Preparing for Industry 4.0 – Collaborative Virtual Learning Environments in Engineering Education

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Abstract*— In consideration of future employment domains, engineering students should be prepared to meet the demands of society 4.0 and industry 4.0 – resulting from a fourth industrial revolution. Based on the technological concept of cyber-physical systems and the internet of things, it facilitates – among others - the vision of the smart factory. The vision of "industry 4.0" is characterized by highly individualized and at the same time cross-linked production processes. Physical reality and virtuality increasingly melt together and international teams collaborate across the globe within immersive virtual environments. In the context of the development from purely document based management systems to complex virtual learning environments (VLEs), a shift towards more interactive and collaborative components within higher educational e-learning can be noticed, but is still far from being called the state of the art. As a result, engineering education is faced with a large potential field of research, which ranges from the technical development and didactical conception of new VLEs to the investigation of students' acceptance or the proof of concept of the VLEs in terms of learning efficiency. This paper presents two corresponding qualitative studies: In a series of focus groups, it was investigated which kinds of VLEs students prefer in a higher education context. Building upon the results of the focus groups, a collaborative VLE was created within the open world game Minecraft. First screenings of the video material of the study indicate a connection between communicational behavior and successful collaborative problem solving in virtual environments.

***Index Terms*—Engineering Education, Minecraft, Oculus Rift, Virtual Collaboration, Virtual Learning Environments**

I. Introduction: Today's Learning and Working in Preparation for Industry 4.0

Todays' portfolio of e-learning solutions is as diverse as never before. Different kinds of media services, software for teaching and learning as well as innovative hardware solutions not only become a bigger part in higher education and the workplace but increasingly adapt to the massive changes our working world is going through. A common and frequently cited example is the use of learning management software, based amongst others on the open-source management system Moodle [1]. Today, Moodle counts 53.738 registered installations with 68.7 million users of 226 countries in 7.7 million courses [2]. Platforms like Moodle have different functions, which can also be viewed as e-learning solutions themselves: With chats, forums or messenger systems, students or workers can communicate in synchronous or in asynchronous ways. Wikis enable cooperative text production and different kinds of assessment modes or quizzes give teachers the chance to test the students whenever they want and as many times they want during the semester. Here, one of the biggest advantages is that the tests are rated automatically, which makes the frequent testing also suitable for large groups. Being tested frequently, the students get instant feedback about their current state of knowledge. Digitally supported learning brings direct individual advantages in terms of self-awareness of the content of the lecture.

The digitalization of education also means that learning becomes more collaborative [3]. The key word "user generated content" describes the fact that in times of web 2.0, content rarely is produced by just one single provider of content, but is generated by several users instead. Transferred to the context of higher education, the students' role changes. Whereas back in the days, when the teacher was more or less the only source who provided information, today students can get basically any information they want from the internet, but can also contribute actively within forums, wikis or blogs. The potential is there to switch the students' role from rather passive users of information to creators of knowledge in networked structures – with all accompanying advantages and disadvantages. With the goal in mind not only to boost the students' knowledge and to support them to strengthen their personality over the years, but also to develop crucial competences for the working world they are about to step in, various types of collaboration have to be trained and tested in learning scenarios.

In a first step, one can differentiate between cooperative and collaborative learning. In cooperative learning scenarios, each group member is given a sub-task e.g. reading and interpreting different parts of scientific literature, technical reports etc. The individually produced results, e.g. a presentation, are simply being added up. Therefore, the main result mostly doesn't represent the state of knowledge of each individual group member. It is more a question of how to divide the work in an efficient, but not necessarily in an effective way.

Collaboration instead focuses on the creation of a new knowledge baseline, which is built through interlinked and co-referenced work during the learning process [4]. Especially in engineering, collaborative learning in virtual environments is highly important in the context of a dynamic and digitalized working world. This can be realized by analyzing a defective machine, coming up with a logistics concept for a virtual factory or designing a virtual car. The last example points out the importance for engineers to link their own specific technical expertise with expertise of other domains. Working in interdisciplinary teams situated all over the world is standard practice. The increasing digitalization of economy and society links knowledge over borders of time, space and systems. In times of industry 4.0, physical reality melts with virtuality [5]. For almost decades now, e.g. finite element models, data models, analytical models or CAD-models of machine elements have been produced with software. The data is used, provided and linked within socio-technical working systems via clouds, ubiquitous computing, product-lifecycle management and product data management. Thus, in engineering, human work processes are increasingly being transferred to virtual spaces of an internationally networked world.

