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Technical section

Overcoming challenges when teaching hands-on courses about Virtual Reality and Augmented Reality: Methods, techniques and best practice

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A R T I C L E I N F O

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A B S T R A C T

This paper presents methods and techniques for teaching Virtual Reality (VR) and Augmented Reality (AR) that were conceived and refined during more than 20 years of our teaching experience on these subjects in higher education. We cover a broad spectrum from acquainting learners with VR and AR as only one aspect of a more general course to an in-depth course on VR and AR during a whole semester. The focus of the paper is methods and techniques that allow learners to not only learn about VR and AR on a theoretical level but that facilitate their own VR and AR experiences with all senses and foster hands-on learning. We show why this is challenging (e.g., the high workload involved with the preparation of hands-on experiences, the large amount of course time that needs to be devoted), and how these challenges can be met (e.g., using our Circuit Parcours Technique). Moreover, we discuss learning goals that can be addressed in VR and AR courses besides hands-on experiences when using our methods and techniques. Finally, we provide best practice examples that can be used as blueprints for parts of a VR and AR course.

1. Introduction

Based on ultrasound technology, novel devices have been developed that facilitate contactless haptic feedback [1]. Users can feel forces mid-air which can be employed to render Virtual Reality (VR) or Augmented Reality (AR) into more multisensory experiences. Virtual objects can actually be touched. But just reading about these devices is not sufficient to be able to really understand them or to assess their potential for VR and AR applications. How do invisible force fields in the air feel like? How convincing is the illusion of touchable virtual objects? Hence, reading texts, looking at images, watching videos, or listening to other people's reports may be not sufficient to educate people properly about VR and AR. This is especially true when learning objectives need to be met that exceed the basic levels of Bloom's taxonomy [2], i.e., when the learning goals are not just remembering terminology or facts but applying acquired knowledge, conducting analysis and synthesis, or making judgments. From our experience, teaching VR and AR without providing hands-on experiences for every learner is a bit like teaching swimming without using water. While the support of learning-by-doing approaches in education is one key application of VR and AR methods and systems [3] and their use for laboratory teaching methods has been explored [4], we focus on VR and AR itself as the teaching subject in higher education in this paper. We identify challenges such as the high effort associated with preparing hands-on sessions that deter educators from providing these VR and AR experiences to learners. The problems are exacerbated by the growing popularity of VR and AR as these subjects are not only taught in in-depth courses devoted to VR and AR but are becoming topics in courses on broader subjects such as civil engineering, telemedicine, or human–computer interaction where the time slot for VR and AR is limited and courses are not only taught in dedicated VR or AR labs with specific equipment readily available. The group of interested learners is not only getting bigger but also more varied. In addition to computer science students, students from other subjects ranging from chemistry to the social sciences are part of the target group for VR and AR courses. This trend can be attributed to several factors. Specific VR and AR hardware is available as consumer products and reasonably priced. Specifically, mainstream smart devices such as smartphones or tablets equipped with cameras or even depth sensors are a suitable platform for VR and AR. Commercial software products for different application domains ranging from medicine to civil engineering are readily available. Thus, VR and AR are becoming basic technologies in a variety of applications, for example, in industry, medicine, civil engineering, marketing, entertainment, and education. As a consequence, interest in VR and AR is growing and so is the demand for learning opportunities about these topics. Not only students are interested in VR and AR, but specialists and decision makers also want to learn about

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VR and AR in order to assess the potential of these technologies for their purposes, improve their work processes, or create new business opportunities. Last but not least, educators are becoming interested as VR and AR have the potential to provide innovative and valuable means for teaching and training.

In this paper, we present methods to meet these challenges that were developed during our more than 20 years of teaching experience in VR and AR in computer science faculties in several universities. This includes a technique we started formulating and refining 10 years ago and that we call the "circuit parcours technique" as it is inspired from circuit training in sports and centers around the idea to build a parcours or "'obstacle course"' of VR/AR demonstrations. We introduced this technique in a presentation at the education track of the Eurographics 2021 conference [5]. This journal paper provides a more in-depth description of the circuit parcours technique, a more elaborated phase model, and additional best practice examples for its use. We expand the related work section as well as the discussion of challenges and the discussion of a phase model for teaching VR and AR. Moreover, we present and discuss unpublished results from a recent survey among our course participants from the last 5 years. We also discuss COVID-19 related issues for hands-on teaching of VR and AR that show perspectives on how our methods can be applied in distance learning.

The contribution of this paper is

- insights about peculiarities and challenges when teaching VR and AR at universities,
- dedicated methods and techniques for teaching VR and AR including the circuit parcours technique and phase-based teaching methods,
- description of different innovative teaching examples that can serve as best practice or template together with a discussion of the rationale for the organizational and didactical decisions made with a view to different learning objectives,
- reflection on our practical experience as well as evaluation results that identify strengths, weaknesses, and limitations of the methods and techniques presented in the paper.

The paper is organized as follows. We review related work in the next section. Then, we identify challenges associated with providing first-hand experience in university courses on VR and AR. Next, we present our teaching techniques in detail before we introduce our phase-based teaching method. Based on this conceptual groundwork, we provide example scenarios. Finally, we share experiences and discuss lessons learned from our practice and our evaluation before we conclude and give an outlook on future work.

2. State of the art

Work in literature over the last decades, e.g., [6,7], highlights the importance of hands-on experience in learning in general. On a fundamental level, several learning theories see experience made by students as an indispensable element. Prominent examples are theories based on constructivism which also influences instruction techniques [8]. Specific theoretical approaches such as motivational active learning [9] focus on positive aspects of constructivism such as increased learner motivation or creativity [10].

In this literature, the term "hands-on" is used figuratively and not linked to the actual use of hands, e.g., for improving motor skills in the education of surgeons [11]. For instance, motivational active learning has been used in teaching computer science where the learning subject is abstract and does not involve really touchable objects. The 6E model (that distinguishes six phases called Engage, Explore, Explain, Engineer, Enrich, Evaluate) features hands-on activity as a key part and has been used with the goal to better the learners' understanding of abstract scientific concepts and building of mental models [3]. In our work, we also use a phase model and literature emphasizes the value of cyclical learning patterns and repetition (e.g., to not only move through the phases once) [12].

