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Development of Hybrid Lab-based Learning Environments with a Design-based Research Approach

Abstract

This paper deals with the complete process of didactic concept development for hybrid laboratory-based learning environments in engineering sciences using the design-based research approach. This includes all stages, starting with the research problem and the research questions, a requirements analysis, the first concept development including sub-concepts (self-directed learning, collaboration, virtual reality), implementation and a formative evaluation with subsequent concept refinement, and a final summative evaluation.

Keywords

Lab-based learning, Design-based research, Hybrid learning

1 Educational problem and research questions

The Internet of Things (IoT) has enormous economic potential with the largest share in the industrial sector. The core element of the economy will be smart networking (BMWi, 2017). Engineering education at universities and colleges is called upon to impart the new requirements to their students, not only theoretically but also practically and close to industry. This requires future-oriented digitization and networking of industrial and logistical systems in the university environment as suitable places to learn and work. It also requires didactical reflection on digitization in engineering teaching and the adaption and design of the methods and digital tools, based on the current state of research in order to support the development of (IoT-)relevant skills (Feisel & Rosa, 2005) among students. A particular challenge here is in the area of digitized laboratory-based research and teaching: Real laboratory infrastructures include personnel, are cost-intensive, and are generally only available to the respective research institution. In contrast, purely virtual laboratories offer advantages in terms of security, scalability, remote access, and cost efficiency, but cannot replace the success of real laboratory environments, as these require and promote different knowledge. One approach to meeting these challenges and at the same time exploiting the potential of digitization for the training and competence-oriented learning of prospective engineers is to digitally integrate real laboratories and virtual learning locations into a hybrid learning and working environment, which additionally links different laboratories with each other via a learning platform and makes them globally available. That is precisely what is investigated in the research project presented here.

This requires a methodological didactic concept that is tailored to the requirements of the target groups and participating institutions and makes profitable use of the available technology and media options for learning. Both methods of collaborative and self-directed learning are relevant here (Kerres, 2018). Research in this respect focuses on the cross-location collaboration of multiple remote users, interaction with real and virtual objects via the Internet, and ways to promote self-directed learning in such complex environments. The availability and performance of smartphones, tablets, as well as AR/VR glasses, have increased massively in recent years. This has made the use of mixed reality (MR) practicable for learning. Thus, the potential of MR to support such learning methods in hybrid environments needs to be explored and exploited.

The central research question here is how such a methodological didactic concept must be designed so that effective learning can succeed in such a hybrid and distributed environment. More specifically, it is about the design of self-directed learning and the possibility of support by means of digital open badges, of collaborative learning and suitable forms of interaction between learners and with remote or virtual learning objects as well as ways of using MR to support these forms of interaction for learning.

In order to derive valid didactical design recommendations, several learning and teaching scenarios were developed, evaluated, and improved upon.

2 Didactical development (DBR approach)

In this project, we developed several lab-based learning scenarios that span several different didactical categories. While all of them have to teach an engineering topic in a lab-based, hybrid learning environment at heart, parts like learning methods, media, or organization can differ widely.

The didactic concepts in the project were created on the basis of Kerres' model for media didactic design (Kerres, 2018). In order to be able to implement this model, a needs and requirements analysis was first carried out, with which relevant information for the didactic design of the teaching-learning scenarios was collected. The focus here was on identifying the prerequisites, wishes, and possible problems on the part of the groups of actors associated with the learning scenarios (teachers, learners, laboratory staff, etc.) as well as on working out the institutional and organizational circumstances at the respective laboratory locations. Five types of information sources were used for this purpose: State of research and theoretical background on laboratory-based learning and the teaching-learning methods used in the project, intentions, and goals from the project proposal, interviews with teachers and researchers from the subject areas relevant to the project, interviews with students from the field of engineering, and so-called scenario surveys that provided information on the structure and framework conditions of the teaching-learning scenarios used. The results of this work were then used to derive more than 175 requirements for the development of the overall methodological didactic concept and the sub-concepts associated with it. For example, it was formulated here that sufficient opportunities for communication between teachers and learners should be provided within the learning management system or that the limited experience of many students in this area must be considered when using serious game applications.

