several visitors were interested in trying out the prototype, ending up mentioning that they thought LMN-Lab was fun to use. There were also some interesting comments regarding other possibilities of use that the system could take, for instance when research students are abroad and need to travel to a certain country to perform a specific lab. LMN-Lab would eliminate the need of travelling, hence travel expenses, as they could perform practices from their current location. Another suggested possibility was to inspire kids who are curious in chemistry at an early age.

However, some participants mentioned having troubles with depth cue and the feeling of not recognizing their hands on the screen. These issues can be due to technical performance inherent to the prototype, such as the low quality of the webcam used, but they are still interesting to think of in the perspective of actual implementation.

DISCUSSION

The project started with an introduction to the field by the stakeholders, but did not include any input from the actual users. Due to the short time span of the project, we needed to start ideating and formulating concepts before we had the opportunity to talk to any students or teachers. This forced us to use our own experience and memories of high school studies to come up with ideas. It would have been more of an issue if the setting was less familiar to us, and in that case we would have needed to plan more studies of the context.

Having a multicultural design group with different language skills helped to contact partners and teachers. It also meant that we had different experiences from high school, thus we could have a richer approach to the problem. However, we had very limited knowledge of the technology. Having programming or developing skills within the group would have influenced the concept in a positive way, since the main topic was technology driven. This would also have allowed usability testing earlier in the design process.

Understanding the technology and implementing the different parts took a significant amount of time for not as much output as it should have brought. It could have been more beneficial to give more thoughts on the concept and user research. Nevertheless, the prototype we ended up with turned out to be more than satisfactory. This is a good experience we will take into account in future projects: beginning with a simple prototype and build from it after the first step is fulfilled.

Future Work

The future work for LMN-Lab consists of analyzing challenges for implementation purposes, and also considering other applications and functions that LMN-Lab could have.

Implementation

There are some challenges that need to be solved for an actual implementation of LMN-Lab. A Kinect device for each student, or pair of students, would be too expensive to purchase for high schools today. A system with a cabinet box would be cumbersome and still need some storage space, even if some compromises would be made - such as using a foldable box. The teachers would have some challenges to face as well. With such a system, they would have to adapt their teaching to the technology and also learn and adapt to the technology itself.

As mentioned earlier, we would like the students to feel as if they are actually performing the lab, thus learning by doing. We would like to insist on the fact that if the components were real, consequences would be real as well. As such, graphics, resolution and animations need to be of very high quality. The tracking also needs to be really precise since a component seen even one millimeter out of phase from the beaker would not seem realistic. The effects of this realism is however something that should be investigated further through user tests and other assessments, as it might work counterproductive regarding understanding that something virtual can be dangerous. Since nothing bad can happen with LMN-Lab, students might lose caution when handling hazardous chemicals instead of being more aware.

Future Applications

For further applications of LMN-Lab, we got some ideas from students, teachers and supervisors. One interesting feature could be to enable students to save their progress. They could return in a later occasion to finish an incomplete lab, or just revise it before a test. This would require a login feature to be added to the system.

Since measurements are important in chemistry, it is something that should be included in the concept. Students could perform the whole lab and make mistakes in the measurements - to which the system should be able to adapt accordingly. Same goes for any students' mistakes such as accidentally pouring a corrosive substance on her arm, the system would display the injury as in real life. Students could also learn safety procedures in case of such accidents.

Chemical reactions involve physical phenomena, which should be present in the system to have a realistic experience. Smoke, for instance, is a visual effect that can easily be added on the screen. Another easy implementation could be sound: when the reaction is detected, the speakers could play the corresponding sound. Other phenomena, which would need more work, are heat and smell. Heat could be included through haptic gloves, and there is some research going on regarding synthesizing smell [8]. These features are in progress, making it possible to include them in LMN-Lab in the future.

Staying in the chemistry subject, it would be interesting to expand the concept to also cover reaction mechanisms at a molecular level. Students could see how atoms interact with each other to create other molecules. On the other hand, broadening the scope is another possibility LMN-Lab can take, mentioned by several students, which implies using the system in other natural science subjects. For instance, it could be possible to apply this system for learning nuclear physics, creating a sun or a black hole, or even antimatter.

CONCLUSION

Mixed reality is an interesting technology to make use of within education since it can help students to better understand certain concepts. LMN-Lab is a mixed reality system replacing real chemical components with virtual ones during chemistry lab practices. It encourages learning by doing and enables unlimited content of reactions and components. It lets teachers focus on the content of the course instead of worrying about students getting injured by hazardous chemicals. The system aims to be eco-friendly and it uses existing technology.

The system has been evaluated and tested by both students and teachers, resulting in mostly positive feedback. The students believed that it could be valuable for them to be able to practice chemistry labs outside of class. The teachers saw the concept as an opportunity to reduce the time of preparation before a chemistry lab, allowing them to spend time on more important activities than measuring chemicals. To conclude, LMN-Lab provides a safe environment for performing dangerous lab practices from which both students and teachers can benefit.

ACKNOWLEDGEMENT

We would like to thank all the supervisors and partners that contributed to the development of LMN-Lab, as well as the visitors and students who gave us valuable feedback. Special thanks to Farshid Harandi, Amir Sabbagh and Nils Andersson, who assisted us with equipments and software throughout the project, Frank Wedding, our main contact from Kattegattgymnasiet and Lynga Huang, who allowed us to record the video prototype in Chalmers Chemistry laboratories.

REFERENCES

1. Arbetsmiljöverket. 2015. Riskbedömning av kemilaborationer. Retreived October 15, 2015 from https://www.av.se/

2. John Branson and Diane Thomson. 2013. Hands-On Learning in the Virtual World. *Learning and Leading with Technology*. 40, 5 (February 2013), 18-21.

3. Laure Charton. 2015. LMN-Lab: AR elements for safer lab practices. Video. (26 October 2015.). Retrieved March 6, 2016 from https://youtu.be/KBXERjqT_z4

4. Kathrina Dankl. 2015. The Paradox of Design Methods: Towards Alternative Functions. Proceeding in the 2015 Nordes Conference. Retrieved March 6, 2016 from http://www.nordes.org/opj/index.php/n13/article/view/403/381

5. Ying-Ju Lin and Andrea Botero. 2015. Sharing Eco-Soap Knowledge-Joosoap Studio. Proceeding in the 2015 Nordes Conference. Retrieved March 6, 2016 from http://www.nordes.org/opj/index.php/n13/article/view/397/375

6. Skolverket. 2015. Chemistry. Retrieved October 27, 2015 from http://www.skolverket.se/polopoly_fs/1.194837!/Menu/article/attachment/Chemistry.pdf

7. Tania Splawa-Neyman. 2015. Discussion with Three Jackets: Making a Material Ecology. Proceeding in the 2015 Nordes Conference. Retrieved March 6, 2016 from http://www.nordes.org/opj/index.php/n13/article/view/376/355

8. Donald A. Wilson and Richard J. Stevenson. 2006. Learning to smell: olfactory perception from neurobiology to behavior. JHU Press.

9. Charles Xie. 2012. Framing Mixed-Reality Labs. *At Concord*. 16, 1 (Spring 2012), 8-9.

10. Charles Xie, Edmund Hazzard and Jennifer L. Chiu. 2015. Mixed-Reality Labs. The Concord Consortium. (May 2015). Retrieved October 27, 2015 from http://concord.org/projects/mixed-reality-labs