Object-based learning [13] is another example of a specific theoretical constructivist approach that is used in higher education. Here, the hands-on experience is tightly coupled with engaging sensations of many senses simultaneously for a better learning outcome. The role of senses in education is the topic of many publications that emphasize their significance [14]. Especially the value of first-hand experiences, i.e., direct sensations made by the learner, is not to be underestimated.

In VR and AR, we have the particular case that senses play a central role. Constructs of perception such as presence [15] is at the core of the overall VR and AR methodology. Hence, much effort is invested in employing immersive technologies in VR and AR applications. The experience and the perception associated with using these immersive technologies cannot be conveyed appropriately with just textual or oral descriptions as we cannot put ourselves in the minds of other persons [16]. Overall, we see this bulk of work in the literature about the hands-on experience and learning as supporting our hypothesis that a technique for instruction and organization of courses that enables and ensures the inclusion of immersive experiences for all students can make a valuable contribution.

This dovetails with the observation made in the literature that one significant benefit of using VR and AR is in teaching. Over two decades ago, experts wondered whether VR is the teaching tool of the twenty-first century [17]. One of the major reasons for employing these technologies is the opportunity that students are able to have hands-on experiences [18]. Many case studies and literature reviews such as [19–21] are described in the literature. There is evidence that the usage of VR technology not only led to better learning performance but also better hands-on capabilities. Some authors even see the potential to revolutionize teaching in VR and AR because of this [22]. VR and AR can even enable hands-on experience in distance learning [23]. Thus, when hands-on experiences are essential for teaching any subject, these experiences should be especially crucial when the subject is teaching VR and AR itself.

There is way more literature available on using VR and AR as technologies in education than on teaching the subject of VR and AR. Häfner et al. share their approach with a practical course for teaching VR that involves four overlapping phases. In the first short phase, learners are introduced to VR in the form of lectures (e.g., brief presentations such as "Definitions and Applications of VR" or "Software techniques and solutions for VR" that are combined with lab demonstrations in order to lay a theoretical foundation. These demonstrations allow for hands-on experiences in order to improve understanding and help the students to stay focused during the lectures. The second phase contains exercises intending to acquaint students with VR-specific software. In the third and longest phase, small groups of learners are formed and assigned a task for a project. Special effort is spent to find tasks interesting for students and in line with the goals of the course as well as to simulate an industrial work environment. The fourth phase comprises a soft skills evaluation and a final evaluation. This method is, however, not flexible in the sense that it always requires a full semester. Moreover, it is not specific to VR and AR but could be used for any other software tool that can be used in a project. We shared a technique for teaching VR and AR that we named the circuit parcours technique. Section 4 contains a more in-depth description of this technique (the same as this journal paper can be considered an extended and elaborated follow-up publication, see also Section 1). With only a few publications on teaching the subject of VR and AR, there is still a need for more techniques that lower the organizational barriers for including VR and AR in teaching, especially if hands-on experiences with VR and AR are part of the instruction.

The lack of dedicated techniques and methods for teaching VR and AR can be considered unexpected as the number of curricula that contain VR and AR is growing. Although these curricula have been characterized as fragmented and heterogeneous [24] a decade ago, courses about VR and AR development are becoming more popular and varied as it is feasible to use low-cost systems for several years now [25]. Now, a more serious obstacle than costs is the creation of content. Here, tools and matching authoring approaches such as VR/AR Nuggets [26] have been identified as effective solutions. Nguyen et al. report that VR/AR applications can be developed successfully within courses and students were able to adopt necessary tools [27]. Therefore, we will assume in our work that the prerequisite of existing suitable authoring tools can be met.

In the literature, a good overview of the discussion of VR/AR courses and corresponding curricula can be found in [28]. Immersion and experiences are often part of VR and AR curricula [29]. Burdea et al. [30] point out the importance of imagination and experience besides immersion. Moreover, VR and AR are often part of longer courses, in particular, capstone courses [31]. Not many approaches in literature employ techniques that are suitable for such in-depth courses as well as basic courses or even short introductions to VR and AR that can be taught within one day. The resulting reduced flexibility can pose challenges to integrate VR/AR teaching in existing curricula structures. As a consequence, VR and AR may still not be well reflected in the curriculum of many undergraduate institutions although ideas that do not disrupt curricular structures exist for some time [32].

Even early work on teaching VR sought the close combination with other skills such as software engineering and teamwork [33]. Meanwhile, experience with courses that teach VR and AR demonstrate the positive effects of group work [34]. Moreover, many approaches to teach VR/AR are project-based [35,36] which provides substantial opportunities for group work. Existing research work also shows that VR/AR courses can address learning goals beyond VR and AR technologies and methodologies such as creativity, problem-solving skills, or presentation skills [37]. Recent work [38] highlights that VR is especially valuable for 21st-century learners who live in an era where the term "experience age" has been coined. In this era, soft skills such as empathy, systems thinking, abstract reasoning, and computational literacy are becoming more important. VR and AR play a crucial role as they support the acquisition of these soft skills in contrast to other learning techniques [39]. Thus, a good instruction technique for VR and AR learning should foster group work, project-based learning, and the acquisition of soft skills. Such suitable instruction and organization techniques were and are still open areas of research [24,28].

One aspect that influences the importance of hands-on experience in teaching VR and AR is the question of what prior knowledge and experiences students already possess when they start a VR/AR course. After all, 6.1 million VR headset units are expected to be sold in 2021 bringing the total cumulative installed base to 16.44 million units [40]. The global VR market size alone is estimated to increase from roughly five billion U.S. dollars in 2021 to more than 12 billion U.S. dollars by 2024 [40]. In 2020, the number of smartphone users worldwide was estimated to be 3.5 billion persons [41]. With the camera and computation capabilities of modern smartphones, billions of people own a technological platform suitable for AR. Therefore, it is good practice to assess the prior experience in VR and AR at the beginning of a VR/AR course as access barriers to these technologies have been dramatically lowered. However, it cannot be expected that all learners had the opportunity to have the first-hand experience with AR and especially VR. Moreover, more sophisticated VR and AR technology such as a CAVE or a Microsoft Hololens is far from commonplace. Because of the dynamic improvements (e.g., increasing field-of-view, increasing display resolution) of VR and AR technology, prior experience from just a few years ago does not reflect the state-of-the-art properly. Thus, affording hands-on experience is crucial despite the higher availability of a subset of VR and AR technology.