Using the information and requirements obtained in the requirements analysis (fields of didactic analysis: actor conditions, environmental conditions, teaching content, and teaching objectives) as well as knowledge gathered from specialist literature, the researchers were able to start the development of the didactic concepts. Creating these concepts represented the beginning of the design-based research process used in the project and contained concrete didactic recommendations, which were examined scenario-specifically for their meaningfulness and feasibility and then, if possible, implemented in the scenarios. Thus, it was considered which teaching-learning methods, which media and tools, and which forms of a learning organization are most suitable in each respective context to convey teaching content and thus achieve the teaching objectives. In this way, the first prototypes of the project scenarios were created, which, if all the concepts are added together, resulted from more than 110 didactic recommendations. Of these, 17 alone were taken from the overall concept, such as “When designing media, display information in a way that uses both coding channels (e.g. image and text), use visual symbols to display processes (e.g. images, videos, animation), avoid merging coding channels of the same type (e.g. text and audio), and give options on how to represent information”.

The learning scenarios redesigned in this way were then formatively evaluated with the help of interviews with students, teachers, and relevant experts from research and laboratory practice. In the next step, the results were used to discuss problems identified and wishes and ideas expressed in the evaluation and, if sensible and possible, to integrate them into the concepts and design recommendations so that they were then partially incorporated into the scenarios. This iterative sequence of tasks was repeated as often as time allowed per scenario and concept in order to optimize them for teaching and learning. In this way, for example, about 75 new didactic decisions were generated for the scenarios at the HFT Stuttgart, including the rejected ideas or suggestions that were not implemented. This involved topics such as task links between different learning phases, the clear communication of learning objectives, stronger referencing of the scenarios to everyday work in companies, or the inclusion and structure of a short introduction at the beginning of the scenario.

3 Collaborative learning

Collaborative learning and working are generally important parts of engineering education (Feisel et al, 2002 ; Tekkaya et al, 2016). Thus, the use of collaborative learning as a method is also of substantial interest in this context. However, one of the major educational problems in this joint learning is that students in the subject often lack team skills (as emerged from the requirements analysis). These include (IoT-)relevant skills, for example, communication, negotiation, and leadership skills. Therefore, to address this problem, these skills were often identified as learning objectives in the original project scenarios and the learning events associated with them. However, these learning objectives had not been optimally formulated and implemented in terms of methodology and media. So, this was exactly the starting point for the sub-research questions and improvement plans for the collaboration concept in the project, which focused on finding out with which methods of learning support social learning processes and interactions in hybrid lab-based learning spaces and with which forms of direct or technically mediated interaction learning and collaboration in such learning environments succeed. Or in short: How can collaborative learning be supported there?

In order to stimulate learning and working together, appropriate didactic decisions were made to promote social presence (and its perception: "awareness") and interaction in the learning environments, so that a feeling of togetherness was created among the participants. Thus, especially in the digital project labs, the perception of other learners was supposed to be prevented from suffering due to a lack of facial expressions, gestures, and spatial proximity. Therefore, an attempt was made to create a feeling of not being alone, for example, by making questioning, chats, emojis, wikis, FAQs, and a generally dynamic feedback system important components of the learning scenarios (Brandon & Hollingshead, 1999). Such feedback and support mechanisms were intended to make it clear to learners that other people are involved and that teachers and tutors are available to provide support, especially in terms of the learning management system. Further design recommendations of the didactic concept refer to the fact that, as can be seen from the requirements analysis at the beginning of the project, the learners in the project scenarios have very heterogeneous prerequisites in terms of previous technical experience. Accordingly, system introductions, for example, were recommended and implemented. Additional recommendations concern the areas of optimal group size—which was set at approximately three to four people in order to keep the benefits of collaboration high in relation to the communication costs—appropriate group composition (according to professional knowledge, gender, previous experience with collaboration and technical knowledge) and the transparent presentation of the goals, assessment, benefits, and process of collaborative learning phases (Brandon & Hollingshead 1999).

