The Potential of Virtual Reality for Computer Science Education - Engaging Students through Immersive Visualizations*

Johanna Pirker†
Graz University of Technology

Johannes Kopf
Graz University of Technology

Alexander Kainz
Graz University of Technology

Andreas Dengel
University of Würzburg

Benjamin Buchbauer
Graz University of Technology

Abstract

Popular problems of Computer Science Education that are often solved using algorithms include various number sorting tasks. Sorting algorithms have the potential to emphasize powerful programming paradigms and also to start discussions about algorithm complexity. Research has shown that hands-on activities using analogies and fun activities instead of programming tasks can foster learning in this area in many different ways. In times when much teaching and learning takes place online, the implementing of such unplugged activities can become difficult. Visualizations and animations can help to achieve learning outcomes by making these relatively abstract phenomena more concrete. In particular, virtual reality environments can provide new forms for interacting with visualizations and might well foster motivational, emotional, and perceptual factors that have an influence on learning processes. This paper investigates the differences between these subjective variables in a web application and a VR application for learning sorting algorithms. The results produced initial indicators that learners experience higher presence, absorption, flow, psychological immersion and positive emotions in a virtual reality setting compared to a desktop setting.

Index Terms: Human-centered computing—Visualization—Visualization techniques—;

1 Introduction

Learning computer science (CS) is a challenging task and many of the concepts and phenomena involved are difficult to understand. Programming can help students develop Computational Thinking skills, fostering the ability of students to think on multiple levels of abstraction [35]. Programming can be seen as a notation for such ways of thinking [13]. In this context, the fundamental idea of algorithmization, including powerful programming paradigms such as divide-and-conquer or basic ideas of control structures including recursion as well as first discussions about complexity [31] can be taught with number sorting tasks using different algorithms (e.g. BubbleSort, MergeSort, QuickSort, etc.) for their solution. The endeavors of educators to increase student motivation and commitment can maximize understanding of difficult topics such as algorithms, data structures, and programming [5]. These learner-specific factors influencing learning processes can be fostered with hands-on approaches such as Computer Science Unplugged activities, that do not even need a computer to both motivate students for and engage them in learning CS [4]. While such activities have great potential for the teaching of many abstract concepts and ideas, they have become difficult to implement during online-teaching and learning periods. Digital learning applications such as visualizations have become an essential tool to both increase learner understanding of these phenomena and also to promote learning progress [18]. But there are many other factors influencing learning outcomes [17] that can benefit from real activities, which might suffer in such isolated virtual approaches. For virtual environments, emotion, motivation, cognition, and perception are considered to be important learning activity influences [12]. As virtual reality (VR) headsets have become affordable, more comfortable to set up and more accessible in recent years, they have also begun to offer new innovative opportunities for interactive and immersive digital learning. VR sets itself apart from classical digital learning due to its innate characteristics such as the feeling of being within a separate world and of feeling alive and interacting with objects within it. Furthermore, VR usage in education has the appearance of looking positive and engaging [15,21]. In these contexts, immersive activities might have the potential to foster person-specific emotional, motivational, cognitive, and perceptual factors in a better manner than can be achieved through non-immersive experiences. This paper investigates the question of whether an implementation of sorting algorithm visualizations in a VR environment will lead to higher engagement and presence plus improved academic emotions and learning experiences compared to desktop-based methods. Since visualization strategies in this field have been shown to be successful learning aids in a previous work of ours [16], we focused our evaluation efforts here on those other subjective factors influencing learning processes, because learning can always be thought of as a process nested within multi-factorial relationships [32]. We conducted an A/B split in a subject user study with 20 participants comparing the visualization about sorting algorithms in two different environments: (1) a WebGL built that is available on a website and (2) a VR version implemented for the HTC Vive. In the remainder of this paper, we present the design and implementation of the two applications and discuss the comparison between the two implementations with a focus on the factors engagement, academic emotions, and learning experience.