3. Challenges and requirements

Although barriers such as high costs, low graphical quality or lack of robustness have been remedied with modern consumer platforms in many application scenarios such as VR exposure therapy [42], VR and AR as technologies are not commonplace today. Many general challenges have been identified in the scientific literature and in studies, e.g., AR industry experts named user experience and lack of content offerings as the leading barrier for mass adoption of AR in a recent survey [40]. All these problems also apply to teaching VR and AR. In the following, we identify additional obstacles that are more specific and are a hurdle for educators to include hands-on experience in their VR and AR courses.

Procurement Challenge There exists a large variety of hardware used for realizing VR and AR, for example, head-mounted displays (HMDs), stereo projections, haptic feedback devices, controllers, tracking systems, and depth sensors, or motion platforms. Moreover, there exists a wide range of setups such as a 3D power wall, a CAVE, a virtual workbench, AR with video-see-through on a handheld smart device, AR with direct-see-through employing AR HMDs, or walking in place setups such as the Virtuix Omni. Ideally, students are provided the opportunity to get firsthand experience across this whole variety. However, this is laborious and time-consuming.

Bottleneck Challenge Some VR and AR devices are still expensive and not available in a large number. This results in lengthy sessions if only one student can have a VR/AR experience at one time and raises the questions of what the other students can do during that time.

Supervision Challenge Especially in HMD-based VR where users might not be able to see their real surroundings, it can be necessary to supervise students during the experience, e.g., because of tripping hazards or because students may suffer from cybersickness. This can completely occupy the educator and result in a logjam.

Access Challenge VR/AR hardware may not be available to students outside course hours. Therefore, it is not possible to plan the VR/AR experience as part of their homework. As a result, a significant amount of the course time needs to be invested.

Time and Effort Challenge Preparing the demonstration of VR/AR hardware with according application examples can take a large amount of time. Moreover, there might be significant effort involved in setting up the VR/AR demonstration before the lesson and putting it away after the lesson. This time burden associated with VR/AR demonstrations could force educators to give up on the idea of integrating VR/AR demonstrations in their courses.

Space Challenge VR and AR setups may need significant floor space (e.g., the VR HMD HTC Vive has a tracking space of up to 20 m^2) and control of environmental conditions (e.g., window blinds to limit direct sunlight). As a result, the lecture room might not be able to accommodate several setups in parallel or some setups at all limiting the opportunity for hands-on experiences.

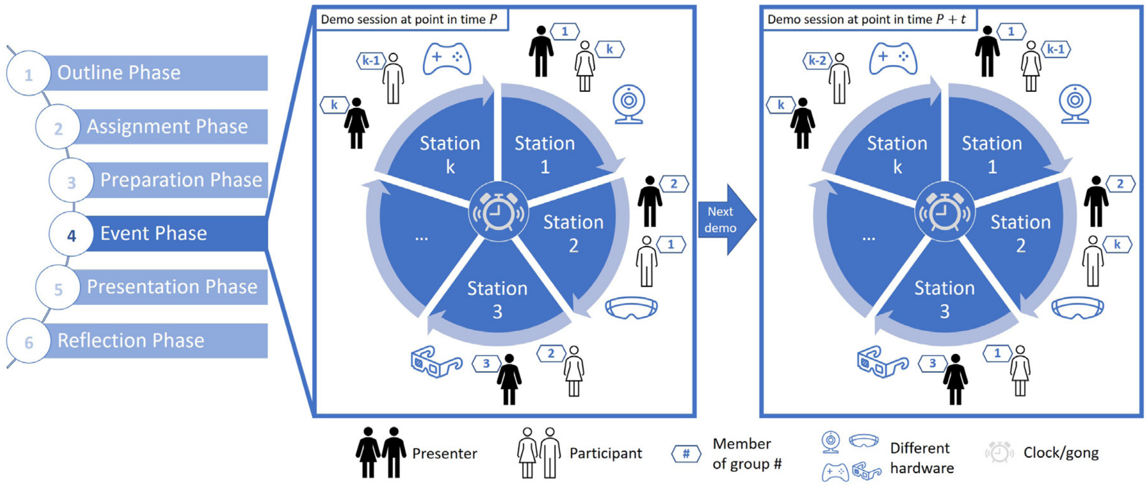

Fig. 1. The circuit parcours technique. Two snapshots of a demo session are shown — in this example groups of two students are formed and each group member has either the role of a presenter or a participant at the various demo stations each with a different VR/AR demo.

Table 1
Overview of variables of the circuit parcours technique.

Variable	Description
T	Circuit parcours duration of one event
e	Number of events for one circuit parcours
E	Overall circuit parcours duration
n	Students
k	Groups/demo sessions in one time slot
s	Group size
t	Time limit per participant per station
g	Guests
N	Total number of demo sessions
t_{setup}	Setup time before an event
b	Number of breaks within one event
t_{break}	Break time per break
t_{end}	Disassembling time after the event

Educator Proficiency Challenge As in other applications of VR and AR [43], the lack of educators' familiarity is a challenge even if they have a positive attitude towards it. This is not so much of a problem in in-depth courses that are taught by VR and AR professionals but in courses where VR and AR are just one among many other topics. Educators are not aware of best practice examples or lack basic teaching material such as textbooks [24]. This can result in low self-efficacy to use VR in teaching in general [44]. As providing opportunities for hands-on experience is more demanding than just lecturing facts about VR and AR, especially less proficient educators might refrain from including first-hand experiences in their teaching if they are not adequately supported. Requirements for VR and AR teaching techniques and methods can be directly derived from all the challenges identified.

4. Teaching technique

In this section, we contribute a technique for teaching VR and AR courses, the circuit parcours technique [5]. The basic idea is to organize and hold an event where multiple VR and AR demonstrations take place simultaneously. This provides ample opportunities for learners to have many experiences similar to circuit training. Also, it is our goal that the format of a parcours is fundamentally different from other learning scenarios in that it is perceived as exciting change and that learners enjoy the event-like character. Our technique is illustrated in the diagram in Fig. 1. The parameters we will use in the following are listed in Table 1.

Let us assume that we have n students and one teacher in the course. We divide the students in k groups of equal size s (with $s = n/k$). Moreover, we have k stations. At each station, several identical VR/AR demonstrations will take place where one student will be able to experience this demonstration and gain firsthand experience at a time. Each station has an according set up of VR/AR hardware and software. The VR/AR demonstrations differ from station to station. For each demonstration, a fixed amount of time is available. The teacher specifies this number of t minutes and communicates this to all groups.