4 Self-directed learning

For self-directed learning, too, a didactic concept was created, design proposals were made, some of them were implemented in different project scenarios, and their implementation was evaluated both during the process and at its end. The aim was to create didactic learning environments that are suitable for the application of this learning method and, above all, support learners who primarily work individually, thereby achieving a more effective learning process and gaining (IoT-)relevant skills. Special attention was paid to the extent to which Open Badges and other tools and media are useful for learners in those self-directed learning environments.

In accordance with the didactic procedure outlined above, a total of eleven requirements for the design of self-directed learning spaces were identified with the help of the requirements analysis and were, henceforth, considered mandatory in the further progress of the project. On the one hand, these were requirements that address the prerequisites of the scenario target groups (different skills, etc. of learners and instructors), and on the other hand, a number of requirements for the teaching-learning environments themselves (ensuring social interactions during learning, etc.), especially also in digital and hybrid learning settings (Ferdinand, 2007 ; Friedrich & Mandl, 1997 ; Faulstich, 2001).

The derived requirements subsequently formed the framework for the creation of the concept and its concrete adaptation in the learning scenarios. With the help of relevant literature, suitable ideas and solutions were then developed for the specific research context of the project, which ultimately resulted in more than 60 design recommendations. Among other things, this included the idea that the laboratory exercises should, if possible, be divided into concrete learning sections with their own intermediate objectives, in order to be able to form learning paths and to simplify the planning of learning—and gladly also with visualizations, for example via Open Badges (Ferdinand, 2007 ; Stauche & Sachse, 2004 ; Cucchiara et al, 2014).

5 Mixed Reality

Traditionally, one would define Mixed Reality in the sense of Milgram et al. (1994) in the context of the Reality Virtuality Continuum. The Continuum spans from the Real Environment on the one hand to the completely Virtual Environment on the other. Mixed Reality in this context includes the complete space between these worlds, such as Augmented Reality and Augmented Virtuality. Nowadays, however, the term Mixed Reality is understood more broadly and is often used as a synonym for all technologies from this area. Speicher et al. (2019) note that it is difficult to find a universal definition for a branch of research that is currently evolving so rapidly. We interpret the Virtual Environment of the continuum as synonymous with Virtual Reality, since the immersion and interaction, as well as the complete isolation, of the user from the real world, are its main foci. For collaboration aspects, we refer to the Time/Space Matrix from Johansen (1988), which classifies collaboration types based on time (Synchronous vs. Asynchronous) and on location modalities (co-located vs. non-co-located or remote). During the project, we developed multiple Virtual and Augmented Reality Applications, both for single users, as well as for collaboration between multiple users, which can be classified via both the RV Continuum and the Time/Space matrix. Based on this and our experiences during development, we created a schematic to show the difficulty of the implementation, extendibility, and maintenance of Mixed Reality applications by combining the RV Continuum and the Time/Space matrix. This way, we determined the dependencies of collaboration modalities with their position on the Reality Virtuality Continuum.

