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Approach of a virtual reality didactic toolkit - implementation and reflection

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Abstract

Virtual reality plays an increasingly important role in design education. However, a holistic view, starting with the didactic concept, the selection of a VR tool suitable for the learning task and a final reflective evaluation of the learning experience, rarely takes place. In this paper, the authors present an approach for a VR didactics toolkit that covers and takes into account all three points as a whole. The application and research environment here was the bachelor's degree module Ergonomics and Industrial Design at the Ostfalia University of Applied Sciences.

Keywords: virtual reality (VR), design education, digital learning, ergonomics

1. Introduction

Today's world is characterized by volatility, uncertainty, complexity and ambiguity (VUCA) (Mack *et al.*, 2016). To prepare future engineers to work in this VUCA world, methods and tools in education and training must be adapted. One approach to this is the CDIO syllabus, a framework for the training of engineers. It focuses on the teaching of technical fundamentals through the steps of conceiving, designing, implementing and operating (CDIO). It defines three core competencies for teaching. These are then further subdivided into sub-competencies. Another approach comes from the TU DELFT, which similarly defines eight attributes of engineering graduates (Kamp A., 2016).

In order to meet the demands of the digital transformation in academia, educators are increasingly using digital tools that will play a role in students' future careers. For instance, virtual reality (VR) is utilized as a tool to support interdisciplinary problem solving, strengthening the imagination and enabling cross-location communication. According to Dean Cofey, (Senior Educational Production Technologist) VR is "still in its infancy but we envision unique use cases for it such as meeting one-on-one with remote faculty, and whole new experiences that no other medium has been able to offer. There's just something about it that's really engaging." (Fauser, 2016) VR-assisted teaching is gaining popularity, yet lacks comprehensive systematic concepts for its employment within teaching. VR is utilised independently by instructors on a selective basis, often according to their own inclinations. Which learning objectives and scenarios VR is best suited for is rarely analysed.

Accordingly, this paper presents an approach to the systematic development of VR-supported design teaching, integrating a structured reflection process. Initially, experience is gathered in a university teaching scenario, which will later be validated in an industrial context. Therefore, this paper presents a best practice for the goal-oriented introduction of VR in the course on ergonomics and industrial design at the Ostfalia University of Applied Sciences.

2. State of the art

The following three sections identify the prerequisites for the successful use of VR in teaching. It will be discussed how learning settings can be designed, how VR can be used as a teaching and learning tool and how to systematically assess learning success and the teaching concept itself.

2.1. Design of teaching and learning scenarios

The approach of Instruction Design examines how learning opportunities and learning environments need to be designed in order to allow specific target groups to acquire specific skills (Reiser and Dempsey, 2018). The approach is based on the assumption that learning processes are efficient and successful if the internal (characteristics of the learner) and external (characteristics of the learning material and environment) learning prerequisites meet certain requirements (Gagne *et al.*, 2005). An aspect of the internal learning prerequisite is that the appropriate logical connection point is guaranteed. In primary school mathematics, for instance, it is imperative that a pupil has mastered addition before being taught division and multiplication. Nevertheless, the learner's motivation and attitude towards the subject matter, as well as the learning methods are relevant factors (Thomas *et al.*, 2018). The external learning conditions include not only the premises and the learning tools but also the desired learning objectives. These may be classified according to Bloom's learning objectives taxonomy (Thomas *et al.*, 2018; Bloom, 1972).

A commonly used model for the application of Instruction Design is the so-called four-component model (van Merriënboer, 2019). It is suitable for learning complex cognitive skills, but can also be applied to simpler issues. The four-component model is consistently based on the teachings of constructivism, a learning theory that considers the learner's individual experiences as a decisive aspect for learning success. The four components of the model are:

- **Learning Task**
- **Supportive Information**
- **Procedural information**
- **Part Task Practice**