In the event, four roles are distinguished: the presenter, the participant, the observer, and the guest. During each demo session, there is one participant present who is actively engaged in the VR/AR experience provided at the station. The role of the presenter is to prepare the next presentation (e.g., to wipe down devices in order to meet hygienic standards or to reset the software), to welcome the participant, to provide some background explanations concerning the demonstration, to guide the participant through the demonstration, to ensure the safety of the participant during the demonstration, and to conduct a debriefing after the demonstration. The role of the observer is to monitor the demonstration (e.g., to check that the time limit is obeyed), to make notes about observations during the demonstration, and to assist the presenter when necessary. In each demo session, there is one person who takes the role of the presenter. The number of persons who take the role of an observer can vary between 0 and $s - 1$. An additional number of g guests can be invited, e.g., students who are not in the course, friends, or family. The educator can be among these guests who also participate in a demo session at selected stations (e.g., to fill open slots).

The educator prepares a timetable where all demo sessions are listed. For each demo session, the timetable provides the following information: the start time, the name of the participant at each station (either a guest or a member of a group that was not assigned to the station), and the names of the presenter and potential observers (who are all members of the group assigned to the station). There are $N = n \cdot (k - 1) + g \cdot k$ demo sessions in total. As there are k demo sessions in a single time slot, N/k time slots of length t minutes need to be planned. The event phase starts with the setup where the demonstration at all stations is prepared and set up. This takes t_{setup} minutes. The educator is in charge of ensuring that the timetable is kept. The educator signals (e.g., using a gong) when a demo session is to start. Each student will visit all stations (except the station the student is assigned to) and experience the corresponding demos in the role of a participant. In the remaining time, the student is at the assigned station and serves either as a presenter or observer.

In order to mitigate the effect that unforeseen events mess up the schedule in the timetable, several b breaks of t_{break} minutes can be planned. The purpose of these breaks is not only relaxation and providing all persons the opportunity for a drink, food, or a bathroom break but also synchronization among the stations. Moreover, the breaks provide time to replenish resources (e.g., load batteries). If one demo session takes longer, further sessions may be affected as the presenter or the participant may not be available in time for their following demo sessions. That can cause a ripple effect that can be stopped with breaks that work as a time buffer. We recommend that the educator stops the time for common actions (e.g., for walking from one station to another, for disinfecting an HMD with wipes, for putting on an HMD) and gathers other time-related information, e.g., battery life or calibration times. This should ensure that enough time has to be planned for switching stations (e.g., to cater for cleaning times between two demos in order to adhere to hygienic standards) and breaks that serve as buffers are important in order to prevent that everything is thrown out of sync. It is also valuable to have a big clock visible from every station and an audible signal (such as a gong or a ring) that informs everybody that a new session starts.

After the last demo session, the stations are disassembled. This takes t_{end} minutes. Overall, the event takes the time $T = t_{setup} + (N/k) \cdot t + b \cdot t_{break} + t_{end}$. If the duration of T is too long to fit in the teaching schedule, the event phase needs to be split. This adds an additional time $t_{setup} + t_{end}$ for each additional meeting. If e is the number of all events to be held and E is the time needed for all event phases, than $E = T \cdot e$ in case we split the event phase in a way that all e events have the same length. We can calculate E directly as $E = e \cdot t_{setup} + e \cdot (b \cdot t_{break}) + (N/k) \cdot t + e \cdot t_{end}$.

5. Phase model

We integrate the event from the circuit parcours technique in a phase model in order to obtain a method for teaching courses on the subject of VR and AR. Here, we distinguish six phases. In phase 1, the outline phase, the educator outlines how the circuit parcours technique is embedded in the course. One of the biggest challenges for the educator is to ensure that each group has roughly the same workload for preparing the demonstration at their station. As all stations are different, suitable tasks have to be identified by the educator that the group is able to accomplish in the time frame of the course. Moreover, these tasks should neither underchallenge nor overwhelm the groups. For this, the educator needs knowledge of the students' competencies. There is a wide spectrum concerning difficulty in content creation for the demonstration. On the one hand, existing applications can be employed as is. However, they are often a black box for the students and the demo preparation is too effortless. On the other hand, students can create the demonstration from scratch using low-level APIs such as Vulkan and corresponding GPU shaders. Here, the VR nugget approach is particularly interesting as it is in the middle of the spectrum where not many solutions are present. The preparation effort on the educator's side should not be underestimated. Not only need suitable tasks and development environments to be identified but also additional material such as 3D geometry assets need to be provided if this cannot be made part of the students' tasks. Moreover, instruction has to be prepared, e.g., in the form of a textbook, video tutorials, or lecture. This might differ from station to station. Part of the planning is also the calculation of the times for the events that need to fit the individual time constraints of the course. Finally, the educator has to assess how the circuit parcours pattern can be tailored to fit the constraints of the course or curriculum. It might be even necessary to change the curriculum or the organization of teaching in order to fully exploit the advantages of the presented technique. One particular problem occurs if the number of students is not divisible by the number of stations. A good solution is to have some groups that are slightly bigger than the others and to invite guests during the event to make sure that all stations are fully occupied during each session and that all students can take the role of a participant and the role of a presenter.

In phase 2, the assignment phase, each group is assigned to one station. The demonstration to be given at each of the k stations is specified and required VR/AR hardware and software is selected and made available to the groups. The educator either hands a complete specification to the group assigned to the station or provides this group with just some constraints (e.g., the hardware to be used in the demonstration). In the latter case, the educator asks the group to complete the specification. This time t has to be considered when specifying the demonstration. Moreover, the groups are instructed as planned in phase 1. For instance, the groups may be assigned some learning tasks (e.g., reading assignments for background information or manuals of VR hardware) and corresponding learning material (e.g., a textbook for VR and AR that is suitable for self-study such as [45]).

In phase 3, the preparation phase, each group prepares the hardware and software infrastructure for the specified demonstration (e.g., procuring the hardware, configuring the software). They test the VR/AR setup at their station. Moreover, they work out an action plan for conducting a demo session that also takes the timing and the different roles into account. In the preparation phase, demo sessions are rehearsed, and based on the outcome of the rehearsal the action plan is altered. The action plan needs to ensure that the time limit of t minutes is obeyed. In the rehearsal, the members of the group assigned to a station take on each role at least once.