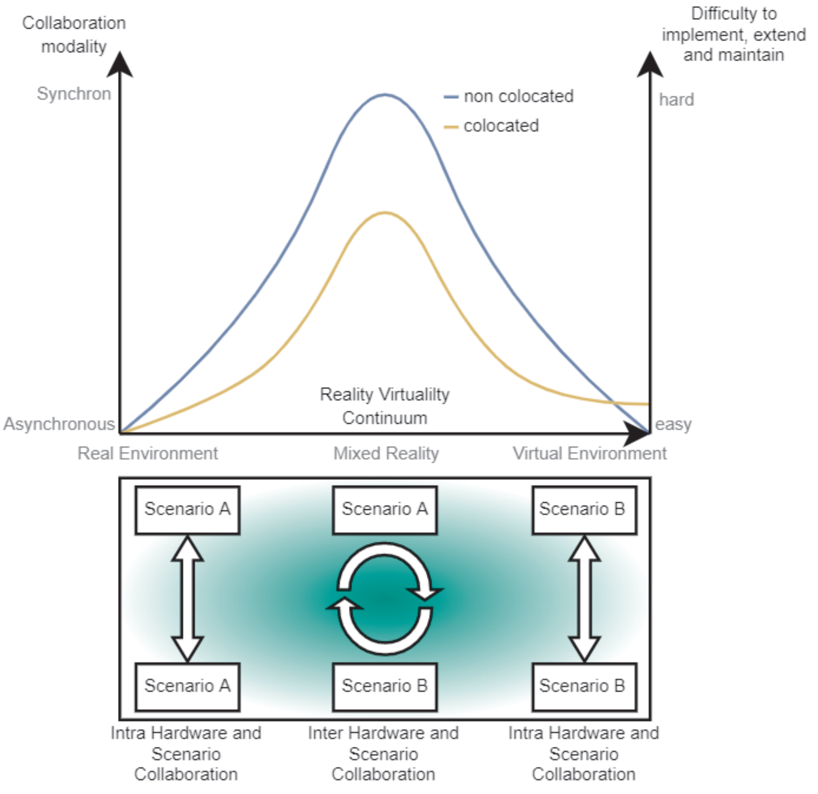

Figure 1: Own illustration (based on Milgram et al (1994) & Johansen (1988))

At the top of Figure 1, the RV Continuum lies on the X-Axis and spans the continuum from Real Environment to Virtual Environment, while the Y-Axis depicts Synchronicity as well as Difficulty. The two graphs, one for co-located and one for non-co-located (remote) collaboration, show that it is typically harder to implement collaborative Mixed Reality applications if the collaboration/communication is synchronous, remote, and placed somewhere in the middle of the RV-Continuum. The reasons for this are briefly summarized below:

Collaboration Synchronicity: The more real-time the collaboration is, the more computing power and network bandwidth is typically needed.

Additionally, one has to deal with filtering incoming positional data if movement is synchronized.

Reality Virtuality Continuum: Since most Mixed Reality applications run on portable devices, they offer the least computational power, restricting the options of the programmer. Additionally, the variety of devices (smartphones, head-mounted displays, etc.) has resulted in many new and changing frameworks, as well as programming environments, which makes maintenance over long periods of time difficult. For Augmented Reality applications especially, external influences that might interfere with camera tracking have to be considered.

Co-located vs non-co-located: Naturally having all devices in the same location and/or running on the same hardware makes things easier in regard to networking and removes most bandwidth issues. However, one has to keep in mind certain hardware limitations, like security spaces for Virtual Reality or interference of different tracking technology. This is the reason why having multiple co-located users in the same Virtual Reality application is rated harder than the non-co-located alternative.

In contrast to the increased difficulty of implementation, maintenance, and extendibility, applications in the middle of the RV Continuum also offer tremendous opportunities to act as a bridge between the two extremes. Whereas scenarios in the real world and in the virtual world are often strictly separated, the boundary is increasingly blurred in Augmented Reality applications. In terms of collaboration, this enables an inter-hardware approach in which, for example, users of Augmented Reality glasses can communicate with users of Virtual Reality glasses.

As we have successfully shown in the project, spatial boundaries as well as boundaries within the Reality Virtuality Continuum can be overcome in this way to enable students to learn together in a profitable way. We believe that our schematic relationships will help to weigh up whether opportunities for inter-hardware collaboration justify the increased effort. We also provide an overview of potential difficulties that may arise along the Reality Virtuality Continuum or the Space/Time matrix.

6 Summative Evaluation

With a view to answering the project's research questions, data on the effects of the concept recommendations in terms of learning progress, different forms of learning motivation, and acceptance of learning environments (dependent variables) were collected after their implementation. For this purpose, quasi-experimental group studies with repeated measurements were conducted and the test persons were assigned to different groups. The groups first had to complete a pre-test and then prepared for the laboratory exercises, which differed depending on the group classification. While some study subjects went through the original scenario as a control group, other groups had self-direction, collaboration and/ or VR treatment. This had consequences above all in terms of which laboratories the test persons used and also in which social form they worked there and how the digital learning management system was designed in the follow-up and report preparation phases—i.e. which possibilities, media, and tools were available. Finally, after the completion of the whole learning scenario, a post-test was conducted. All the surveys were primarily quantitative and were executed via questionnaires, most of them consisting of already tested and validated items and only slightly adapted to the respective contexts of the scenarios. The knowledge tests, on the other hand, were created in the project itself.

