Using Virtual Laboratories as Preparation to a Practical Laboratory Course: Preliminary Empirical Investigation

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ABSTRACT
Virtual laboratories are a specific kind of e-learning application. They allow students of natural sciences to conduct experiments in a highly-interactive almost photo-realistic virtual environment built into the computer as simulation engine. Goal of virtual laboratories is to train the student's procedural knowledge that is needed for conducting experiments in a real laboratory environment. Students can train themselves comfortably in a secure environment using the computer and without wasting precious resources such as substances and devices. Despite the existence of virtual laboratories for a while now, there exist to the best of our knowledge so far no empirical study that investigates the actual impact of using virtual laboratories as preparation to a practical laboratory course.

In this paper, we present the design and results of a preliminary study conducted using the virtual laboratory GenLab for genetics and genetic engineering. While one group of students (n=18) did receive a training using GenLab prior to real laboratory experimentation, the others did not (n=14). We have measured the task performance for two typical experiments in genetics of different complexity. In addition, we have recorded the students' own assessment of the experiment complexity and comprehensibility. The results show that there is a statistically significant difference for the more complex experiment task, while it has not been observed for the less complex one.

Keywords
Virtual Laboratories, Summative Evaluation, E-learning, Genetics, Genetic Engineering

INTRODUCTION
A virtual laboratory is an almost photo-realistic depiction of a real laboratory in a computer for the purpose of conducting experiments in virtual reality. A concrete example of a virtual laboratory is GenLab [OFF03] for genetics and genetic engineering. GenLab consists of two central components [Sch02]: The seminar room allows the students to gain knowledge about the theoretical foundations of genetic tools just like a traditional computer-based training application. In addition, it provides small, interactive e-learning units that allow for training individual skills such as using specific laboratory devices. The virtual lab room allows for a highly-interactive and exploratory learning of procedural knowledge in the domain of genetics and genetic engineering. While the students are conducting the experiment, a tutor constantly tracks the experiment progress and provides feedback when the learner makes a mistake. Advantages of virtual laboratories are that the students can train the procedural knowledge arbitrary often. As the experiments are conducted in virtual reality, precious resources like reagents and samples are saved and experimental devices can be explored without risks. In addition, the students are not exposed to any hazards while being in the virtual training phase.

In this paper, we present the design and results of a preliminary study investigating if students using GenLab are actually better prepared for the practical course in a real lab. First, we present the related work in the field. Subsequently, we describe in more detail the seminar room and experimentation room of GenLab. We provide a brief introduction into the two experiments considered in this study, namely the agarose gel electrophoresis (AGE) and the polymerase chain reaction (PCR) [SR01]. Subsequently, the design of the study and its results are presented, before we conclude the paper with a discussion.

RELATED WORK
E-learning has been an important and highly interesting research field over the last decades. Initially called computer-based training, its popularity tremendously increased since e-learning has reached the web. For example, significant media attention is currently drawn to so-called Massive Open Online Courses (MOOC) [Wal13]. An interesting area of research in e-learning are so-called virtual laboratories [NAA12, OFF03, Sch02], which allow for training procedural knowledge safely and without wasting resources in a computer environment before going into a real world lab. In contrast, remote laboratories are real laboratories that are controlled over the Internet and often make use of a web cam for providing immediate feedback to the learner [RML+09, RAM+08].

An example of a virtual laboratory is GenLab [OFF03]. It allows for executing different genetic experiments in a computer-based simulation (see also Section "Overview of GenLab"). While GenLab is delivered on CD-ROM, virtual laboratories are also available online and can be used for MOOC such as the web-based version of GenLab[1]. Furthermore, virtual laboratories are specifically designed as being part of a physical curriculum (*blended learning*) and being used as preparation for a real-world (laboratory) training and experience phase, respectively.

A tool to test the effectiveness of virtual labs on the overall learning performance would be the method of summative experiments [LFH10]. An example of a summative experiment is given by Franz et al. who studied the usability of a standard desktop PC in comparison to a semantic desktop, where relations between e-mails, contacts, appointments, files, and others are explicitly stored and used for typical tasks of personal information management [FSS09]. To this end, the participants in the experiment were randomly assigned to two different groups, one working with the standard desktop and the other group using the semantic extensions. Measurements such as task completion time, number of clicks, and error rate were measured and compared to determine which group performed better. Overall, the results show that the users of the semantic desktop performed statistically significant better when conducting complex tasks of personal information management. While such evaluations aim at comparing two different software systems, our work is somewhat different from this scenario: In our experiment, the participants are also split into two groups. However, while one group has received preparation using a virtual laboratory prior to the real laboratory course, the other group did not use any software at all and thus served as control group.

