Virtual Reality in Computer Science Education: A Systematic Review

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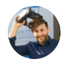
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ABSTRACT

Virtual reality (VR) technologies have become more affordable and accessible in recent years. This is opening up new methods and opportunities in the field of digital learning. VR can offer new forms of interactive learning and working, especially for subjects from the STEM (Science, technology, engineering, and mathematics) area. In this context we investigate the potential and application of VR for computer science education with a systematic review in this paper. We present a formal literature review on the use of VR technologies in computer science education. We focus on the identification of factors such as learning objectives, technologies used, interaction characteristics, and challenges and advantages of using fully immersive VR for computer science education.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; • **Social and professional topics → Computing education programs**; **Computer science education**.

KEYWORDS

Virtual Reality, Computer Science Education, Literature Review, VR

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1 INTRODUCTION

Immersive virtual reality (VR) experiences are simulated experiences and require a VR headset (a head-mounted display, HMD, such as the Oculus Rift) or a room-based setup with projectors and 3D glasses (e.g. a CAVE [11]). Early prototypes of immersive VR experiences were introduced decades ago, but these were limited, however, due to their technology and price range and therefore never commercially successful [22]. With the introduction of the Oculus Rift DK1 prototype in 2012, a new rise of consumer-oriented VR headsets can be observed. Devices such as the Oculus Rift, the HTC Vive, Playstation VR, or even mobile-based VR headsets enable new possibilities for fully-immersive, cost-effective VR experiences. This not only applies to VR for entertainment, but also to VR for education and training.

The promise of immersive technology for education is compelling. Learning activities and practical experiments, which are often too expensive, too dangerous, or simply too time-consuming to be conducted in a real classroom, can be replaced by virtual experiences, especially in the STEM area. The translation of these experiences into immersive virtual realities can be highly beneficial for students, because the sense of being physically, socially, and personally present in the virtual environment contributes to the learning processes [1, 3, 21].

Recent studies show that learning outcomes in educational virtual environments for computer science education can benefit from this sense of presence [15]. Furthermore, virtual learning environments can be used to facilitate

- learning tasks leading to enhanced spatial knowledge representation,
- experiential learning tasks that would be impractical or impossible in the real world,
- learning tasks that lead to increased intrinsic motivation and engagement,
- learning tasks that lead to improved transfer of knowledge and skills to real situations through contextualisation of learning, and
- tasks that lead to richer and/or more effective collaborative learning than is possible with 2D alternatives [12].

Current research questions of computer science education [16] comprise

- the development of a notion for programming (teaching a mental model of how the computer interprets and executes programs, see [8]),
- programming as a notation for thinking (which form/visualization of programming can support learning?), and

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- representing execution (finding fitting visualizations of the program's execution to teach the selected mental model).

The issues raised within these current research questions could be addressed using the named affordances of virtual learning environments combined with immersive technologies (namely fully immersive virtual reality environments).

While the potential for using immersive media in the classroom is great, many challenges and open questions still remain in this field and the design and development efforts are also referred to as *"largely hit-and-miss, driven by intuition and 'common-sense' extrapolations rather than being solidly underpinned by research-informed models and frameworks"* [12].

To better understand the VR space for computer science education, its challenges and also useful but also still suboptimal application scenarios, we present a formal literature review of VR experiences for computer science education. We focus our work on research and development efforts for a fully immersive VR experience using technologies designed for consumer experiences (since 2013). We categorize the work in terms of used technologies, the primary educational goals, and processes, and the identified benefits and issues.

2 IMMERSIVE VIRTUAL REALITY FOR EDUCATION

We describe in more detail the potential of immersive VR for education for various fields outside computer science education (CSE) before presenting the literature review.