2 Related Work

Many efforts have been made in computer science (CS) to support students in learning through visualizations and simulations. Examples include topics such as computer networking, software engineering, computer architecture, or computer science principles [2,36,37]. A number of recent studies have found concrete evidence that using computer simulations or visualizations improves learning and can lead to higher achievement levels by students [23,29,30,34]. Only a few simulations have been implemented in VR environments, however, although they show promising signs in relation to education as they provide new ways to support interaction with the learning content [15, 21]. There are examples of VR simulations in the literature in areas such as cybersecurity, programming, robotics, and CS fundamentals [1, 7, 8, 19]. Several studies report an increase in critical thinking, higher motivation and engagement, greater excitement, improvement of the learning experience, and positive learning effects [9, 15, 22]. In contrast to this, one recent study found that adding VR to a science lab simulation increased presence, but over-

*(Preprint) 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)
†e-mail: jpirker@iicm.edu

loaded and distracted the participants, resulting in a lower learning outcome compared to the PC-based version [23]. In summary, using web-based or desktop versions of simulations and visualizations is a well-established method to support learning, but VR also shows many promising signs related to education. This work is thus directed towards the direct comparison of visualization by sorting algorithms in two different environments. In the following, we discuss related work for interactive forms of CS education and factors influencing learning outcomes in virtual educational environments.

2.1 Interactive Computer Science Education (CSE)

Activities offered by the Computer Science Unplugged program [4] explore the idea of exposing children to the concepts and theories of CSE without using computers. The 'parallel sorting network' allows students to engage in a number sorting activity where they have to work together to get to the other side of the network in the correct order. This activity was subsequently transferred into a virtual context in Second Life as well [3]. Another interactive visualization is SATSim: an interactive animation tool that provides information about superscalar architecture concepts. It was used in an undergraduate course about computer architecture to visualize the complicated patterns of e.g. out-of-order execution, in-order commitment, and the impact of cache misses and branch mispredictions. Observations of the course through quizzes and participation showed that the understanding displayed by the students improved significantly [36]. SimSE simulates a realistic software engineering process where students learn to deal with specific situations that occur during such a process. It requires skills to understand and deal with software engineering issues [24]. In a multi-layered study, they show that students appear to learn the concepts presented successfully. The students are of the opinion that using it is an enjoyable experience but also that giving the correct instructions is crucial for use. It is most effective when used in addition to other teaching methods [25]. Furthermore, many CS visualizations are freely available on the web and can help in learning principles — for example, visualizations about sorting and pathfinding [37].

2.2 CSE in Virtual Reality

A study on the use of an immersive visualization tool on CS concepts carried out as early as 2004 showed that it increases the understanding and mastery of selected subjects [26]. Recent studies also reported promising results. MYR is a web platform for teaching coding in VR. Users write code, which then generates a three-dimensional animated code. An evaluation featuring 13 middle school pupils with little prior experience with text programming was carried out. These pupils said the visual aspects improve the learning experience, they enjoyed seeing the output of their code and liked the creative controls. Engagement and enthusiasm were high throughout the study [6]. Another work shows a VR implementation that aims to help novice programmers understand object-oriented programming. It combines analogies and visualization to deliver the content. An evaluation with 17 CS2 students shows that the tool is effective, as the students' ability to visualize the object-oriented concepts improved significantly [33]. Moreover, a study of an interactive teaching environment in VR, which focuses on teaching some sorting algorithms, indicates that the tool is effective in software engineering education [1]. The teaching concept 'Computer Science Replugged' takes the Computer Science Unplugged approach and transfers hands-on activities from a real context to a virtual context by using the 'perception of nonmediation' that is gained through presence in an immersive virtual environment. A follow-up study showed ambiguous results: The level of technological immersion had effects between β=-.17 and β=.41 on learning outcomes, leading to the conclusion that there are more factors influencing learning outcomes [11], which is why this study focuses on related factors relevant for learning. In [28], the authors give an overview of the landscape of VR learning applications for CSE by presenting a systematic mapping of the literature. They only identified 13 relevant applications. While these applications showed interesting results, they often covered only one particular element of CSE. The authors point out in summary that VR has potential for different CS applications, but also see an open gap here, since only a few visualizations and experiments have been developed and VR is still not a technology often used in CSE.

2.3 Learning Process in Virtual Environments

Research shows that learning is a process influenced by multiple factors [17, 32]. Following the idea of a virtual educational environment as an instructional supply that has to be used actively by a learner, objective factors such as the technology used influence learning together with subjective variables including motivation, emotion, perception, and cognition [12]. The user's perception and interpretation of the learning environment would appear to mediate the effect of the virtual environment's characteristics on learning benefits [10]. Such perceptual and interpretative characteristics can be assessed as the combined engagement of the users in the environment using the factors absorption, flow, presence, and immersion [14], leading to H1: The VR setting induces a stronger perception of (a) absorption, (b) flow, (c) presence, and (d) immersion than the web setting. Emotions influencing learning activities (academic emotions) can be distinguished according to their valency and their degree of activation. To the terms of control-value theory, academic emotions related to a current learning activity (such as operating within a virtual educational environment) depend on the level of perceived controllability and on the perceived value of the activity [27].Regarding the learning process, positive activating emotions, such as happiness, can support learning while emotions with a low valency tend to impede learning. Following this theoretical model, a higher level of control (better interactivity in a VR setting) might lead to stronger positive and weaker negative emotions. Similarly, a higher intrinsic value (stronger meaning due to the sense of presence) provided through the VR setting might also lead to stronger positive and weaker negative emotions. These assumptions lead to H2: The VR setting induces (a) stronger happiness, (b) weaker sadness, (c) weaker anxiety, and (d) weaker anger than the web setting.