In another study, Lucca et al. [LRS+04] have investigated if telecommunication technologies can support e-learning. They have compared remote groups working together via teleconference, face-to-face groups (groups at disparate locations but that meet in person), and groups that are at the same location. The results are to some extend not surprising and show that the groups at the same location perform best. Investigating the influence of using e-learning tools as preparation to some subsequent laboratory work has not been investigated.

Dagger et al. [DWC04] have investigated the process of developing adaptive e-learning content. They argue that production of adaptive content requires an interdisciplinary team and is of high effort [DWC04]. Although not specifically considered by Dagger et al., virtual laboratories are necessarily adaptive e-learning applications as they need to provide individual feedback to the learner. The authors conducted a preliminary evaluation in form of a case study with the aim to investigate the user-friendliness and comprehensibility of their approach. To this end, the authors have asked the participants to create a short adaptive e-learning course. However, a comparative evaluation of using a virtual laboratory as preparation to a real laboratory course like it is done here has not been conducted.

OVERVIEW OF GENLAB

The virtual laboratory GenLab has been developed at the research institute OFFIS in Oldenburg, Germany [OFF03]. It is commercially available and can be used by students to prepare themselves to a various selection of different genetic experiments. Besides the commercial GenLab application, there exists also the non-commercial variant called ViPGen that has been distributed and used at universities for educational purposes. However, ViPGen is not available for general public use.

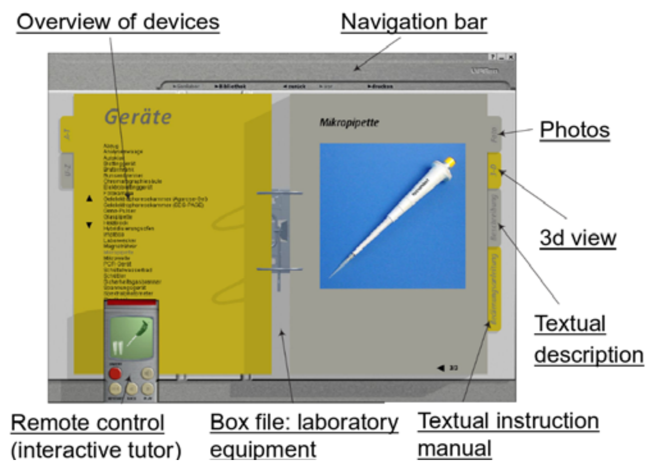

Figure 1. Screenshot of the seminar room in GenLab (captured from [OFF03]).

Thus, instead we have used in this study the commercially available GenLab. It consists of two central components, the seminar room and the experimentation room [Sch02]. A binder found in the bookshelf of the seminar room is depicted in Figure 1 and is very similar to traditional computer-based training applications. It allows students to study the theoretical foundations of genetic laboratory work (see the folder depicted in the figure). However, it also provides 3D views and photos of laboratory devices. Finally, unlike other traditional computer-based training applications, the seminar room of GenLab offers small, interactive e-learning units to train individual skills such as using specific laboratory devices (which can be seen at the bottom left part of the screenshot in Figure 1, leading to Figure 2).

[1] Example experiments are available online at: http://www.virtual-labs.org/

Figure 2. Screenshot of the interactive tutoring component for training the skill of using the micropipette (captured from [OFF03]).

The experimentation room depicted in Figures 3 – 5 is the actual core of GenLab. It provides a virtual lab room that allows for conducting virtual genetic experiments in a highly-interactive and exploratory simulation engine. Thus, the theoretical knowledge gained in the seminar room is put into practice. Students can learn essential procedural knowledge needed for conducting experiments in a real laboratory environment. In the top left of Figure 3, a tutoring window is shown. It constantly tracks the progress of the experimentation and is coupled with the simulation engine. While the students are conducting the single steps of the experiment, it instantly provides feedback when the student makes a mistake such as waiting too long and letting solidify the gel before pouring it into the gel tray during the AGE experiment (see also experiment description below).