Immersive virtual educational environments show merit in improving student learning. In a ten-year review of educational applications of VR, Mikropoulos [23] finds that features such as first-order experience, natural semantics, size, transduction, reification, autonomy, and presence contribute to learning with virtual educational environments. Further, constructivism seems to be the most popular approach on which the didactic design is often based when VR devices are used for teaching and learning. Avatars and the user's relationship to them offer a new dimension to computer-assisted learning. Since these characteristics can only be exploited in dependence on the educational context and content [23], reviews such as the one presented in this paper can benefit from focusing on a specific topic, such as CS, to capture the potential of immersive media for specific content and contexts. Freina and Ott (2015) [17] discuss the findings of a literature review on immersive VR applications for educational benefits and issues. Between 2013 and 2014 they identified 93 relevant papers describing immersive VR applications for education. Most of the papers refer to subjects such as medicine, physics, or chemistry. Most of the applications address adult vocational training or high school and university education; only a few VR experiences relate to younger elementary school pupils. The authors summarize the following motives for using VR: access to times and historical periods that are normally not accessible (e.g. time travel to learn about history); access to places and experiences that are not physically accessible (e.g. travel in the solar system); access to places which are normally too dangerous (e.g. firefighter training); access to experiences with ethical problems (e.g. surgery by non-experts). They summarize benefits such as increased motivation, control over students, training of dangerous or expensive scenarios, feeling of presence, and time.

Previous work has also discussed the potential of VR for educational settings. Bricken (1991) [9] discusses advantages such as the experiential nature of VR, the ability to interact with information in a natural way, the options for shared experiences, control over time, scale, and physics, and the potential to tailor the experience to individuals.

Bricken also describes challenges, such as cost, usability, and fears about the technology. He describes the system usability and usability of the interfaces for students (of different ages), teachers, and curriculum designers as the most important issues for integrating VR into classrooms. In addition, he describes various fears and concerns in the educational field, such as fear of VR misuse, loss of control, or the fear of confusion.

Due to these opportunities and challenges alike, the use of VR in computer science education needs a solid understanding of both the subject-related benefits and potholes. Analyzing existing research on the use of immersive media for teaching computer science in terms of relevance, learning objectives, reported advantages, used technologies, interaction characteristics, target groups, and corresponding engagement strategies, as well as issues and problems, can help enhancing strengths and avoiding or tackling weaknesses. To foster evidence-based design, research, and practice related to teaching and learning Computer Science with VR, this paper addresses seven research questions:

- RQ_1 How relevant is the topic learning and teaching computer science topics with VR in relation to the numbers of research publication?
- RQ_2 What are the learning scenarios and reported learning objectives regarding computer science education?
- RQ_3 What are the reported advantages of using VR for reaching the learning objectives?
- RQ_4 What technologies were used for the VR experiences?
- RQ_5 What forms of locomotion and interaction with the environment are implemented within the VRs?
- RQ_6 What are the distinguished target groups and which engagement strategies were chosen regarding the respective target group?
- RQ_7 What issues and problems were reported within the studies?

3 METHOD

The primary goal of this work is to identify and discuss relevant literature on fully immersive VR experiences for computer science education. In this review study, we followed the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines [20]. Liberati et al. propose the stages *Identification*, *Screening*, *Eligibility*, and *Included*. We used four literature databases: ACM Digital Library, Scopus, SpringerLink, and IEEE Xplore. To be included, the paper must be (1) from a peer-reviewed conference or journal, (2) be written in English, (3) be published after 2013 (the release of the Oculus Rift DK1), (4) focus on computer science education topic and (5) use VR technology. Figure 1 illustrates the process.