These four components interact with each other. In this way, the learning task promotes inductive learning. The supporting information helps to process the newly learned material. The procedural information supports the discovery and formation of rules, which are consolidated through part-task practice. In order to design a teaching concept based on this model, the following activities should be carried out: design learning tasks, set standards for acceptable performance, sequence learning tasks, design support information, design procedural information and part-task practice. The exact description of each individual activity can be found in (van Merriënboer, 2019). In addition to the Four-component model, there are other models such as the ADDIE (Reiser, 2007), the DO ID (Thomas *et al.*, 2018) or the SAM model (Hyojung *et al.*, 2019). Each of these models provides a framework for designing learning environments. In order for VR to be used as a tool in teaching, it must be integrated seamlessly into these or other existing teaching/learning concepts. However, in none of the models there is any explicit consideration of whether the teaching has been successful after implementation of the teaching concept. Accordingly, there is no formal provision for reflection, neither on the part of the teachers nor on the part of the learners.

2.2. VR as a learning tool in engineering education

Virtual reality (VR) technology is playing an increasingly important role in teaching and training. In 2017, the proportion of companies that used VR to train and develop their employees was already 17 percent of the companies interviewed. By 2020, this proportion had risen to 36 percent (Scholten and Buehler, 2017; Zabel and Telkmann, 2021). How exactly VR is to be understood is not yet clearly defined in the literature. Various definitions exist in parallel, some of which overlap but also have their own emphases. Dionisio *et al.* (2013) states: "VR is a computer-generated simulation of 3-dimensional objects and environments with seemingly real, direct or physical user interaction". Abdelhameed (2013), on the other hand, states: "VR is a Human-Computer interface in which the computer creates a sensory immersing environment that interactively responds to and is controlled by the behaviour of the user". There is agreement that every form of VR requires a **VR environment** in which the **user** feels

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immersed. Just as there are many different definitions of VR, there are also many different VR tools for teaching, some examples from the field of engineering education are given: Retnanto et al. provided a virtual field trip for students at Texas A&M University (Retnanto *et al.*, 2019), Deutsche Bahn trains train attendants in the operation of a wheelchair-lifting device (Groß *et al.*, 2019) or there is a platform to simulate temporal bone dissection (Locketz *et al.*, 2017). In the following, the Glassroom project is presented in more detail, because it was introduced in 2018 as a needs-based education concept as described in section 2.1 (Thomas *et al.*, 2018). It pursues the goal of building up competence, e.g. in the field of maintenance and repair, by using virtual reality. The competencies acquired in this way are then deepened and further developed with the help of augmented reality. Glassroom is designed to enable training, especially on expensive and error-sensitive equipment. This will reduce high basic acquisition costs and any repair costs that may arise due to incorrect operation during training. At the same time, it enables relatively lifelike handling of these devices without any major cost risk. Furthermore, it allows to provoke errors already during the training in order to cause a stronger learning effect. Application goals of the software are among others:

- a high level of user-friendliness
- an easy and inexpensive introduction
- the fast generation of new training scenarios

However, the article leaves open how exactly Glassroom can be integrated into existing teaching and learning concepts, for example at colleges, universities or technical schools. It does not address which didactic methods such as flipped classroom, blended learning, role-playing or EduScrum are suitable for the use of VR and which are not. However, this is essential for the successful use of VR (Balzerkiewitz *et al.*, 2022). Furthermore, there is no information on identified best practices or problems that have arisen in VR-based learning concepts.

Lyrath *et al.* (2023) take a different approach. Although the authors refer to the use of assisted and augmented reality (AR) and not VR, they follow a systematic approach to the use of new digital technologies in engineering courses. First, the existing course is analysed in a similar way to the four-component model. The learning tasks and current weaknesses are described. The AR functions are then assigned to the learning tasks in a meaningful way and the corresponding supportive and procedural information is developed. Finally, the Part Task Practices are described. The students were accompanied during the implementation with a questionnaire and the learning outcomes of the test group were compared with the control group. It was found that the use of new digital technology can lead to better learning outcomes. However, success is still dependent on many boundary conditions such as the teaching concept, the quality of the teaching materials, and the existing level of learning and knowledge. These boundary conditions are sometimes difficult to identify and require further investigation, for example with the help of structured reflection.