3 Visualization of Sorting Algorithms

In this research work scope, an application for visualizing and understanding how nine of the best-known sorting algorithms work was developed with the game engine Unity 3D[1].In addition, we used the Unity plugin named Virtual Reality Toolkit[2] (VRTK) to implement the application, which allowed us to switch between VR and PC keyboard/mouse input methods easily.The web and the VR version are feature-identical in terms of selecting and controlling sorting algorithms. By contrast, the input method is naturally different in the web version (keyboard and mouse) than in VR (controllers of the HTC Vive). The VR version is designed as a standing application and includes features to support a room-scale VR experience with the HTC Vive, offering the functionality of a virtual boundary needed to warn the user before stepping outside of the given virtual boundary to avoid physical accidents. While the primary learning objective of the application is to enable students to explain the differences between the sorting algorithms, the environments can also be used later in the learning process to spark discussions about time complexity. The nine implemented sorting algorithms were: Bubble Sort, Gnome Sort, Heap Sort, Insertion Sort, Merge Sort, Quick Sort, Radix Sort, Selection Sort, and Shell Sort. In both versions, users can spawn multiple sets of elements with random numbers and apply one of nine sorting algorithms to analyze and study their behavior.

[1]http://unity.com/

[2]https://www.vrtk.io/

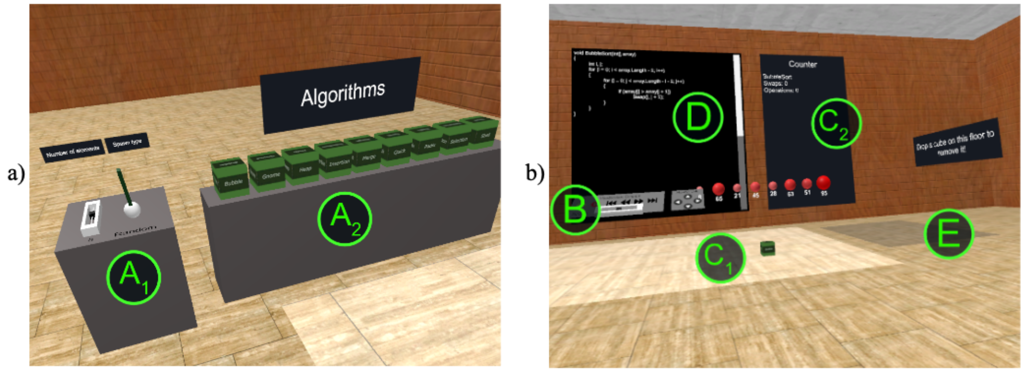

Figure 1: Overview of the user interface and layout

Each set of elements includes a counter for executed swaps and operations. Users have full control over the visualization at all times. They can pause, resume, and step through the algorithms.

3.1 User Interface

The user interface of the VR application is shown in Figure 2 and is split into the following sections:

(A_1) and (A_2) represent the selection panel. (A_1) allows the changing of the number of elements that are sorted, and (A_2) offers the different sorting algorithms in the form of cubes. **(B)** is the control panel, as it enables users to control the state and speed of the visualizations. Users can pause and resume the simulation, make single steps forward or backward, and control the simulation's speed using a slider. **(C_1) and (C_2)** represent the visualization section. A cube visualizes each algorithm that is taken from (B). If one of those cubes is put onto the area (C_1), the elements to sort are shown above the cube. An element is represented as a sphere. The bigger the sphere, the higher its number and its color saturation. A big sphere is red, and a small sphere is gray. The number of executed operations and element swaps during the sorting process is counted and displayed in the panel (C_2). Multiple algorithms can be executed simultaneously. They can be rearranged to allow easier comparisons between different algorithms by placing them side by side. **(D)** is the coding panel where the code of the sorting algorithms is shown. If a cube is dropped in (C_1), the code switches to match the dropped algorithm box. **(E)** is the trash basket. When a sorting algorithm cube is put here, its state is reset, and it is placed at (A_2) again.