II. COLLABORATIVE LEARNING IN VIRTUAL ENVIRONMENTS

In higher engineering education computer-supported cooperative and collaborative learning (CSCL) have long been established as methods which support self-driven and work-related learning processes. By further technical development as well as new requirements of the changing working world such common methods can be lifted to a new level. Virtual learning platforms like moodle can systematically be linked to virtual or teleoperative laboratories. Every student gets the opportunity to experiment with physically real equipment without the necessity to be physically present at the location of the machine [6]. With special booking systems, expensive equipment for teaching and training processes can be used more efficient, since students from different time zones (e.g. USA and Germany) can log in at different schedules. Thus, it is possible to introduce students to learning settings, which would otherwise be too dangerous (e.g. an atomic power plant), too hard to access (e.g. the surface of mars) or too big a risk for ongoing production (e.g. in a factory) [7] .

Moreover, in massive open online courses (MOOCs), each student can learn at his own speed. Serious games offer the possibilities to learn in a playful manner, in single-player or in multi-player mode. Innovative virtual knowledge spaces therefore offer all kinds of possibilities for learning and working in times of industry 4.0. In order to use the new technologies for engineering education in a proper way, deeper insights in reception, cognition and communication in virtual environments are necessary. Simply providing the technical infrastructure doesn't automatically guarantee successful collaboration. Therefore, the analysis of key factors for successful collaboration in virtual environments is an important field of research in the context of the working world of the future. Linking the different fields of this research is a core point for its success.

In the project "Excellent Teaching and Learning in Engineering Sciences" the three large german universities RWTH Aachen University, Ruhr-Universität Bochum and Technical University Dortmund focus on the development of virtual and remote laboratories as well as non-experimental collaborative learning spaces. In order to show students the "bigger picture" of the engineering profession, but also in the light of increasing numbers of students in engineering, the necessity of experimental equipment is obvious.

When working on the development of virtual or remote laboratories, the focus is clearly laid upon the final product and its future way of use. From a different point of view, looking at the current media use of students can help to predict the steps that still need to be done, if one day collaboration in virtual learning environments is supposed to prepare for industry 4.0 on a large scale. But are today's students ready for innovative teaching methods? Current studies of digital media usage show a rather passive usership. The majority of students hardly uses media services which require an increased work load by generating content (e.g. wikis or blogs), as a long-term study on media use of students shows [8]. A study with german engineering students (n = 1587) focused on the frequency of usage of different kinds of media services. The results show that interactive and collaborative media services are not used very often by the majority of the sample. This conclusion also counts for blogs or tools for collaborative text production such as wikis. In other words: Absorbing content is still more popular than generating it [9].

But the same study reveals another important aspect. Although not many students have been in contact with innovative teaching formats such as serious games or virtual courses in real-time; those who have experience with such formats are highly satisfied with it. These results are of high relevance for the development of virtual collaboration spaces, but also for companies who wish to use them. Developers need to know which the crucial features of a virtual environment are that really solve students' problems and are not just "nice to have". Moreover, universities or companies who invest in virtual learning environments aim for some kind of return on invest, which is not likely to come if the VLE isn't used. However, there is still little evidence on the motifs of students for using, or better for not using media services which require active participation. Although today's students all grew up in a digital society, user profiles are highly diverse. Providers of virtual collaboration spaces such as universities or companies need deeper insights in actual user preferences of specific target groups. Which level of graphical precision is required to understand complex processes, which level of gamification is preferred or which kinds of narrative scenarios would motivate this user group to deal with the content longer or more often still needs to be answered. Therefore, in order to investigate the described quantitative research in the field of collaboration in virtual environments, a qualitative research design was chosen, which will be explained in more detail in the following chapter.

III. EXPERIMENTAL SETTING FOR THE ANALYSIS OF COLLABORATION IN VIRTUAL ENVIRONMENTS

A. Lead User Workshops with future Engineers

Since today's students are going to be working within industry 4.0 contexts it is important to integrate them in the research process on VLEs which are supposed to prepare for the corresponding requirements. The approach of user-centered design is well-known in the field of software development, but also under the label of open innovation in the case of new product development [10]. Within idea competitions or lead user workshops, the approach has also proven to be helpful in the development of new teaching methods or new formats of virtual learning in context of the Bologna Process [11]. As representatives of future user groups of such innovative learning and working spaces, students are questioned within focus groups. Two workshops with 23 students from Germany and one workshop with 13 participants of a European study program were conducted.