Analysing existing approaches shows that VR tools used in teaching are tailored to their specific area of application. With regard to the acceptance of tools, it can be deduced that, in addition to the didactically appropriate preparation of the course, the so-called usability of the tool also has a decisive influence. Usability indicates how well a tool is suited to fulfil a specific (learning) task in a specific context. As many subjects place different emphasis on individual learning aspects (analysis or synthesis), pursue their own learning objectives (maintenance tasks or physical effects) and have to take different boundary conditions into account (lecture or laboratory), it is logical that there are many different highly specialised VR software solutions in the field of teaching and training.

2.3. Reflection to improve the teaching setup

West (1996) defines reflection as a deliberate and purposeful process in which individuals or teams recapitulate their experiences in a particular situation (goals, strategies, processes) and re-evaluate them in the current context to guide and adjust future actions. Structured reflection in engineering projects promotes continuous and timely project evaluation and process adaptation (Conforto *et al.*, 2016). To facilitate systematic planning and execution of reflection in earlier work (Inkermann, 2021; Inkermann *et al.*, 2020) the “Reflecting Collaboratively on the Adaptation of Processes (RECAP)” framework has been introduced. This framework supports in defining objectives, stakeholders, objects, process, and timing for reflection. With regard to the engineering context (Bender and Gericke, 2016), three layers for reflection are defined: strategic reflection considers long-term context changes, tactical reflection addresses medium-term changes on a project level, and operational reflection focusses on short-term changes during a project. While these layers form the rows of the framework, the columns specify why (objectives), who (stakeholders), and what (objects) to reflect on. A detailed description of the RECAP framework (Figure 1) and its application in VR can be found in (Inkermann *et al.*, 2022).