3.2 Differences between Web and the VR Application

The main functionality and elements are the same in both applications. However, the interaction in a VR space can require different user interactions than those for a web-based version. The cubes, slider, and lever in the VR version can be grabbed with VR controllers and placed accordingly. In the web-based version, those objects are dragged by keeping the left mouse button pressed. The VR space is navigated by moving around physically or by the user teleporting virtually. In the web-based version, the typical keyboard keys (W/A/S/D, arrow keys) are used. For both applications, typical and traditional interaction strategies were used.

4 User Study

Our two versions of the application (web and VR) were evaluated as part of a first user study to test the hypotheses for engagement and emotions as well as the learning and overall experiences.

Participants. This study involved 20 participants (6 female). They were aged from 15 to 34 (M=24.80; SD=5.77). On a Likert scale from 1 (= not agree) to 5 (= fully agree), most of them rated their experience with computers (M=3.85; SD=1.27) and computer games (M=3.50; SD=1.32) above average. Seven participants had no or limited experience with VR; three were experts on this topic (M=2.50; SD=1.50). Nine out of 20 participants have already used the HTC Vive before. 15 people said they like playing video games. Most of them (15) rated their knowledge about computer science as average or higher (M=3.3; SD=1.38). Their highest level of education ranges from high school graduates to Ph.D. Included were teachers, nurses, assistant professors, project managers, process engineers, project assistants, and students. They rated their knowledge about sorting algorithms somewhat balanced overall on the given Likert scale (M=2.85; SD=1.35), with a high standard deviation. The participants were not paid for their participation in the study.

Study Procedure. We used two Alienware Aurora computers with identical specifications: a GeForce RTX 2080 graphics card, an Intel Core i7-9700K processor, and 16GB DDR4 RAM. We set up a full HTC Vive head-mounted display (HMD) using one of the PCs. The other PC was used for the web application. The study was designed as an A/B-split within-subjects study. First, the participants were required to answer questions regarding demographic data and previous experience with computer science, applications, and VR. After this, they tested the first application. Half of them started with the web version and the other half with the VR version. In each environment, they had to familiarize themselves with the user interface and perform basic tasks. In both versions, they were faced with the task of trying out and understanding Gnome Sort and Bubble Sort. There was no introduction at the beginning, but we provided verbal explanations if they were not able to perform one of the tasks. After finishing each version, they had to answer a post-questionnaire. This was comprised of open questions about their overall impressions and motivation, the Computer Emotions Scale [20], and the Game Engagement Questionnaire (GEQ) [14]. On conclusion, they were asked to fill out a final questionnaire which aimed at the direct comparison between both environments.

5 Results

The results describe (1) engagement, (2) emotions, and (3) the learning experience of the two versions of the application. Table 1 summarizes the findings of the two standardized questionnaires. Qualitative results and the participants' feedback from the open-ended questions are described in the following sections.

5.1 Engagement

An overview of the GEQ (Game Engagement Questionnaire) results in the form of box plots is illustrated in Figure 2. Hereby, a Likert scale from 1 (=not at all) to 5 (=fully agree) was used.

Web Application: The results of the Game Engagement Questionnaire are in the following order, from lowest (1.45) to highest (2.30):

Table 1: Overview of average and standard deviation of values based on the Game Engagement Questionnaire (GEQ), and the Computer Emotion Scale (CES). Also, results of significance testing using Wilcoxon Signed-Rank test for paired samples, are provided.

Scale	Factor	Web	Virtual Reality	Significance Test Result	Sig. Dif.
GEQ	Absorption	1.45 (0.66)	2.23 (0.92)	Z-score=2.794, p=0.005	Yes
	Flow	1.77 (0.69)	2.34 (0.65)	Z-score=3.081, p=0.002	Yes
	Presence	2.09 (0.82)	2.78 (1.08)	Z-score=2.240, p=0.025	Yes
	Immersion	2.30 (1.03)	3.50 (1.19)	Z-score=2.810, p=0.005	Yes
CES	Happiness	1.33 (0.75)	2.02 (0.77)	Z-score=2.238, p=0.025	Yes
	Sadness	0.33 (0.65)	0.18 (0.29)	Z-score=1.025, p=0.305	No
	Anxiety	0.39 (0.55)	0.21 (0.27)	Z-score=1.035, p=0.301	No
	Anger	0.55 (0.91)	0.15 (0.23)	Z-score=1.875, p=0.061	No