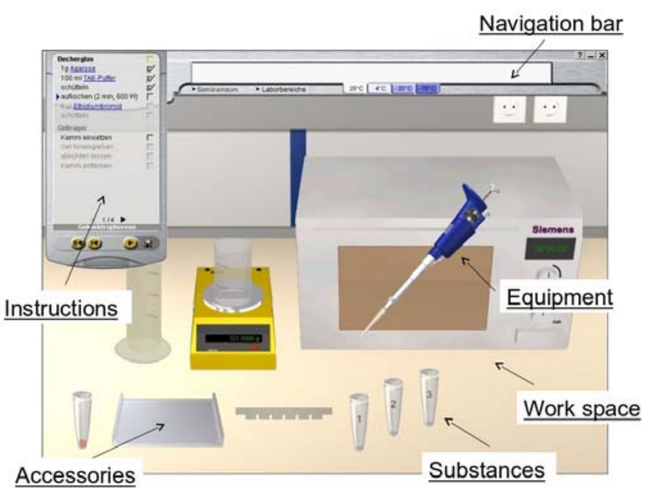

Figure 3. Screenshot of the laboratory bench in GenLab (captured from [OFF03]).

GENETIC EXPERIMENTATION

As example experiments in our study, we have selected the agarose gel electrophoresis (AGE) and the polymerase chain reaction (PCR) [SR01].

Agarose gel electrophoresis (AGE)

The procedure of AGE consists of several steps which are very closely reenacted in the virtual lab. First the students had to make their gels, including the weighing and mixing of components, the melting of the gel solution in the microwave, as well as the preparation of the gel trays prior to the pouring of the gel. Once the gel had solidified, it was transferred to the electrophoresis chamber and covered with the electrophoresis buffer. Now, the samples could be loaded on the gel. For this purpose, the samples were mixed with the loading buffer and each sample was carefully applied with a micropipette to the gel slots. The chamber was closed with the lid putting the electrodes in place. Current and voltage were adjusted and electrophoresis was started. Finally, the gels were placed on a UV-transilluminator and imaged for documentation purposes and subsequent analysis. A screenshot of the virtual AGE experiment in GenLab is shown in Figures 3 and 4.

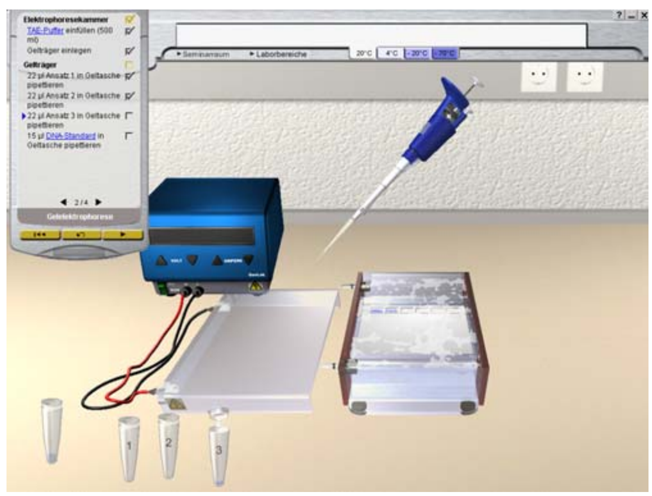

Figure 4. Screenshot of the agarose gel electrophoresis in GenLab showing the electrophoresis chamber (captured from [OFF03]).

Polymerase chain reaction (PCR)

The preparative steps for PCR are less numerous than for AGE, which was also the case for the virtual version. The students first had to calculate – depending on the numbers of samples – the volume of each component of the so called ‘mastermix’. The appropriate volumes of each component were then pipetted into a reaction tube and mixed. The mastermix was distributed into new reaction tubes according to the number of samples and the samples were added. After brief mixing, the reaction tubes were placed into the thermocycler and the program was started to conduct the PCR. A screenshot of the virtual PCR in GenLab is shown in Figure 5.