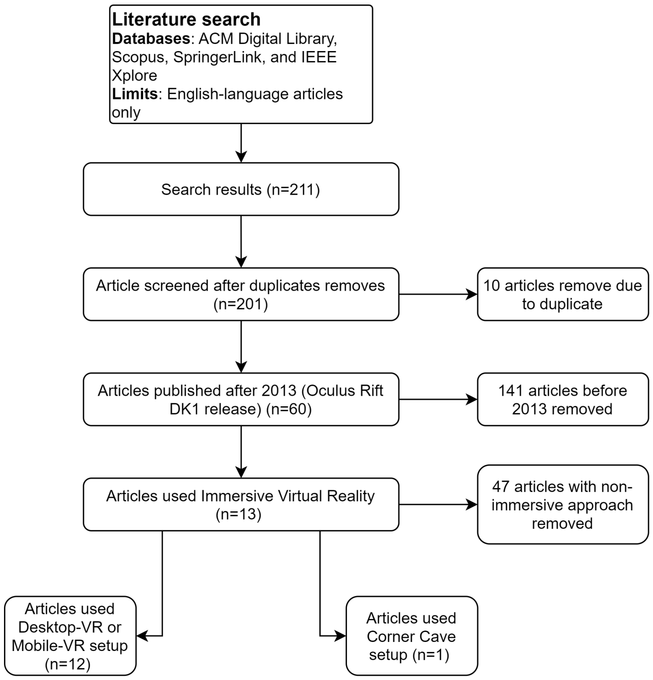

Figure 1: Search criteria diagram according to PRISMA guidelines

3.1 Search Criteria

For the literature collection in the *Identification* phase, we used an advanced search function with an input search term of *"virtual reality"* and *"computer science education"*. The last search was carried out on December 28, 2019. These articles were then reviewed by four researchers in the field (authors of this paper). We identified 211 papers. After the *Screening* process, 10 duplicates were removed. 141 papers were removed because they did not meet the inclusion criteria. After reading the full texts, 47 papers were excluded in the *Eligibility* phase because they did not report on an implemented virtual educational environment, did not use immersive technology, or did not focus on computer science education topics. Paper [26] was identified as an early work in progress of Paper [27]. In the end, 12 studies were included in the qualitative analysis (*Included* phase).

3.2 Categorization Criteria

To categorize the selected papers, we used the year of publication of each article, the technology used (e.g. computer, mobile phone with/without a headset, or a professional head-mounted display), the level of immersion (immersive or non-immersive), the learning objectives, and the form of the social experience in the virtual environment (individual or collaborative).

4 RESULTS

Our final corpus is summarized in Table 1 and contains 13 papers. The papers [27] and [26] describe the same VR environment from different perspectives, thus both papers are referenced in this review.

From the categorization made, we analyzed the learning scenarios and learning objectives of the studies, the technologies used, the interaction characteristics, the target groups, the effects of the interaction characteristics on user learning outcomes, the use cases, and the problems.

4.1 Trend of the Number of Publications

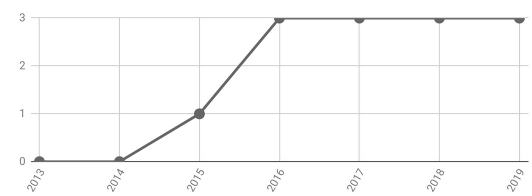

Figure 2: Number of publications over the years.

Over the last seven years, research interest in the field of VR for computer science education has increased in the beginning, but was constant since 2016 with three papers a year. With only 13 papers in total, the interest in this topic can be described as relatively low. As shown in Figure 2, the majority of articles focusing on immersive applications for computer science education were published between 2016 and 2019. Only one publication using immersive VR could be found in 2015. All publications that were identified in the selection phase for the years 2013-2014 were excluded because they use non-immersive technologies.

4.2 Learning Scenarios and Learning Objectives

Learning objectives in immersive learning environments (see Table 2) are found at all cognitive levels. Some studies reported the intended learning objectives directly using Bloom's operators for describing activities on the different cognitive levels. For the other studies, the intended learning objectives were concluded from the activities within the virtual environments, assuming some form of constructive alignment [5] between the learning activities and the intended learning objectives.

Some applications focus on Bloom's cognitive level of the *remembering* content [6], e.g. remembering filter rules for firewall concepts [30] or internalizing software architecture models [31]. When using VR for these learning objectives, having the content presented accurately would appear to be an essential requirement. The learning content is presented in text, audio, or graphic forms.

Others focus on *understanding* concepts, such as the concept of finite state machines [13] or fundamental programming principles [19]. VR can contribute to learning by providing metaphorical explanations for CS concepts, such as the use of analogies [14] for visual representations in the virtual educational environment. Analogies used to teach computer science, e.g. by engaging students in hands-on computer science unplugged activities [2], can be translated into virtual environments as 'computer science replugged' activities [14].

Application skills still represent the majority of CS learning objectives, as many immersive educational virtual environments focus on coding skills (e.g. [36]; [32]; [33]; [3]). Here, VR is used for

Table 1: Corpus of fully immersive VR experiences for computer science education after 2013.