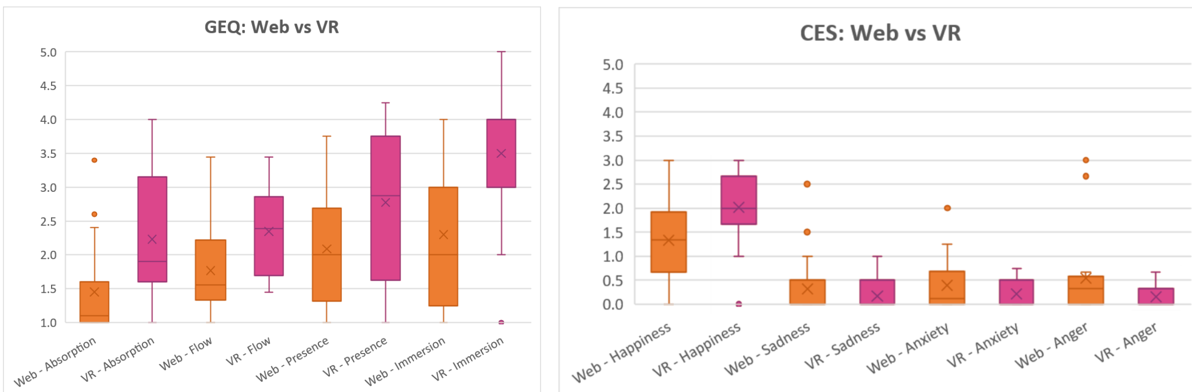

Figure 2: Box plots showing the results of the GEQ and the CES for the VR and the web application

Absorption, Flow, Presence, Immersion. In the open-ended questionnaire, five participants said they did not find it in the least engaging, seven found it partly engaging and eight rated it as engaging and motivating.

VR Application: The order of the parameters in the Game Engagement Questionnaire is similar to the web version. However, the scores range from 2.23 to 3.50. The factor motivation was mentioned by many participants as an important part of the VR experience: [The VR version should be used] "in school, with younger students, as learning these algorithms can be frustrating". 16 participants found the experience engaging and motivating; four participants found it partly engaging and motivating, and none found it not motivating or engaging at all. Figure 2 shows that the median of all four GEQ factors in the VR application was rated higher than in the web-based version. The interquartile ranges reveal that the dispersion of the ratings of the VR application is lower, although there was one outlier.

Significance Test: Using the Wilcoxon Signed-Rank test for paired samples revealed that there are significant differences in all four categories Absorption, Flow, Presence, and Immersion. For H1, we can suggest that the VR-based application is more engaging than the web-based application.

5.2 Emotions

Web Application: On the Computer Emotions Scale the emotions Sadness (M=0.33, SD=0.65), Anxiety (M=0.39, SD=0.55), and Anger (M=0.55, SD=0.91) received the lowest scores. Happiness scores an average result with a standard deviation in line with the other factors (M=1.33, SD=0.75). The box plots in Figure 2 show that the medians of Sadness, Anxiety, and Anger of the CES in the web application were higher than in the VR version.

VR Application: The results of the Computer Emotions Scale are: Happiness (M=2.02, SD=0.77), Sadness (M=0.18, SD=0.29), Anxiety (M=0.21, SD=0.27), Anger (M=0.15, SD=0.23). Opposed to the other three factors, Happiness when using the VR application was rated higher when looking at Figure 2. The interquartile ranges reveal that the dispersion of the ratings of the VR application is lower. Here, we can also see a single outlier, which is due to the fact that one participant suffered from cybersickness and rated the Happiness questions with 1 (=not at all).

Significance Test: Applying the Wilcoxon Signed-Rank test for paired samples on each of the four categories showed a significant difference in the Happiness category. This indicates for H2 that players experience stronger happiness using the VR application compared to the Web application.

5.3 Learning

We asked the participants if they would use the application for learning, about the perceived learning objectives and how they would rate several learning experience items on a Likert scale between 1 (= no agreement) and 7 (= full agreement). The results are shown in Table 2.

Web Application: Only four of the participants said that they would like to use it for learning as it is (rating 6 or 7). 14 stated they might possibly learn with it (rating between 3 and 5), and two declared that they would not use it for learning at all (rating of 1 or 2). Nine people stated that they would learn with the application in combination with a different learning setting (rating 6 or 7). When asked what they have learned, many said that they now understand that there are different ways of sorting and how the different sorting types behave. Only six fully agreed that the application was suitable for learning (rating 6 or 7).