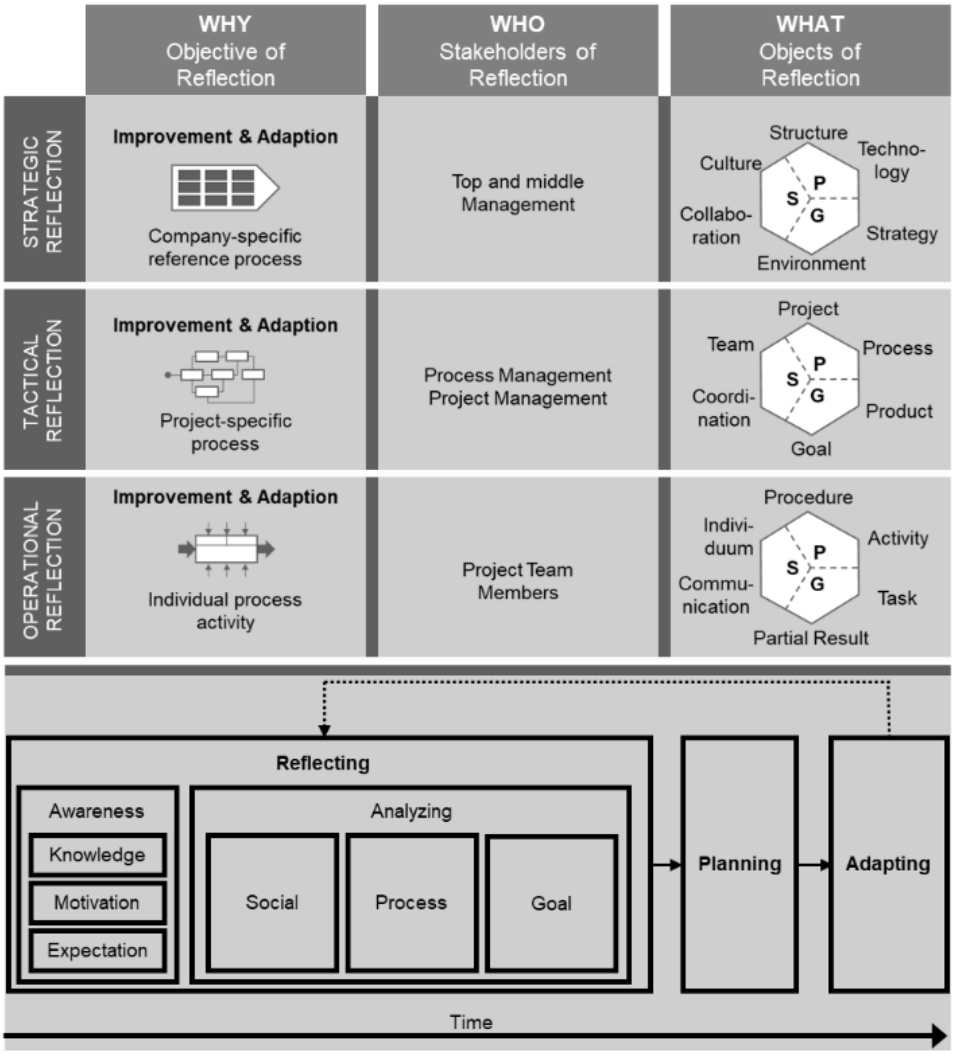

Figure 1. Chart of the RECAP framework (Inkermann et al., 2022)

Reflection processes have also found their way into teaching. In modern approaches such as EduScrum, they represent an essential part of the teaching concept. Since teaching methods and learning tools are based on the knowledge to be imparted and should be used in a learning group-oriented manner, the focus here is particularly on the operational and tactical levels. In the context of this paper, this results in the possibility to evaluate the targeted use of VR in teaching and to initiate a continuous improvement process on the strategic level. Tactical reflections usually address adaptations of project-specific processes, which requires stakeholders from process and project management to reflect on projects, teams etc. Due to its focus on individual process steps, operational reflection normally involves project team members, who reflect on particular procedures, individuals and others. It is therefore analysed how VR is integrated into existing courses and how well it is implemented in individual teaching units.

The layers also define the objects of reflection ("What") such as projects and products on a tactical level, and activities and partial results on an operational level. The process of reflection is structured into three phases that are reflection, planning and adaption, see lower part of Figure 1. The reflection phase itself is divided into awareness activities, to gain for instance new knowledge about VR technologies, and

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analysis activities that are focusing on the challenges in current engineering tasks with regard to social, process and goal aspects.

The RECAP framework supports in identifying needed stakeholders for reflection activity along with guidance around setting up their reflection steps. It also allows for reviewing reflection activities themselves of current and previous projects, in order to find the right frequency and objects of reflection.

3. Methodology and implementation of a VR-based learning concept

In the following, the VR teaching concept at Ostfalia is presented using the example of the ergonomics and industrial design course. It is examined whether the use of VR was conducive to learning for the students. Based on the knowledge gained from this, an attempt is made to identify best practices for the general use of VR in teaching.

3.1. Planning and preparation of the course

The lecture takes place in the sixth semester and is part of the design and development specialization in the bachelor's degree program in mechanical engineering. According to the CDIO concept this course falls into the areas of "personal and professional skills" and "interpersonal skills". The structure of the lecture is designed according to the four-component model described in section 2.1:

The learning task:

In this course students should learn the "basics of understanding and designing usable products, taking ergonomic aspects into account". This requires an understanding of the terms, concepts and theories of rational and emotional functions, usability, anthropometry, informational-mental ergonomics, and industrial design. In addition, the familiar concepts from the basic studies should be applied to the ergonomic development and design of technical products, e.g. along the approach according to VDI 2242 or VDI 2424 using practical examples. The aim is also to improve communication and teamwork skills. The entire course is designed as a series of workshops. The first workshop is permitted by the instructors as an introductory event, the remaining three events are organized by student groups.

Supportive Information

The entire course and the information required to run the course are conveyed to the students in the introductory event as "an easy and inexpensive introduction", as requested by the Glassroom project. This included a timetable and an introduction to using VR as well as information on how to conduct and implement a reflection process as part of each individual workshop.

Procedural Information

The technical content is taught in workshops. These are designed in such a way that the students work on a topic themselves and prepare it so they can communicate the content to their fellow students. For this purpose, the class is divided into groups of five students. The workshop organizers share the theoretical knowledge and all the necessary information for performing the practical tasks with the other participating students. However, the learning content is developed in close coordination with the instructors.