Year	Ref	Topics	Technology	Social
2015	[36]	basic components of algorithms	Oculus Rift	yes
2016	[27] [26]	various fundamental computer science concepts	Oculus Rift, Kinect	no
	[18]	express creativity and innovation	Oculus Rift	no
2017	[10]	creativity and invention skills	Oculus Rift	yes
	[32]	object oriented programming and binary search	Oculus Rift, Corner Cave	no
	[30]	firewall security concepts	Mobile VR, HTC Vive	no
2018	[13]	finite state machine	HTC Vive	no
	[24]	bubble sort	Mobile VR	no
	[37]	network security concepts	Mobile VR	no
2019	[33]	object oriented programming	not described	no
	[3]	basic components of algorithms	HTC Vive, Oculus Rift, Mobile VR	no
	[19]	basic components of algorithms	HTC Vive	yes

modeling approaches to support an active design process. In many projects, the students learn coding by programming and testing the VR, rather than learning inside an existing VR.

Some approaches focus on higher cognitive levels, such as *creation* in the sense of invention skills [10]. Harms and Hastings propose a model where students can improve their creativity and inventiveness by developing projects involving VR technology [18]. In addition, some of the applications enable social experiences in the virtual environment to support collaborative learning (e.g. [19]; [10]).

While the majority of computer science education learning objectives focus on cognitive learning outcomes, the named projects involving teamwork or raising awareness for cybersecurity issues show that immersive technology can be beneficial for Bloom's affective domain as well [6]. There are no examples of computer science education topics in the selected papers that refer to the psychomotor domain, but there are other impressive examples for using immersive technologies for this domain of educational objectives (such as [4]).

4.3 Advantages

The authors have described various advantages of VR in learning settings.

- **Interaction and Immersion** [27] use immersive embodied interaction, combining an HMD with a Kinect sensor. They have been able to stimulate interest in computer science education in middle school students and change their perception of computing. They use VR to engage students in embodied activities to promote embodied thinking and cognition.
- **Visualization and Metaphors** Several authors have described the visualization of complex topics as a useful element of VR experiences for teaching theoretical concepts such as algorithm or OOP [13, 27, 33]. The use of analogies and metaphors for constructing mental models seem to benefit from immersive media and the perception of non-mediation.
- **Playful Design** Another possibility of using VR is the playful design. Several authors describe playful, educational entertainment strategies combined with VR [30, 36, 37]. This strategy has often been described when teaching programming but also security concepts.
- **Social Experiences** While social experiences are an essential element for learning STEM fields, only two of the experiences described have used social elements as part of the VR experience. Collaboration as an element was mainly used in experiences for learning programming.

In summary, the following main advantages of VR were described: engagement, playfulness, visualizations, collaboration, content as a metaphor, learners experience content.

4.4 Used Technologies

We have summarized various technologies used in the literature in Figure 3. It illustrates a higher trend for VR setups running on PCs (such as Oculus Rift or HTC Vive) than mobile VR experience or CAVE-like experiences. Most experiences use an HTC Vive or the Oculus Rift as HMD [19]. When using mobile VR, performance issues or graphical issues have often been described as potential problems. Many authors used the game engine Unity in combination with a VR toolkit such as VRTK[1] to develop the VR experience[19].

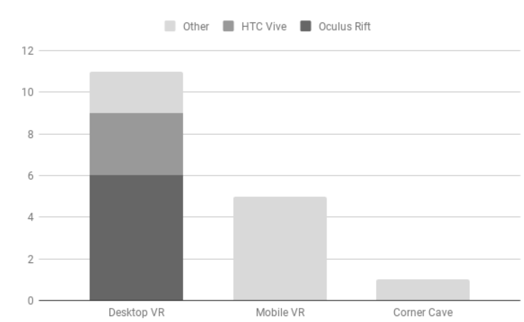

Figure 3: Distribution of VR technologies used in the literature

[1] https://vrtoolkit.readme.io/

Table 2: CS learning concepts taught in VR.