VR Application: 11 participants said that they would use it for learning as it is and rated it 6 or 7. Eight stated they would maybe learn with it (rating 3-5), and only one declared that he/she would not use it for learning at all (rating 1 or 2). Eighteen participants said that it was suitable for learning: *"Perfect — interactive learning"*. In all questions, participants rated the VR experience higher than the web-based application (see Table 2). They noted that it was more motivating than regular classes and that it makes the content more exciting and engaging. Twelve participants fully agreed that it was suitable for learning (rating 6 or 7), and thirteen stated that it is an excellent supplement for learning (rating 6 or 7).

5.4 Overall Experience

We also asked the participants about their overall experience and perceived issues and advantages.
Web Application: Overall, they stated the web version was relatively good and self-explanatory, but they also mentioned various possible improvements like a short introduction and further explanations of the sorting algorithms. Some thought it would have been better if they had been able to bring in a little more background knowledge. They liked the different methods of sorting and the visualization of moving objects. In some cases, they did not like the interaction with the interface and said they lacked instructions. One participant also said *"it's a bit boring"* and not easy to understand.
VR Application: The textual feedback of the VR version was overwhelmingly positive. The participants liked the capability for throwing things around, that it is fun to learn with, the ability to teleport, the interactivity and also the sense of being in a virtual world. Furthermore, they found it motivating and engaging, that it makes the content more interesting and said they would use it for learning. One suggestion for improvement was the introduction of a full and adequate starting tutorial . Unfortunately, one of the participants had to cancel the tryout of the VR version early due to experiencing cyber sickness. Especially playful items, such as the interaction with the cubes, were noted as very positive. *" I think the cubes are a good idea and I like the concept of throwing them in order to interact and work with them"* and the concept of interacting in a different world: *"[I liked] moving in a virtual world"*.The form of visualization was mentioned as an essential and exciting element, but specific user interaction elements, such as settings, buttons, and graphical design, should be improved. Some noted that a VR tutorial might be helpful.

5.5 Comparison

When being asked which experience they would prefer, 17 of the 20 participants preferred the VR environment over the web-based experience, two persons like both equally and a single person only preferred the web version. The participant who preferred the web version experienced cyber sickness during the experiment and we thus had to cancel the test. We also asked the participants which platform they would recommend for use to learning CS topics. Fourteen of the participants preferred VR; three stated that this would depends on the content and only three said they would prefer to use a web version. Their reasoning for using VR instead of the web-based version included statements to the effect that it is more interactive, more user-friendly, self-explaining, refreshing, more fun, more interesting, more engaging and more motivating. When asked which version they would recommend for different scenarios, the participants mentioned the following concepts: *"Web-based one for school and university because they often have large groups. VR version for small groups that are less focused on quick learning and more on fun learning"*.

6 Discussion

From this study, we learned that users see much potential for a more interactive and engaging form of learning with the new VR headsets. Users described the VR version as more interactive and especially more engaging. The results of the GEQ show that all elements indicating engagement, such as Absorption, Flow, Presence, and especially Immersion, were rated higher. Looking at the open-ended questions, many participants accurately described the feeling of immersion and active engagement when interacting with the VR version. The results of the CES questionnaire show that VR can contribute to a higher valency in terms of achievement emotions. Users also mentioned frustrations when interacting with the web-based version. Even though the features and functionality were the same, the application was described as "boring" and complicated to use. When learning, users should be able to focus entirely on the learning experience and should be engaged by the learning environment, instead of frustrated. It was also noted that the web-based version has advantages and valuable use-cases. One participant mentioned that he/she only uses the web-based version because of motion sickness. Other participants stated the value of web-based versions for learners who cannot afford VR headsets, want to learn remotely, or for classroom experiences where many students need to learn simultaneously.