Part Task Practice

The interior and exterior design as well as the design of the driver's cab of a rail vehicle for passenger transport is used as a practical example. VR should be used in the practical part as a tool with "a high level of user-friendliness", as requested by the Glassroom project. A 3D train model exists and is available in the VR tool. A presentation with slides and clear examples should be utilized to explain the theoretical aspects. The assessment of the students considers the preparation and implementation of the workshops as well as the results of the performance tests that take place after each workshop.

3.2. Implementation and reflection

As those responsible for the module, the instructors determine the framework of the overarching learning objectives and the media used at a strategic level.

The student groups each prepare their own topic area. Three student groups were established to deal with the topics of anthropometry, informational-mental ergonomics and industrial design. Each group sets out definite learning objectives in their respective fields, establishes the exact educational content, and identifies which learning materials are appropriate to be conveyed through specific media. The

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practical example is always explained to their fellow students using VR. Therefore, the VR-tool allows "the fast generation of new training scenarios", as requested by the Glassroom project. The students take on the role of the teacher for their special topic and thus represent the tactical level.
The students who are not currently presenting their own topic take part in the presentations of their fellow students. They actively participate in the presentation to understand the theoretical basics and use VR as a tool in the practical examples. Since they have to pass a test at the end of the performance, they have a high extrinsic motivation to understand the learning content and thus achieve the learning goals. They represent the operational level.
In order to evaluate and improve the success of the use of VR, a usability test of the tool and finally a structured reflection of the course on the different levels described are carried out. The structure of the course follows the flowchart in the lower part of Figure 1 and is described in more detail below:

- **Phase of awareness**
  The first lecture was organized by the instructors. In the first section, general information about the process and the organization was presented. Subsequently, the basic concepts, theories and procedures are taught by the instructors. The aim is initially, in the spirit of constructivism, to create links to lectures from the basic course, for example technical requirements in comparison to ergonomic requirements. The groups are then divided and the specific topic areas for each group are determined. The students prepare for their role as teachers with an initial questionnaire (Reflection I).
- **Phase of planning and adapting**
  In the second section, the instructors conducted the first workshop. First, the theoretical knowledge of ergonomic principles and the human-machine interface was deepened. A concrete usability test is then carried out in a practical part. The specific task is a design review of a mechatronic product (Timekeeper Gadget) in VR. The task is set in such a way that all relevant functions of the VR tool must be used to solve it. All students act one after the other in the VR and answer qualitative questions in the role of the test person. The students who are not currently in the VR themselves answer quantitative questions in the role of inspector. The evaluation of the questionnaires determines the degree of usability of the VR tool used with regard to the specific task. Since there is no usability test for VR tools, the questions were developed based on ISO 9241 (International Organization for Standardization, 2022). To help students use their acquired experiences to plan their own presentations, they must complete another questionnaire (Reflection II).
- **Strategic level analysis**
  As is common practice at Ostfalia, each course is evaluated by the students at the end of the semester. Here, the instructors receive feedback and tips on how to improve the quality of teaching. This information is used for the reflection of the instructors and the further development of the course.
- **Tactical level analysis**
  The next lecture dates are each designed by a group of students. The specific group topic is initially derived theoretically as a slide presentation and smaller application examples or through exhibits. Thus, for example, the group that prepared the topic of anthropometry developed a VR scenario on the topic of "Accessibility for people with disabilities and people with reduced mobility". The theoretical part is followed by a practical application in VR, where, among other things, a wheelchair had to be moved through the virtual train. After a group has finished its event, the group analyses to what extent its planning and final implementation worked and whether the set learning objectives were achieved. Another questionnaire on the tactical level (Reflection III) serves as the basis for this reflection step.
- **Operational level analysis**
  After all student groups have presented their topics, a final analysis is conducted. At this point, all students assume the role of learners, thereby representing the operational level. The aim is to determine whether the use of VR leads to better results in fulfilling the learning task (Reflection II).

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4. Evaluation and interpretation of the reflection results

In the summer semester 2023, 16 students took part in the course on ergonomics and industrial design. After the course was completed, the collected results of the reflection and performance assessments were evaluated. As described earlier, the reflection took place on three levels (operational, tactical and strategic). The results are presented below. The focus is primarily on the insights gained from the reflection questionnaires and the observation of the student groups during the discussion when answering the stimulus questions. These stimulus questions are based on those developed earlier by the authors and presented in (Inkermann et al., 2022).