In phase 4, the event phase, the event takes place as described in the previous section. We found it to be beneficial that the educator is not just an observer during the event but a guest at every station participating in each demo. This allows the educator to interact with each group and provide some feedback after the event. Alternatively, the educator can serve as a pilot user for each station during the preparation phase.

Phase 5, the presentation phase, data gathered during the event phase is analyzed and presented. For instance, students could be asked to perform a qualitative or even quantitative evaluation based on their observations at their station. These results together with the description and discussion of their demonstration protocol, lessons learned when implementing the prototype software, lessons learned when conducting presentations and user tests, and overall observations and conclusions could be assembled in a report or presented to the other groups in a session following the event.

Phase 6, the reflection phase, is added to deepen the experience and reinforce the learning results at the end of the course. Reflections could range from filling in a questionnaire individually to short informal discussions among students about their own experiences and observations to more formal reports. The reflection phase is valuable for the educator to evaluate the progress of the students or for grading purposes. Moreover, the educator can gather pieces of information about the students' performance by observing the presentations (especially if the educator serves as a pilot participant or guest), by examining the software created, and by evaluating the overall presentation design. As presenters can be observed individually and the group can be asked to detail and rate each team member's contribution, it is feasible to assess each student's individual performance despite relying heavily on group work. In the simplest case, the goal is to provide a firsthand experience of VR/AR and the mere participation of a student trying out a VR/AR presentation is sufficient to ensure that this goal is met.

The educator can tailor the phases to the requirements and constraints of an individual course. For instance, phase 3 can take several weeks when the learners develop their own demonstrators or just a couple of minutes when students learn how to start a pre-installed software. The educator may also decide to omit phases, e.g., the reflection phase may be omitted if the educator has not sufficient time for it.

Instead of a linear succession of phases, iterations can be introduced in the phase model. We distinguish inner iterations and outer iterations. In an inner iteration, the phases 2 to 5 can be repeated multiple times. Thus, several events take place, the learners prepare multiple demonstrations, more opportunities for hands-on experience are provided, and the students can apply the lessons learned in one iteration directly to the next iteration. In an outer iteration, the whole group of learners is split into subgroups for whom the phase model is applied separately. As a result, multiple isolated events take place with the same stations. For the educator, it is interesting to compare the results. If time permits, all subgroups can share phase 5 and are also able to compare the results made at the same station by different subgroups. In order to save time, a variation is to have parallel meetings of all student groups that were assigned to the same station. As they were given the same task, for these groups it is particularly interesting to compare results and exchange experience.

Finally, we introduce coupling points in the phase model where a connection to other courses can take place. Being conducted in a relatively short time frame and being self-contained, the event phase serves as an excellent coupling point. For instance, course A is an in-depth course where students prepare even the demonstrations themselves while VR and AR are just one of many subjects in course B. Both courses can be coupled by inviting learners in course B to take the role of guests in the circuit parcours. Learners from course A benefit as they can gather more data and more experience. Learners from course B benefit as they are provided with opportunities to get some first-hand experience. Other coupling points can be placed in phase 5. For instance, course A again is an in-depth course on VR and AR while course B is a course on human–computer interaction or usability engineering. The learners from course B can attend the presentations from course A which affords these learners to hear the first-hand experience from their fellow students how they conducted demonstrations or even how they planned, executed, and analyzed usability tests. If learners in course B identify interesting research questions, they can submit these questions to course A. Here, the coupling point lies in phase 2. The complete phase model is depicted in Fig. 2.

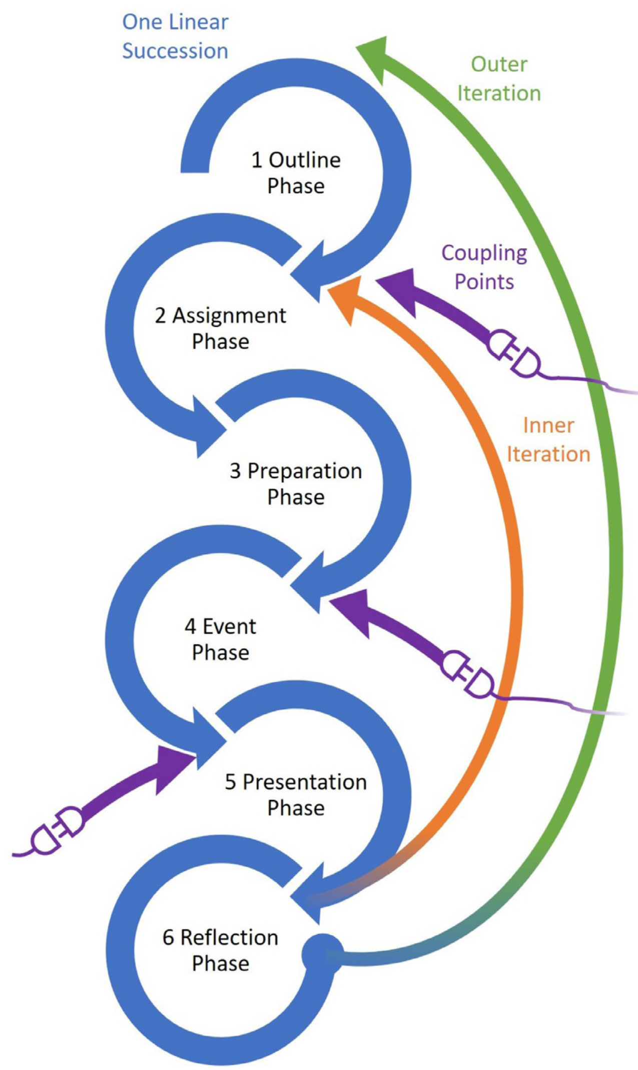

Fig. 2. Phase model for teaching VR and AR.