CS Concept	Learning Objectives	Concept of VR	Ref
OOP	Learners can design and implement a class, correctly reason about control flow in a program, and use object-oriented encapsulation mechanisms such as private members.	visualization for understanding	[33]
Programming, Coding	Learners can change variables, use functions, and create a new object; learners can solve puzzle tasks with loops and if-then-else conditions using a visual scripting language; learners can apply the Bubble Sort algorithm to sort balls; learners can apply inheritance, polymorphism, and encapsulation in C++ code; learners can use simple algorithmic components (e.g. conditions, loops) for manouvering robots.	playful concepts, engagement, joy, collaborative learning	[3, 19, 24, 32, 36]
Computational Thinking	Learners can program dance moves using loops and conditions	embodied activity, natural embodied thinking and cognition, critical thinking via physical actions	[26, 27]
System Development	Learners can spatially organize learning materials and working documents in collaborative spaces.	spatial freedom, creative interactions, innovation	[10]
Security Concepts	Learners can explain the security concept of a packet-filtering firewall; learners can differentiate IT security terms and can explain them.	playful interactions, educational entertainment, engaging students	[30, 37]
Theoretical CS	Learners can draw finite state machines and navigate between states	visualization of FSM, metaphorical learning	[13]
Innovation, Invention Skills, Project-oriented working	Learners can apply knowledge to solve product-oriented tasks in formal learning setting	student-led VR projects	[18]

4.5 Interaction Characteristics

A different locomotion system can lead to a significant difference in the user experience. Often the target group for CS training using VR has no previous experience with VR environments. The choice of an uncomfortable locomotion system can lead to cybersickness, nausea, a strong reduction of user engagement, and the termination of additional VR sessions. Tanielu et al. [33], for instance, used teleportation for locomotion in their mobile VR application. Teleportation in VR applications is one of the easiest ways to avoid most problems of locomotion.

4.6 Target Groups and Engagement Strategies

The described target groups of the analyzed publications are mainly high school and university students. Different application scenarios were developed for different target groups. Especially for younger students engagement strategies are an important element of experience design

Today's students are used to engaging, self-directed, and flexible learning methods. The lack of interest shown by students in scientific topics is still a great challenge for schools and universities. Immersive and engaging learning methods should help to reach the new generation of learners. The entertainment application VEnvI [26], for instance, attempts to appeal to middle school students by combining computational thinking with dance and movement choreography. The aim is to engage young students through fun and an intuitive interface. Another approach to spark the interest in computer science of this generation of learners is used by the browser-based, educational platform MYR ("My Reality") [3]. The authors provide an environment for building VR scenes by applying programming concepts to increase the students' interest in computer science topics.

Most of the educational VR applications in the field of computer science other than in schools are aimed at undergraduate university students. Computational topics are perceived by students as difficult to understand and lead to high dropout and failure rates. To support computer science students in understanding abstract topics, Dengel [13] and Tanielu et al. [33] used metaphorical representations and analogies using VR technologies. In addition to understanding the theoretical concepts, it is also important for CS students to learn creativity, inventiveness, and innovation skills. The immersive VR system developed by Bujdosó et al. [10] contains several methods that can be used for activating cognitive processes and to improve students' inventive thinking.

4.7 Issues and Problems

One major challenge described by several authors is the interaction with programming interfaces in virtual environments. These are often not intuitive and described as cumbersome [27]. One common issue is the design of the user interface (UI) and the introduction of UI elements. UI elements are often designed similarly to their 2D twins. However, a significant major advantage of VR is its immersion and feeling of presence. Traditional menus, buttons, or UI elements break this immersion. This is also shown in the study by Horst et al. [19]. HMDs and interaction systems of VR allow embodiment. To give a better feeling of presence or embodiment, we suggest using 3D-interactive objects into the scene where users can interact with them in a physical, natural, and intuitive way.

User acceptance has also been described as an issue. The study by Bujdoso et al. [10] shows that students are not willing to use VR to communicate during the project. They prefer to use traditional social applications like Whatsapp. This shows that this VR application does not provide them with any additional benefit in communication. It is an important point when we think about the use of disruptive technologies. Even if the experience is interesting at the beginning, the everyday use will depend on the usability and the benefits of these technologies. It seems that in the case of the social application of VR, further interactions and tools need to be implemented to create a richer environment. These tools should be designed explicitly for VR to provide a user-friendly experience.

In this paper, we have focused on the review and discussion of pedagogical applications whose main interaction is designed primarily for VR. However, several publications also describe 3D experiences, which are designed for PCs, but also work with VR. An example is discussed in [7]. They present a playful 3D environment for exploring basic computer science concepts and offer an optional VR mode (for HTC Vive). However, these systems are often not specifically designed for VR or interactions in VR, which can lead to significant usability and experience flaws [9]. When working with game engines like Unity, the integration of a VR viewer into an existing game/3D application is a simple task. However, this only applies to the interaction with the camera. VR applications require a suitable interaction design with the VR experience. This usually requires a different form of interaction with the environment, new menu designs, and also well-designed solutions for locomotion to avoid nausea and discomfort.