Unfortunately, the samples in some scenarios were not particularly large, especially in the one that was most significant for the concepts presented here (n=34). As a result, fewer groups were able to be formed than necessary for a properly conducted treatment study. This circumstance will most likely have an impact on the accuracy of the results.

Currently, the results are not yet available, as the analysis phase has just begun. At present, there is only a brief insight into the mean values of the scenario just mentioned for the dependent variable *amotivation*; in this case, over three measurement points, as there was also an intermediate measurement after the laboratory phases.

Of the study groups, the one in the original scenario actually performs the worst: After the last measurement, it has the highest amotivation (1.92; complete amotivation: 4.00; no amotivation at all: 1.00). Although it was able to reduce this by 4% over the course of the scenario, it also ranks worst in comparison with the other groups. The group in the remote lab with Self-Direction Treatment is in a somewhat better position, with amotivation of 1.85 in the end, but was able to reduce it by 12.32% until then. The VR probands even achieved more than 20.5% and 1.62 here and thus already better values than the average of all test subjects (-16.75% and 1.69). The revised hands-on scenario, in which all forms of treatment (collaboration, self-directed learning, and VR) were implemented simultaneously, took a good second place in this ranking. Despite the highest start motivation (2.22), the second lowest final value of 1.59 was measured here due to a reduction of 28.38%. Only the participants of the remote lab without self-control treatment did better, showing a very low amotivation value of 1.22 in the end, after they had been able to reduce it by more than 31.4%.

The first results thus give slight indications that the scenario revisions made had positive impacts on the extent of amotivation in the exercise. However, the significance of the results remains low for the moment due to the small number of cases, the types of calculations made, and the preliminary exclusion of important control variables, and does not yet permit any meaningful interpretation. More detailed information will follow shortly.

7 Conclusion & Outlook

In conclusion, it can be stated that the creation of the overall didactic concept and the sub-concepts of collaborative learning, mixed reality, and self-directed learning has succeeded so far and was extremely complex in terms of content, as there were a large number of design options. It was therefore not always easy to remain goal-oriented and to pass on only those design recommendations that had a very strong presumed benefit for learning in the aforementioned learning environments. This task was made all the more difficult by the inevitably heterogeneous framework conditions and target group prerequisites that prevail in an international project with different partner universities. These circumstances meant that the creation of the concepts was relatively time-consuming, which must be considered when planning such projects.

The implementation of the design recommendations was also largely successful. However, it was necessary to forego the realization of many ideas here because the selected learning scenarios, which were intentionally kept quite simple and short, would otherwise have been overloaded. This development shows that it is important to anticipate the relationship between the research project and its real possibilities as early as possible in order to be able to work accurately. For this purpose, information and findings from the initial phase can and should be used, such as those from the requirements analysis conducted at the beginning of our project.

The iterative process of the design-based research approach that was used, in combination with the qualitative surveys and analyses of the formative evaluation, played a very important part in identifying practical problems and implementable ideas for improvement in the individual learning scenarios. By doing so, they built a bridge between theory and practice, which led to new insights. This approach has hence proved successful overall, but at the same time was quite time and resource-intensive.

With regard to the summative evaluation, there were unfortunately some problems that will affect the quality of the results. For example, the global pandemic situation in the survey year 2021 meant that the number of probands, which was already tightly calculated in some scenarios, shrank even further, some scenarios could not be tested or could only be tested under different circumstances than planned, and the scheduling and preparations turned out to be extremely difficult.

Nevertheless, it was possible to carry out the data surveys. As described above, it remains to be seen which conclusions will be possible after the analysis due to the data collection problems. The analysis is scheduled to be completed by the end of March 2022. If possible, the types of treatment will then be assessed for their success and conclusions will be drawn on how didactic concepts in hybrid engineering laboratory environments can be designed to improve learning.

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