6. Best practice

A first example for employing our methods to an undergraduate course '"Virtual and Augmented Reality"' for computer science students in their 4th semester. The course has 15 participants and a workload of 150 h. The course is taught in a VR/AR lab. Four hours per week consist of lecture-based instruction, student presentations, practical work, and tutoring. The proportion of these varies over time with an emphasis on instruction at the beginning of the course and a focus on students' practical work at the end. Overall, the ratio of instruction and practical work is roughly 40:60. Moreover, students possess a chip card to freely enter the VR lab where each student has access to a locker that stores their VR/AR equipment. In phase 2, the students are divided into five teams of equal size. Each team receives some VR/AR hardware and a research question where a user test needs to be conducted in order to evaluate two alternatives. For example, one group receives a VR HMD and is tasked to compare two different techniques for navigation in a VR environment. Another example would be a group that receives a tablet and an AR HMD and is asked to evaluate the advantages and disadvantages of direct-see-through and video-see-through. A third example is a task where different techniques to visualize teleportation in VR should be compared. The educator prepared these tasks in phase 1. The time for each demo session was set to $t = 20$ minutes. In phase 3, each group needs to develop prototype software that serves as the basis for the user test. Various software such as game development platforms (e.g., Unity), dedicated VR software (e.g., Autodesk VRED), or toolkits (e.g., ARKit) is used so that students do not need to start from scratch. The educator supports the students concerning prototype development but also provides feedback to the planning of the user test, e.g., by reviewing the questionnaires to be used. The educator provided a schedule, so it was clear who had to be at which station in which role during the event. The main event (phase 4) had to be split into two dates. Two guests were also present. One of the guests was the educator who could also experience each station. Two breaks with $t_{break} = 5$ min were planned, t_{setup} was set to 15 min, t_{end} was set to 10 min. Two stations of the event are depicted in Fig. 3. In summary, each of the two events had seven demo sessions and took 175 min. The students organized the third event voluntarily where they invited friends, family, and fellow students. In phase 5, each group gave three presentations. The first presentation

Fig. 3. An example of two stations in the circuit parcours.

was about educating the other students in the course about the software they have used for prototyping and the lessons learned using this software. In the second presentation, each group reported the results of the user tests (including statistical analysis) and discussed them. With the two regular events, each group had conducted 14 user tests (involving the twelve other students who were not in their group plus the two guests), with the additional third event this number was increased to 22 user tests which provide a good amount of data for meaningful statistical analysis and discussion. For phase 6, the third presentation was about the reflection of the experiences in the course where all groups focused on the experiences they made when trying out the VR and AR equipment at other stations. The 15 weeks of the semester were distributed among the phases as follows: phase 2 took one week, phase 3 took nine weeks, phase 4 took two weeks, phase 5 took two weeks, phase 6 took one week. The outline phase (phase 1) took the educator ca. 40 h in total before the semester started (e.g., procuring the hardware, time planning, ideas for tasks, elaboration of the tasks).

The second example for employing our methods is a two-day course for the further education of university teaching staff who have no background in VR or AR but want to assess how far these technologies can benefit their teaching. The number of participants is 12. In the second phase, groups of two are formed and each group receives a device with VR or AR capabilities (e.g., an iPad, an Oculus Go VR-HMD, a Microsoft Hololens). There is one pre-installed app on each device, for instance, Froggipedia (an AR learning app about biology from the Apple App Store), Human Anatomy VR (a VR App available in the Oculus App Store that supports the exploration of the human anatomy), Samsung's BeFearless VR app for training public speaking, or Microsoft's Dynamics 365 AR-based collaboration app for the Microsoft Hololens. For the 60 min preparation phase, each group was given the task to become acquainted with the software, read manuals or watch video tutorials, and plan a 10-minutes-long demonstration. The groups are told that in this demo, a short introduction should be provided, and the VR app or AR app should be exhibited. Immediately afterwards, phase 4 started with a total of 10 demo sessions at six stations. Overall, this event phase took 120 min (t_{setup} = 0 minutes plus $10 \cdot t = 10$ minutes plus two breaks with $t_{break} = 5$ minutes plus $t_{end} = 10$ minutes). In total, three hours of the course time were devoted to the demonstration so that participants could get some firsthand experience. Phase 5 was skipped. In the sixth phase, a group discussion is started where experiences made are reflected and each participant is asked to write down three (or more) ideas in light of the impressions of the demos on how VR and AR technologies might improve their teaching.

A third example is an undergraduate course in chemistry in the third semester where students have a laboratory course in which they spend four hours per week in one of the university's laboratories and four hours per week preparing the course at home. Digitalization also became an important topic in chemistry and the educators want that their students get some firsthand experience with virtual laboratories. They want that students are able to assess the value of VR as a tool for preparing laboratory experiments. The 120 students of the course are already divided into six groups of 20 students for the practical lab work and these groups are treated identically in the following. In phase 2, each of these groups is further divided into groups of 3 students each (and one group with only two students) who are assigned to seven stations. Each station has a different topic (e.g., the presentation of some lab equipment or a specific chemical experiment) and has some VR headset (reaching from simple headsets such as Google cardboard to more sophisticated VR HMDs). In the preparation phase, the students work through a video tutorial where they learn to use a dedicated editor for demonstrating laboratory experiments. This editor is based on the concept of VR Nuggets [26]. The basic idea of VR Nuggets is that they are standalone, always functioning VR software components to be used for education purposes. The VR Nuggets provide all the complex base functionality for a certain use pattern, e.g., the *show and tell pattern* where a virtual object can be interactively explored in 3D together with labels that provide additional information. If the student group aims to demonstrate a certain lab device, they need to select the matching VR Nugget and change its configuration, i.e., substitute the existing dummy virtual object with the specific object from an asset store and place the labels in 3D space accordingly. The VR Nugget software makes sure that the labels are always positioned in the virtual world that they are readable by the students and provides interaction techniques for exploration. VR Nuggets are not meant for creating a whole course in VR but to support the introduction of some VR content in a regular course where VR has a substantial added value. The student groups have two weeks to create the VR content and prepare the demo at their station. Hence, the software used must allow for a short familiarization period. In phase 4, the event is conducted. The event takes 120 min (t_{setup} = 10 minutes, 18 demo sessions with $t = 5$ minutes, $t_{end} = 10$ minutes, two breaks with $t_{break} = 5$ minutes) and is short enough that there is no need for a split. In phase 5, the students are expected to write some text about the outcome as part of their usual lab report. Because of time constraints, no specific activities were conducted during course time for phase 6. Instead, students were just encouraged to discuss their experiences within the group and to take some time and reflect on them.