4.8 Corner Cases: VR Projects as a Teaching Tool

In recent years, VR has become more and more popular not only as a learning platform but also as a technology used for teaching and engaging through the development for VR. In [39], for instance, the authors describe the use of VR to bring computer science and art students together to create VR experiences. In [38], the authors describe how to engage students by writing VR programs. In [1], the authors describe the potential of VR to engage CS students and use it in areas such as *computer graphics*, *gaming*, or *simulations*. Reasons are often given to engage students with this innovative and interesting technology and enable them to see their developments in a more appealing way (see also the Hour of Code for Virtual Reality project [21]). This is becoming increasingly important as students can easily experience their VR applications on their smartphones. In summary, working on a virtual reality project as part of the curriculum has several advantages [18]. Computer science curricula should prepare students for the industry. Students should be familiarized with different technologies, tools, and programming languages. They should also learn soft skills such as communication, teamwork, and problem solving. And they should know how to work on a large project as part of an interdisciplinary team. In [18], the authors describe how working for several months on a virtual reality project helped students not only to learn new tools and techniques, but also to acquire essential skills such as teamwork, project management, and organization. Furthermore, students were able to express innovation and creativity, which are necessary and effective skills for their future career.

5 DISCUSSION AND LIMITATIONS

The results show that the research interest in the use of VR for the teaching of CS has grown in recent years (*RQ_1*). The learning objectives cover a wide range of CS topics: While programming skills are sometimes taught by developing and testing VR programs, existing applications can be used in the classroom to teach about other concepts and ideas of CS such as IT security, theoretical computer science, and creativity skills. Most learning objectives focus on application skills (i.e. programming and problem-solving skills); some focus on understanding concepts (*RQ_2*). Most studies reported positive effects of the use of immersive media for educational purposes, particularly in terms of interaction, immersion, visualization, playful design, use of metaphors and analogies, and social experiences (*RQ_3*). Most VR programs use professional VR headsets (e.g. the Oculus Rift or the HTC Vive), some use Mobile VR devices, and only one was identified using a CAVE system, which shows that the opportunities of VR can be exploited best by using an HMD device (*RQ_4*). In most VR experiences, teleportation has been used as a way to interact with the environment in a comfortable way (*RQ_5*). In addition, most studies focus on target groups from schools; some use VR for undergraduate students. Efforts to engage the students are made primarily by selecting themes from the target group's everyday life or age-appropriate interests (*RQ_6*). In addition to the positive effects, some issues include the current unfamiliarity with the medium, which leads to insecurity on the side of the students, the transformation of 2D user interfaces into 3D environments, as well as cybersickness (*RQ_7*).

A large part of the analyzed literature had to be excluded as it focused on non-immersive applications for CS education, or did not refer to CS education at all. While these articles were excluded from this analysis, it must be considered that they still contribute to the overall research on the use of virtual worlds for computer science education. In particular, the efforts to create hands-on activities to transfer computer science unplugged projects [2] to virtual experiences (see e.g. [34]) show merit in instrumentalizing interactive playful 3D-environments for learning. Future work can benefit from adding the results of those non-immersive efforts to the insights gathered in this review. It was also a problem that the term VR is often used for non-immersive experiences. Another challenge that had to be faced when writing this paper was that, on the one hand, not all studies clearly formulated the learning objectives, which led the authors to summarize them from the reported user stories or the design of the environments. On the other hand, some studies reported the learning objectives in detail, but gave only little information on the technology used or the design of the environments (e.g. interaction characteristics, etc.). It should be noted that the conclusions drawn from the studies are often based on qualitative measures or reports from participants. Thus, the results of this systematic review "best-practice" guidelines rather than being purely evidence-based. It is the task of the studies to estimate e.g. the effect of sizes of using immersive technology for learning about computer science concepts.