4.1. Reflection on operational level

A workshop on the topic of usability was organised and conducted by the instructors themselves in order to give the students their first impressions of VR and to encourage reflection at an operational level. After this first VR experience, the students were asked the questions shown in Table 1. The following observations were made with regard to the objects of reflection (social, process, goal) (cp. Figure 1).

Table 1. Questionnaires of Reflection II "planning and adapting"

RII.1	Was your prior VR experience (if any) helpful in completing the tasks? How did this make itself felt?
RII.2	How well were you able to complete the tasks in VR? How would you rate your results?
RII.3	Which additional tools and functions would you have liked to have for carrying out the tasks?
RII.4	How would you change the methods used so that they are better supported by the existing VR tools and functions?
RII.5	In your opinion, what positive or negative effects can the use of VR have in everyday working life?
RII.6	In your opinion, how should the VR application be developed to be used efficiently and effectively in everyday work?
RII.7	In your opinion, how would methods and processes in day-to-day work must change in order to be able to use the VR application efficiently and effectively?

- **Goal (RII.2 and RII.5)**
  With regard to the workshop held, a large proportion of the students (15/16) confirmed that the task could be solved well by using VR and that they were satisfied with the results achieved.
- **Social (RII.1)**
  During the practical VR exercise, it was observed that VR generally met with a lot of interest and the tasks were carried out having fun. Three students were rather reserved towards VR. One reason for this was that they already had bad previous experience with motion sickness. On the other hand, there was simply a lack of interest in getting to grips with VR.
- **Process (RII.3, RII.4, RII.6 and RII.7)**
  The survey revealed that the main wish when using VR is to have a low entry threshold. Functions must be clear and easy to find (RII.3, RII.6). It was also noted that the framework conditions (RII.4, RII.7) must be suitable for VR. This means that there must be suitable and high-performance communication and data exchange interfaces. It was further mentioned that a focus on collaborative and digital working methods is necessary for the efficient and effective use of VR.

4.2. Reflection on tactical level

To facilitate tactical reflection, students were asked questions before (awareness) and after (analysis) workshops. The analysis questions mirror the questions in the awareness questionnaire, see Table 2.

Table 2. Questionnaires of Reflection I "awareness" and Reflection III "tactical level analysis"

RI.1	How do you want to ensure that all workshop participants can actively take part in the VR experience?	RIII.1	How did you ensure that all workshop participants were able to actively participate in the VR experience?

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RI.2	Which workshop activities do you want to implement/apply in the virtual world? How much effort will this require?	RIII.2	What workshop activities did you implement/apply in the virtual world/how much effort did you put into this?
RI.3	How can virtual reality help you to communicate your workshop topic?	RIII.3	How did virtual reality help you to communicate your workshop topic?
RI.4	What previous experience have you already had with virtual reality? How do you want to use this experience in the workshops?	RIII.4	What experience have you gained with virtual reality / how can you benefit from it in the future?
RI.5	What communication possibilities do you expect in virtual reality?	RIII.5	What communication options did you use in virtual reality?
RI.6	How much time should the VR part of the workshop take?	RIII.6	How much time did the VR part of the workshop take?
RI.7	How do you think virtual reality can be optimally used in the workshops?	RIII.7	How can VR integration in workshops be improved? What changes would you make for next time?
RI.8	What do you want to take away from the individual workshops and what positive effects/benefits do you hope to gain from using VR in this regard?	RIII.8	What did you take away from the individual workshops? What positive/negative effects, advantages or disadvantages did the use of VR have?