The fourth example illustrates how our method can be modified during the time of the COVID-19 pandemic and how it could translate to distance learning. If presence at the university is not feasible at all, of course, first-hand experiences cannot be made to the same extent as if the event in phase 4 can be held in a face-to-face setting in a VR-Lab. The major idea here is to use a web conferencing tool such as Zoom, Webex, or Microsoft Teams that all allows to divide the participants into smaller groups and hold sessions in parallel. In these sessions, either the demonstrator remotely instructs the participants and navigates them through the demo provided the VR/AR equipment is available at the participants' site. Or the presenter gives a description of the experience in a one-to-one session where a higher degree of empathy can be feasible as a dialogue between presenter and participants arises. Here, the idea is to approximate a hands-on experience as well as possible. If the policy of the university allows it, the VR/AR equipment can be lent to the students who take it or even have it shipped to their homes. Alternatively, equipment that might be present in the students' homes (such as a Playstation VR or a sophisticated smart device with a LIDAR scanner) can be used. Here, the educator needs to have a high degree of flexibility as the planning of tasks cannot be accomplished in phase 1 as the information on what equipment happens to be accessible is not available. In case presence at the university is feasible as the pandemic policy allows for the presence of small groups at the university or more generally, if a blended learning approach is pursued, the event in phase 4 can be conducted. However, additional time has to be taken into account during planning (e.g., more time for disinfections, more time to switch rooms, more time for breaks due to airing). Moreover, more rooms may be needed in parallel. All other phases except phase 4 can more easily be transferred to distance learning.

The fifth example illustrates the usage of coupling points in our method. As course A, we take our undergraduate course "Virtual and Augmented Reality Systems" already introduced in example 1. As course B, we take a 6th semester course in medicine where at the end of the semester students should become acquainted with modern methods of digitalization. Course B has roughly 70 students. The students in course A are tasked with preparing VR/AR demonstrations in medicine and interviewing the participants about the added value they see in using these technologies and their attitude towards VR/AR. All five groups in course A are provided with dedicated software for medicine that uses VR/AR in order to visualize data from radiology in 3D. All groups had the same task. The time for a demo session is set to 10 min. Each student from course B visits only one of the five stations. The event was split to three consecutive weeks. Thus, at the end of the lecture of course B, a third of the students, of course, B took part in the event. There were 14 sessions in total, i.e., up to five sessions per week where a student had to wait up to 40 min until they had a spot at one of the five demo stations. In course A, a second event was performed where this time, students visited the demos of the other four groups. This way, students were able to see how the other groups responded to the same task and planned the demonstration during phase 5. Moreover, they were also able to compare their evaluation results from interviewing the students from course B and see the variations of the data among groups.

7. Evaluation

In teaching a VR/AR course for computer scientists in a university (see example 1 in the previous section), we have employed the circuit parcours technique seven times (in the period from 2009 to 2020). We have never experienced any problem with applying this technique that resulted in a failure. The technique proved itself to be robust and working well. Students particularly appreciated the event-like character and the variation in teaching methods. In five out of seven cases, the students voluntarily organized additional events and invited fellow students and friends or family. We take this as a strong indication that students felt motivated and were well engaged. In our universities' quality assurance where all courses are evaluated with a standard questionnaire, our VR/AR course was rated well above average. While this is not necessarily due to the circuit parcours technique, written comments in the evaluation questionnaire (that highlighted the practical and hands-on experiences as valuable or mentioned the event as fun) provide some anecdotal evidence that this approach to organizing the course was perceived as positive. There was not a single negative comment referring explicitly to the circuit parcours technique in all seven questionnaires.

We also surveyed the students where we used our methods in the last four years. We received 15 answers. We asked the former students to rate the importance of making a hands-on experience in a course about VR and AR on a scale from 0 (not important) to 6 (highly important). The result is shown in

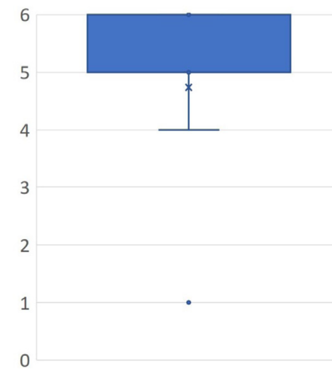

Fig. 4. Results of the survey "From your experience, how important is it to make hands-on experiences in courses about VR and AR?" on a scale from 0 (not important) to 6 (highly important).

Fig. 4 there is a clear trend in this group that rates hands-on experiences as important. Moreover, we got written statements from the comments field in our survey. Only a few addressed hands-on experiences directly, e.g., "Trying out a VR program with VR goggles is more authentic". Most statements addressed other aspects of our methods. Several of them state that the opportunity to experience more variety was appreciated: "[It is an advantage to] see different approaches to the implementation of the projects and user testing"., "You can see how the others have implemented the user tests", "[It is an advantage to] to see more cool ideas (or their implementation)", "[It is an advantage to] try out other VR headsets".. Here, former students highlight the ability for comparison: "[It is an advantage] in order not only to be able to evaluate the work of fellow students but also to get a comparison to your own work"., "You can see how much the others have done, and how much you could have done"., "Others were a bit more creative and brave to try something different than required". Statements show that empathy is addressed by our methods: "You get a better understanding of the subject's situation (e.g., what might stress a subject or make them uncomfortable) when you do another user test yourself"., "How different people's views and approaches can be, even when studying the same thing"., "Cool event, people perceive very different aspects of the demo".. Moreover, one statement shows that our methods can encourage reflection: "One reflects on the usability of one's own application for future implementations".. The opportunity to receive feedback is mentioned in several statements, such as "Feedback for one's own work is extremely useful".. Here, the former students show that taking over teaching tasks can be considered positively: "[It is an advantage] To enable feedback to fellow students", "I have been helped, so I return that too". Former students offered the following advice: "It was good that we have scheduled substitutes to perform the tests"., "That you should take enough time for the test person and that it is also okay if the user test does not run exactly as planned beforehand".. While these statements are not representative, they show the potential of our methods to help in the acquisition of soft skills.

8. Discussion

8.1. Advantages and disadvantages

Concerning the time and effort challenge, the circuit parcours technique is superior to a linear demonstration of VR/AR applications by the educator alone. While the latter takes at least $n \cdot k \cdot t$ minutes of time for demonstrations, our technique takes less than $1/k^{th}$ of that time. For instance, in example 1 a linear approach would take a demonstration net time of 1,500 min (25 h) compared to 280 min. Our technique is a solution for the educator being a bottleneck in demonstrations (i.e. an aspect of the supervision challenge). On the other hand, additional time needs to be invested by the students for the preparation. However, here groups of students can work in parallel. Moreover, the students can reap benefits from the preparation in addition to the benefits of experiencing the demonstration. The circuit parcours technique also ensures that idle or waiting time for students is reduced. They are active and involved, either as participants, presenters, or observers (which addresses the bottleneck challenge).