6 CONCLUSION

In this paper, we reviewed publications on VR experiences for computer science education to gain a better understanding of opportunities, challenges, and application scenarios. While the interest in the use of virtual experiences and virtual environments is high, the use of fully immersive VR technologies is still at an early stage. Several studies already reported on the potential of VR and immersive experiences for computer science education many years ago. Now, with access to affordable and high-quality HMDs such as the HTC Vive or the Oculus Rift, new and innovative teaching approaches for computer science education in the classroom and also for self-regulated learning scenarios can be implemented and tested. But this innovative, educational medium opens up new perspectives for the design and integration of immersive experiences in the classroom. The design of virtual environments can be used for teaching programming or existing environments can be used to focus on theoretical concepts of CS. In the latter case, the results of this systematic review could show that the professional design of immersive virtual environments for teaching and learning CS

- can focus on a large variety of topics and is not bound to a particular level of cognitive complexity,
- should make use of interaction, immersion, visualization, playful design, use metaphors and analogies, and social experiences within the virtual environments to support factors relevant for learning activities and learning outcomes,
- might have the best effect when using HMD devices, but has to keep the schools' technological equipment in mind (in favor for multi-platform solutions, whenever possible),
- can benefit from using teleportation as a method of locomotion as a best-practice guideline to avoid cybersickness,
- can add to the target group's motivation by arranging stories about themes that are relevant/interesting and age-appropriate for the students,
- should try to minimize potential risks within the environment causing cybersickness and keep the controls as simple as possible to reduce insecurity,
- can benefit from social experiences to support pedagogical models which rely on peer discussions.

When using educational virtual environments in the classroom, the findings of this study show that

- the virtual environment often resolves around a specific learning objective, which means that careful considerations need to be made in order to embed the immersive experience within the overall teaching sequence (e.g. as motivation, for showing a problem, for acquiring fundamentals for solving a problem, etc., see [35])
- educational media with a higher level of technological immersion should be preferred, if they are available to enhance the effects of the experience on learning activities and factors influencing learning such as engagement, presence, and motivation.
- to avoid insecurity, teachers can integrate an additional introduction phase (especially when using VR for the first time) in which the students get comfortable with the common controls. Teachers should also be present to support insecure students during the VR experience or to provide different tasks if students feel cybersick.

With regard to current issues of computer science education research [16], VR can support the development of a notion for programming in such a way that situated learning and active learning in immersive educational virtual environments can support the construction of a mental model. Programming as a notation for thinking can benefit from various playful ways to design algorithms in interactive VRs, or to design interactive VRs using algorithms. This is also the main characteristic that differentiates the use of VR for CSE compared to other subjects: educational virtual environments can be used for teaching and learning various concepts and ideas, but also the design process of a VR can be utilized to learn about programming, object-oriented programming, and project-oriented working. The use of visualizations, especially the use of analogies and metaphors, can add value to the question of how execution is represented.

Although this review has identified many advantages and interesting use cases of virtual reality in computer science education, the limited number of only 13 relevant papers shows that there is still a lot of potential for research and development. There are many potential paths for future work that can be taken from here. The concepts of embodied activities and metaphorical learning in VR as presented by [13, 26, 27] have shown interesting first results. However, the number of studies and developed VR experiences in this field is still very limited and leaves much room for further investigations. Playful approaches were also suggested as a valuable tool for learning computer science topics **[25]**, but only very few reviewed VR experiences have included game elements in their work. Investigating the effect of playful VR experiences on the learning of computer science topics in VR can also open up new research paths. Another still open, but very important pedagogical aspect that was missing in the reviewed work is also the discussion and investigation of how virtual reality can be integrated in the curriculum and how it can be part of a classroom experience. Setting up VR experiences can be a challenging task as they require space and additional setup time [29]. Further investigations of potential use cases in classrooms is an important gap for future work. Furthermore, most of the reviewed papers have identified the potential of VR from the students' perspectives. Future research should also address requirements, potential issues, and potential use cases from the teacher's perspective as this perspective is often not given enough attention in the development of learning environments [28].

With these considerations in mind, VR experiences could be a viable method to support the teaching and learning of CS. As discussed above, there were several issues in which either the pedagogical or the technological side of current VR experiences suffer from poor considerations or a lack of information in the analyzed documents. This need calls for collaborations between educators and game designers for future studies. We believe that there are many opportunities for fully-immersive VR applications for computer science education, and with interdisciplinary teamwork, immersive learning could have the potential to shape the future of how we teach and learn computer science.

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