Table 2: Comparison of the learning experience on a Likert scale between 1 (=Not At All) and 7 (=Fully Agree)

	Web	VR
I would like to learn with X	4.35	**5.35**
It is a good idea to use X for learning	5.10	**5.60**
X is a good supplement to regular learning	5.25	**5.80**
I learned something with X	5.20	**5.45**
X makes the content more interesting	4.90	**5.90**
X makes the content easier to understand	5.10	**5.15**
X makes learning more engaging	5.10	**5.75**
X makes learning more fun	4.55	**6.35**
X makes learning more interesting	5.15	**5.95**
The experience with X inspired me to learn more about CS	3.30	**4.15**
Learning with X was more motivating than ordinary exercises	5.10	**5.90**
It makes course content more interesting to learn about	5.00	**5.75**
I would rather like to learn CS with X than with traditional methods	4.95	**5.55**
Seeing the CS simulations on X was engaging	4.80	**5.60**
I would like to learn with X at home	4.30	**4.70**
I would like to learn with X in the classroom	4.85	**4.90**

Limitations and Future Work. This study represents a first attempt to evaluate and discuss the potential of VR as a tool for strengthening important factors influencing learning processes in CSE. There are a number of limitations that have to be considered in future studies: The number of participants for this experiment was small but gave first impressions for directions of VR for CSE. There was an age gap of 17 years between the youngest and oldest participants. It is challenging to compare teenagers in high school with Ph.D. graduates from university. There were some VR experts but also novices among the participants. An ideal study would test those groups separately. We used only one learning scenario from the field of CS (sorting algorithms). There was no measure of the learning retention rate. This can be a crucial point for future studies as highly engaged learners can still experience cognitive overload and get distracted from the core learning content. Additionally, gaining more insights into different forms of interaction strategies could be an interesting future research path. This first study's main focus was to explore the fundamental potential of VR environments as environments for the representation of computer science concepts concerning the subjective factors engagement and emotion influencing learning processes. While it was not the purpose of this study to compare digital learning methods with traditional and nontraditional (such as the CS Unplugged activities) approaches to teach sorting algorithms in an analog way, such comparisons regarding learning, engagement, and emotional effects will be carried out in future research.

7 Conclusion

We designed a simulation of sorting algorithms in a web-based and in a VR-based environment to evaluate the potential of VR as a learning tool for CSE. In a first empirical study designed as an A/B-split test with 20 participants, we evaluated both environments focusing on engagement, emotions, and general learning experience. The VR application earned better scores for all assessed factors that are thought of as influences on learning activities. Additional qualitative feedback was used to identify different use cases for learning in VR. Participants found the VR experience more user-friendly, more natural to interact with, more fun, and better for visualizing concepts such as sorting algorithms. Teaching and learning in CSE is a complex interaction between objective and subjective factors, just like any other learning process. As times of online-teaching and -learning require new, virtual ways of re-thinking CSE, future research can benefit from integrating and investigating multiple relevant factors for teaching and learning rather than just focusing on learning outcomes.

References

[1] A. Akbulut, C. Catal, and B. Yıldız. On the effectiveness of virtual reality in the education of software engineering. *Computer Applications in Engineering Education*, 26(4):918–927, 2018.

[2] M. Alnoukari. Simulation for computer sciences education. *Communications of the ACS*, 6, 01 2013.

[3] T. Bell, J. Alexander, I. Freeman, and M. Grimley. Computer science unplugged: school students doing real computing without computers. *The New Zealand Journal of Applied Computing and Information Technology*, 13, 01 2009.

[4] T. Bell, F. Rosamond, and N. Casey. Computer science unplugged and related projects in math and computer science popularization. In M. R. Fellows and H. L. Bodlaender, eds., *The multivariate algorithmic revolution and beyond*, vol. 7370 of *Lecture notes in computer science, 0302-9743*, pp. 398–456. Springer, Heidelberg, 2012.

[5] M. Ben-Ari. Constructivism in computer science education. *SIGCSE Bull.*, 30(1):257–261, Mar. 1998.

[6] C. Berns, G. Chin, J. Savitz, J. Kiesling, and F. Martin. Myr: A web-based platform for teaching coding using vr. In *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, SIGCSE '19, pp. 77–83. ACM, New York, NY, USA, 2019.

[7] M. Chandramouli, M. Zahraee, and C. Winer. A fun-learning approach to programming: An adaptive virtual reality (vr) platform to teach programming to engineering students. *IEEE International Conference on Electro/Information Technology*, pp. 581–586, 2014.

[8] R. Crespo, R. García, and S. Quiroz. Virtual reality simulator for robotics learning. In *2015 International Conference on Interactive Collaborative and Blended Learning (ICBL)*, pp. 61–65, 12 2015.

[9] I. D. Curcio, A. Dipace, and A. Norlund. Virtual realities and education. *Research on Education and Media*, 8, 12 2016.

[10] B. Dalgarno and M. J. W. Lee. What are the learning affordances of 3-d virtual environments? *British Journal of Educational Technology*, 41(1):10–32, 2010.