Figure 1. Lead user workshops with students on the topic of virtual learning environments

The two major aims of the workshop series were to collect the students' requirements but also their retentions on VLEs. The students were asked the following questions:

- Which scenarios would you like to experience within VLEs?
- Which didactical method would you prefer, e.g. game based learning, free exploration etc.?

The students first had to work on the questions in small teams and then presented the results to the whole group. Each idea had to be written down on a prompt card. For a deeper insight into the workshop results, the cards were analyzed with qualitative analysis [12]. The contributions to the two questions were therefore clustered into topics. Afterwards, the quantity of contributions in each category was counted. The topics with the most contributions were considered the ones of greatest interest or greatest concern of the students.

The results of the analysis show that students equally prefer realistic (e.g. factory simulations) and fictional scenarios (e.g. traveling through a factory from the product's perspective). In case of fictional scenarios, the main principle is to exceed the limits of time, space and physics. The students like to be immersed by the virtual environment and to interact with it intuitively and naturally. The possibility to get instant feedback is valued very positive by the students. To combine learning with playing in terms of game based learning is welcomed by the students, but not necessary to enjoy the learning process within the VLE or to consider the VLE useful. The students had no major retentions to VLEs in general, but a few contributions referred to the concern that too many unnecessary features of the VLE could distract from the actual task and the content that should be learned or practiced.

Although surely not being the main contribution to learning success of students, the insights in students' preferences on VLEs delivered important information for the didactical design of future learning environments.

B. Work in Progress: Study on collaboration in virtual environments

In line with the preference of students to be immersed in a VLE, a previous experimental study showed that students who used natural user interfaces for interacting with the virtual environment in individual learning scenarios experienced more immersion than students who solved the task on a laptop. Immersion generally referred to as "diving into the virtual environment" had been operationalized with the constructs of spatial presence and flow. An interaction of experienced flow and errors in task performance revealed the complexity of working in virtual environments: Being immersed by the environment unfortunately can also mean that one is absorbed more by the exploration of the environment than by solving the given task [13]. This finding stands in conflict with the user preferences found in the lead student workshops.

However, the nature of collaboration might help to compensate this problem. Since more people are involved in solving a given problem, more attention can be spent on problem-related details. Moreover, as mentioned in the introduction, the prediction of the working world of the future under the label of industry 4.0 specifically emphasizes the importance of controlling complex, geographically distributed industrial processes [14]. Collaborating in teams with diverse professional and cultural backgrounds is an important precondition for the success of such processes.

To understand the complex interactions of different human factors in situations of virtual collaboration, a current experimental study focuses on preconditions for successful collaborative problem solving in virtual environments. This study assesses the relationship between personal characteristics, objective hardware characteristics, subjective experiences, objective collaboration behavior and task performance. Their expected relationship is visualized in Figure 2.

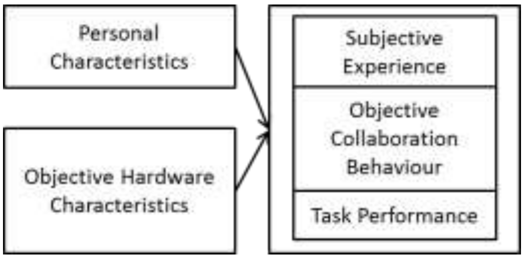

Figure 2. Expected relationship between personal characteristics, hardware characteristics, subjective experiences, objective collaboration behaviour and task performance

The virtual environment is based on the results of the lead user workshops. Therefore the VLE had to be immersive, interactive, give instant feedback on the task performance and have elements of gamification in it. Since in the context of higher education personal and financial resources are mostly small for the development of virtual learning environments, the open-world game Minecraft was chosen as the setting for the learning environment. Minecraft has already been used for teaching and learning settings in the USA and the UK [15] and provides many features which are crucial for virtual collaboration:

- Quick construction of simple learning settings without any programming skills,
- Possibility to build more complex technical environments with the use of blue prints, available mostly for free within the Minecraft community [16],
- Simple and easy to learn modes of interaction without sophisticated gaming skills,
- Possibility to move around freely and to explore the scenario as a user actively.

To link the study to an industry 4.0 scenario, pairs of students are given a task with an engineering background. All participants have to solve the same problem in the same virtual environment, which is to restore electricity in a virtual building. From no perspective within the VLE the whole electrical setting can be viewed completely, which leads to the necessity for the students to actively communicate with each other. The students only know the target state, but not the steps how to get there. The task of restoring electricity within the building can be divided into the following sub-tasks, which have to be encountered by the students without further instructions:

- Get overview of the complete electrical setting of the building,
- Find out, at which spots the electrical circuit is broken,
- Remember the necessary steps to repair the electrical circuit,
- Find the spot within the building from where the success of the problem solving can be controlled.