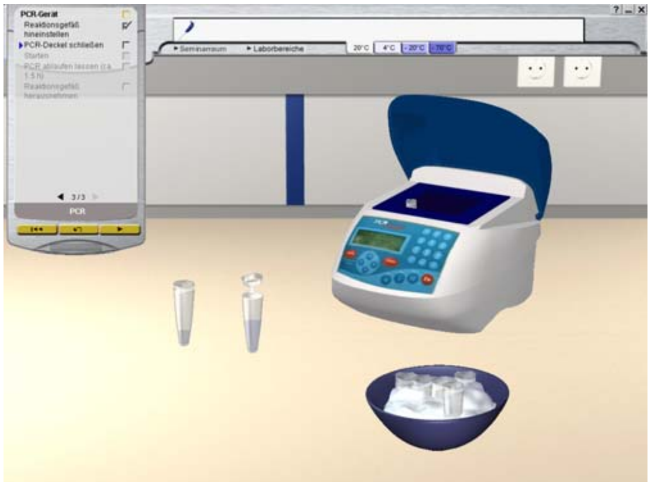

Figure 5. Screenshot of the polymerase chain reaction in GenLab (captured from [OFF03]).

EXPERIMENT DESIGN

Participants

32 students (19 female) of biology from the University of Koblenz-Landau in Germany took part in our experiment. The average age of the students was 24.5 years (SD=3.63). Participation was voluntary. No compensation for the effort in participating in the experiment was given.

Procedure

We have conducted a summative evaluation, where we have split the students in two groups. One group has been trained using GenLab prior to the practical course (n=18, 10 female). The other group has served as control condition and was not trained (n=14, 9 female). As example experiments, we have selected the agarose gel electrophoresis (AGE) and the polymerase chain reaction (PCR) [SR01] described above.

The first group, i. e., the GenLab group received a two hour training in the procedures of genetic engineering using the virtual laboratory. The students were allowed to the use software as they like. However, it was mandatory to read the theory on PCR and AGE in GenLab, to learn the use of the micropipette with the software, and to conduct the virtual experiments AGE and PCR using the software. Subsequently, the students participated in a real laboratory course where they have conducted experiments in pairs of two. Among the experiments conducted in this course were AGE and PCR. The students were asked to measure the time and among others provide a subjective rating of the difficulty and comprehensibility of conducting the individual experiments. The latter were captured using a questionnaire.

The second group, i. e., the control group did not receive training a priori to the real laboratory course. Except from this difference, both treatments were the same. The control group conducted the same set of experiments in the same laboratory and equal conditions like the GenLab group. In order to allow also the students of the control group to investigate the usefulness of the virtual laboratory GenLab, the students were invited after the laboratory course to work with the software as well.

RESULTS AND DISCUSSION

In summary, the results of our study show that the GenLab group needed on average less time conducting the experiments. However, applying a Mann-Whitney U test did not find the differences significant (U=137.0, ns, z=0.71). We have also asked the participants how well they felt prepared for conducting the experiments in the real laboratory. Here, again the difference was not significant (U=122.5, ns, z=0.22). This basically meant that the students were not more self-confident while conducting the experiments when having received treatment in using GenLab as preparation.

Among further questions, we have asked the participants to rate the experiments regarding their comprehensiveness. Here, we made a very interesting observation that the participants in the GenLab group did understand the procedure of the AGE and PCR experiments much better, based on their subjective judgment. The differences in the ratings of the comprehensiveness of the AGE experiment were statistically significant between the groups (U=172, p<.05, z=1.75), while the results for the PCR experiment were not (U=155.5, ns, z = 1.12).

Surprisingly, this result was not reflected in the participants' subjective rating of the experiments' complexity. The participants in the treatment group using GenLab rated the complexity of the AGE and PCR experiment higher than the control group. While the difference in the ratings of the AGE experiment were pronounced and statistically significant (U=172.0, p<.05, z=1.75), the differences in rating the complexity of PCR were minor and not significant (U=126, ns, z=0).

We explain the different outcome for the AGE experiment by the fact that the AGE experiment is more complex than the PCR. As the AGE experiment includes more steps to conduct and the virtual version depicts the real procedure much closer than it does for the PCR, we assume that the students have gained much more from the AGE preparation using the virtual laboratory than for the simpler experiment. However, this results need to be investigated in more detail in the future.

CONCLUSION

In this paper, we have conducted an early experiment measuring the influence of the use of a virtual laboratory like GenLab on the performance when conducting experiments in a real laboratory course. Overall, we can state that virtual laboratories may play a significant role in better preparing students in real laboratory work and thus have the potential to safe precious resources when conducting experiments in the real world.

However, more extensive user studies are needed in the future. These user studies need to particularly investigate the usefulness of virtual laboratories as preparation for real laboratory courses. In addition, it will be interesting to investigate if knowledge acquired additionally through the virtual laboratories is more sustainable than traditional learning methods.

ACKNOWLEDGMENTS
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