The presented technique does not only mitigate the problem that individual hands-on experiences take time and space (i.e., mitigating the time and effort challenge as well as the space challenge). Moreover, the educator is relieved of the tedious task to oversee every demonstration which might be even mandatory because of safety considerations (e.g., tripping hazards when students wear HMD that do not let them perceive the environment). In addition, the educator is not required to fully plan and prepare the demonstration (install software, create or customize the demonstration, set up the hardware equipment). In a sense, the students take over some work of the educator which provides learning opportunities to them. As a consequence, the significant overall reduction of the educator's workload could mean that the inclusion of individual hands-on experiences in a course can become feasible in the first place. In this case, our technique has all the advantages that come with hands-on experience as opposed to just hearing or reading about VR/AR experiences. We have not evaluated the extent and scope of these advantages further as they are not specific to our technique but the provision of individual experiences in VR/AR education in general. Our technique is rather an enabling factor in this situation. For instance, we did not evaluate the added value of first-hand experiences in VR/AR education with an experiment that had a control group. However, this is examined in the literature and our experiences confirm findings that first-hand experiences are crucial for the understanding of VR/AR.

Enlisting students to conduct VR/AR presentations might be seen as inferior to the educator performing this task as the presentation abilities, didactical competencies, or verbal capabilities of the students might not be as well-developed compared to the educator. However, the first-hand experiences each student is able to make with VR/AR even with an inexperienced student presenter instead of an experienced educator are valuable. This is especially true if the choice is not between inexperienced student presenter vs. experienced educator but between first-hand experience vs. no first-hand experience because limited resources and other constraints can force the educator to abandon the idea to provide first-hand experiences in VR/AR. Based on enlisting students, the circuit parcours technique can again be seen as enabling factor for first-hand experiences and solution for the access challenge. Moreover, the student presenters conceive and rehearse their presentation within their group during the preparation phase. Here, the group members can provide valuable feedback. The educator can also use the preparation phase to perform some quality assurance of the presentations and demonstration protocols before the event phase, especially if the educator takes the role of a pilot user. The concrete task to act as presenter can be a good occasion to motivate students to work on their presentation skills and didactical competencies. Hence, the educator should consider providing fitting learning opportunities (such as instructional videos or even a compact course about relevant soft skills also addressing the educator proficiency challenge).

An additional advantage of the circuit parcours technique lies in the fact that students do not just experience k demonstrations. They invest significantly more time and effort in the one demonstration that they are responsible for. As a result, a good balance can be struck between getting an overview and getting to know one example more in-depth (which is also a contribution to addressing the procurement challenge). Moreover, the technique enlists the learners as tutors for their fellow students. This provides opportunities in learning soft skills and can also have motivational aspects that their work is rewarded with supporting and educating others. There may be additional motivational aspects based on the high degree of active involvement, the work in groups, or the event character.

A disadvantage of our methods is that they are still more demanding to the educator than just showing a video on a slide. Educators need to perform meticulous planning as especially the event is highly sensitive to delays or other disturbances. In principle, handing groups of students not the same task but different ones opens the door for unequal treatment (e.g., differences in workload requested as one group task may turn out to be considerably more challenging than the tasks of the other groups). Our methods provide only a framework that needs to be tailored to the individual learning goals of a course and the constraints (e.g., availability of equipment). The need for the first-hand experience wanes if the students have already extensive experience in VR and AR usage. Here, other advantageous aspects of our methods could still make their application sensible.

8.2. Pedagogical considerations

From our experience, the circuit parcours technique allows us to address more learning goals with the opportunity not only to hear about but to experience VR/AR hardware and software:

- The students are trained to be attentive and observe VR/AR users actively.
- The students switch the roles of presenter and participant and thus improve social skills such as empathy.
- Students learn to self-assess their performance when comparing their work to the work of other students.
- Students learn about presentations and especially the demonstration of VR/AR applications to third parties.
- Time management and discipline in carrying out a demo or test protocol can be trained.
- The methods provide opportunities to be creative and learn how these creations are experienced by others.
- With the peer teaching aspect included in our method, students learn how to facilitate the learning process of others.
- Fundamentals of user tests can be also learning objectives, e.g., the circuit parcours technique facilitates the recording of test data in a short amount of time that can serve as a basis for further analysis. In particular, meaningful statistical analysis requires a minimum amount of test data. This amount can be obtained in the event phase.

9. Conclusion and future work

The circuit parcours technique describes a basic pattern for best practice how hands-on VR and AR demonstrations can be integrated into a course about VR and AR. The major idea is to define several demonstration stations that are used in parallel during a carefully organized event. Moreover, students switch roles as participants and presenters. Thus, students are not only recipients of the demonstrations but are entrusted with preparing and actively presenting VR and AR applications. This relieves educators from time-consuming tasks that are associated with integrating VR/AR demonstrations in courses. The central event is embedded in a six-phase model: outline, assignment, preparation, event, presentation, and reflection. Moreover, inner and outer iterations, as well as coupling points, can serve as means to build a robust framework for learning experiences that even transcend the boundaries of a single course. By comparing time efforts with traditional demonstration approaches, it can be shown that the presented technique is significantly more time-efficient. Besides time efficiency and the reduction of the workload of the presenter, the methods have additional potential advantages such as the ability to address several learning goals ranging from several soft skills (time management, presentation skills, etc.) to user testing or VR/AR programming, the increase in student motivation, and the balance between in-depth learning and provision of an overview. As a result, obstacles are mitigated by this technique that could prevent educators to include a hands-on demonstration of VR/AR in their courses such as the bottleneck challenge or the supervision challenge. Thus, a major advantage is that the technique contributes to providing students the opportunity to experience VR and AR applications themselves instead of just reading, hearing, or seeing a video about them. These experiences are considered to be of key importance when learning about VR and AR. Describing five different application examples of the circuit parcours technique, we showed how flexible the technique can be used in different situations that range from semester-long courses to one-day seminars, from specialist target groups such as computer science students to non-technical specialists, from courses with few participants to courses with a large number of participants. This leads to one direction for future work where further techniques for teaching can be derived from the technique presented exploiting the potential of the coupling points within the phase model presented. Another direction for future work would be to provide a dedicated authoring tool for preparing demonstrations for the circuit parcours technique and an environment for content creation. Here, the VR nugget approach can serve as a promising starting point.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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