The process of the collaborative problem solving has to be organized by the students themselves. Before they start as a pair, each student has to run through a tutorial individually. A screenshot of the virtual environment is pictured in Figure 3. To analyze the possible interaction of immersion and task performance, the effect of natural user interfaces is integrated in the research design. The research plan consists of two groups. In both groups, the students work on laptops. Both groups use a simplified keyboard, where all keys except the arrows have been removed. With the arrow keys, the participants control horizontal movement. With a mouse, participants in both groups interact with the VLE. By clicking on the keys of the mouse, they can select different kinds of tools or resources they need to solve the problem. The experimental group fulfills the collaborative task wearing a head mounted display (Oculus Rift, DK 2). The field of view is therefore controlled by natural head movement. The control group controls the field of view by twisting the mouse.

Figure 3. Screenshot of the VLE, implemented in Minecraft

Subjective experiences focus on immersion, operationalized with the constructs of spatial presence and flow. In this study, spatial presence is measured with elements of the MEC Spatial Presence Questionnaire of Vorderer et al. [17]. Flow as the mental state of operation in which a person performing an activity is fully immersed in a feeling of energized focus, full involvement, and enjoyment in the process of the activity, is measured with the shortscale of Rheinberg. According to this instrument, in essence, flow is characterized by complete absorption in what one does, as well as the feeling of smooth and automatic running of all task-relevant thoughts [18].

Additionally to the questionnaire, the participants of the study are being interviewed about their experiences. Within the interviews, the experiences are linked with personal characteristics of the participants, e.g. their gaming experience. The subjects are also asked about the experienced quality of the collaboration itself, more precisely their strategies of problem solving, communication and task management. Since diffusion of responsibility within teams has proven to be an inhibiting factor for the success of group work [19] this aspect is also part of the interview. The behavior of the users is being captured by video camera, screen casts and spatial tracking systems. The task performance is measured in time needed for solving the problem.

A total of 8 students between 24 and 34 years (M = 26; SD = 3.28; n = 5 female) volunteered to take part in the pre-study. First screenings of the video material and the screen casts indicate a connection of problem-related speech-acts and task performance. Students who explicitly verbalize what they do and what they think the other one should do, get quickly to the point when they identify the necessary sub-tasks. For some students, especially those using the oculus rift, the tendency to "chit-chat" about the virtual environment from a meta-perspective and about its immersive effects was noted. For the analysis of the interviews it will be necessary to link this fact to the corresponding task performance. On the one hand, a strong interest in such "meta-information" can mean a positive effect regarding motivational aspects, but on the other hand it can mean some sort of distraction from the actual problem solving task, as it was indicated in previous studies on learning in virtual environments [13].

Comparing subjective experiences of the quality of collaboration with the actual task performance of the subjects will be another important aspect of the data analysis. However, corresponding conclusions will always have their limitations, since one of the greatest advantages of virtual learning environments is that people can use them at their own preferred speed.

IV. Conclusion

The qualitative research on collaboration in virtual environments gives deeper insights into the relationship of personal preferences for VLEs, subjective experiences within them and actual task performance. To focus on virtual collaboration delivers important research results for universities and companies who wish to use virtual environments in the future with the vision of industry 4.0 in mind. The preliminary results of the video analysis of the pre-study indicate the importance of communication within virtual environments. If performance within VLEs was to be enhanced even from today's point of view, to train staff in virtual communication skills would be a promising point to start.

The approach of user-centered design helped to get deeper insights into specific design preferences of VLEs from a user group, who grew up in a digitalized society. However, the preferences can also be due to age instead of cohort. Especially in the light of demographic change and aging populations in Europe, it will be crucial to continue the kind of studies which have been presented in this paper. For the effective virtual collaboration within diverse teams, another research area covers collaboration of pairs with different skill levels: of novices and experts, of young and old co-workers or of IT-close vs. IT-distant people. Who can work best with whom, and in what kind of virtual environment will be an important aspect for effective human resources planning in companies.

Should research one day prove actual financial benefits of virtual collaboration, e.g. by reducing travel costs, this way of working will soon become established. Companies who know how to collaborate in virtual environments efficiently will have a strong competitive advantage compared to those who don't. Continuing this kind of research therefore is an important contribution towards a globalized, connected and digitalized working world in terms of industry 4.0.

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