- **Goal (RI.1, RI.3 / RIII.1, RIII.3)**
  At the beginning of the course, students should explain how they want to use VR to support their teaching topic: The tenor was that short VR sessions should be used for simple tasks. Most students retrospectively confirmed that they had done this. However, it also emerged that communication between students (students in VR and students not in VR) played an important role. The VR image was transmitted on monitors and projectors so that the students outside of VR could also participate. In addition, some students were keen to motivate their fellow students to try it out. This correlates with the results of question three (RI.3 and RIII.3). In reflection I, an overwhelming majority said that the visualization was conducive to conveying the learning task, while in reflection III a large proportion said that visualization was important, but that performing the activities in VR themselves was at least as important. It was stated that the understanding of the individual topics could be improved with the help of VR, but that VR was not always useful. Furthermore, although VR was easy and intuitive to use, not every student found the VR experience pleasant (e.g. due to motion sickness).
- **Social (RI.4, RI.5, RI.8 / RIII.4, RIII.5, RIII.8)**
  At the beginning, the students had little previous VR experience. They were able to gain this in the course and can now assess where VR can be used and how long it takes to prepare for it. In addition, the students stated that they had better internalize the course content thanks to the organization of the workshop. The instructors were able to observe that, like at the operational level, there were students who did not want to engage much with VR. However, these students were not excluded from the group, but instead focused on preparing for the theoretical part of the workshop.
- **Process (RI.2, RI.6, RI.7 / RIII.2, RIII.6, RIII.7)**
  At the beginning of the course, the questions about the use of VR were only vaguely answered. Due to their lack of experience, the students were unable to say how much time (estimates ranged from 10 minutes to 90 minutes) or which specific activities they wanted to have carried out in the VR. Through communication with the instructors and the acquisition of theoretical knowledge on their workshop topic, it was possible to see that the ideas of how VR could be used became more and more concrete. In addition, it became apparent that the time for the practical VR part was almost the same for the first two groups (45 to 60 minutes). Only the last group planned only 30 minutes in VR, but justified this by saying that the students had now gained sufficient experience and that there should be no more major operating errors. In addition, it was noted that the focus of VR teaching should not necessarily be on good-looking, polished experiences, but that it would be better to depict many and simple exercises with VR.

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4.3. Reflection on strategic level

The instructors did not carry out a strategic reflection with a questionnaire. Instead, they compared the students' results and performance with those of other semesters. They also consulted the evaluation form completed by the students for the university's central quality assurance.

- **Goal (Personal and professional skills)**
  To evaluate whether the use of VR enhances students' learning outcomes, course outcomes were compared with previous semesters. Following each course, all students wrote a learning success check which included ten comprehension questions related to the topic, to be answered within ten minutes. No significant impact was identified. The mean grade of all students during the summer term of 2023 was 80%, which falls within the typical range.
- **Social (interpersonal skills)**
  In particular, students were much more active in making appointments with the instructors to discuss the content and try out the technology than was the case in previous semesters. Specific, prepared questions were asked during the appointments. Due to the close communication between the students and with the instructors, as well as the organization and implementation of the workshops, it can be assumed that the students were also able to benefit on an interpersonal level.
- **Process**
  In the evaluation form, the quality of the course was rated 1.55 on a scale from 1 (very good) to 5 (failed), a significantly better value than the average rating within the university. The students particularly liked the fact that they were allowed to prepare their own topic and were also able to decide to a certain extent how to implement it. The mix of theory and practical exercises and the use of VR were also highlighted as positive. The performance checks at the end of each workshop were noted as negative, although the students did not give plausible reasons for this.

5. Conclusion and next steps

This article outlines a methodical approach to develop VR-supported teaching with a reflective process. The course on ergonomics and industrial design is used as an example to illustrate how students perceive the use of VR in teaching as stimulating and effective. This observation was confirmed by the reflection. However, it could not be verified on the basis of learning outcomes. Nevertheless, the approach presented here is considered promising. The students were perceived as being much more active, so that in addition to their professional skills, their interpersonal skills were also improved. Through reflection, they were ultimately able to use and adapt the VR tool appropriately for their learning task in terms of individual goals, social composition of the group and the process of acquiring knowledge. The authors therefore assume that this approach provides an answer to lifelong learning in the VUCA world.
The next steps are to further refine the VR-supported teaching concepts. Small, flexible VR experiences need to be developed that can be used independently and adaptively in student groups. The reflection process needs to be tailored further to the teaching context. Student groups must carry out an independent reflection in order to adapt the VR learning experience to their individual needs. Furthermore, the application of VR must be expanded in basic engineering courses such as design fundamentals on the one hand and transferred to the industrial context on the other.

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