[11] A. Dengel. How important is immersion for learning in computer science replugged games? In *Proceedings of the 51st ACM Technical Symposium on Computer Science Education*, p. 1165–1171. Association for Computing Machinery, New York, NY, USA, 2020.

[12] A. Dengel and J. Mägdefrau. Immersive learning explored: Subjective and objective factors influencing learning outcomes in immersive educational virtual environments. In M. J. W. Lee, ed., *Proceedings of 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, pp. 608–615. [IEEE], 2018.

[13] S. A. Fincher and A. V. Robins. *The Cambridge Handbook of Computing Education Research*. Cambridge Handbooks in Psychology. Cambridge University Press, 2019.

[14] C. M. Fox and J. H. Brockmyer. The development of the game engagement questionnaire: A measure of engagement in video game playing: Response to reviews. *Interacting with Computers*, 25(4):290–293, 7 2013.

[15] L. Freina and M. Ott. A literature review on immersive virtual reality in education: state of the art and perspectives. In *The international scientific conference elearning and software for education*, vol. 1, pp. 10–1007, 2015.

[16] S. Grissom, M. F. McNally, and T. Naps. Algorithm visualization in cs education: comparing levels of student engagement. In *Proceedings of the 2003 ACM symposium on Software visualization*, pp. 87–94, 2003.

[17] J. A. Hattie. *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. New York : Routledge, London, 2008.

[18] O. Hazzan, T. Lapidot, and N. Ragonis. Guide to teaching computer science: an activity-based approach, 2014.

[19] G. Jin, M. Tu, T.-H. Kim, J. Heffron, and J. White. Game based cybersecurity training for high school students. In *Proceedings of the 49th ACM Technical Symposium on Computer Science Education*, SIGCSE '18, pp. 68–73. ACM, New York, NY, USA, 2018.

[20] R. Kay and S. Loverock. Assessing emotions related to learning new software: The computer emotion scale. *Computers in Human Behavior*, 24:1605–1623, 07 2008.

[21] C. Kumar. A new frontier: How can you profit from augmented and virtual reality?, 2017. [Online; accessed August 23, 2019].

[22] K. C. Madathil, K. Frady, R. S. Hartley, J. W. Bertrand, M. Alfred, and A. K. Gramopadhye. An empirical study investigating the effectiveness of integrating virtual reality-based case studies into an online asynchronous learning environment. *Computers in Education*, 8, 09 2017.

[23] G. Makransky, T. S. Terkildsen, and R. E. Mayer. Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*, 60:225–236, 2019.

[24] E. Navarro and A. van der Hoek. Simse: An interactive simulation game for software engineering education. pp. 12–17. CATE, 01 2004.

[25] E. O. Navarro and A. v. d. Hoek. Comprehensive evaluation of an educational software engineering simulation environment. In *Proceedings of the 20th Conference on Software Engineering Education & Training*, CSEET '07, pp. 195–202. IEEE Computer Society, 2007.

[26] M. M. North, J. Sessum, and A. Zakalev. Immersive visualization tool for pedagogical practices of computer science concepts: A pilot study. *J. Comput. Sci. Coll.*, 19(3):207–215, Jan. 2004.

[27] R. Pekrun. A social-cognitive, control-value theory of achievement emotions. In *Motivational Psychology of Human Development - Developing Motivation and Motivating Development*, vol. 131 of *Advances in Psychology*, pp. 143–163. Elsevier, 2000.

[28] J. Pirker, A. Dengel, M. Holly, and S. Safikhani. Virtual reality in computer science education: A systematic review. In *26th ACM Symposium on Virtual Reality Software and Technology*, 2020.

[29] J. Pirker, I. Lesjak, and C. Gütl. An educational physics laboratory in mobile versus room scale virtual reality-a comparative study. *International Journal of Online Engineering*, 13(8), 2017.

[30] C. Sarabando, J. Cravino, and A. Soares. Contribution of a computer simulation to students' learning of the physics concepts of weight and mass. *Procedia Technology*, 13:112–121, 12 2014.

[31] A. Schwill. *Computer science education based on fundamental ideas*, pp. 285–291. Springer US, Boston, MA, 1997.

[32] T. J. Shuell. Teaching and learning in the classroom. In *International Encyclopedia of the Social & Behavioral Sciences*, pp. 15468–15472. Elsevier, 2001.

[33] T. Tanielu, R. Akauola, E. Varoy, and N. Giacaman. Combining analogies and virtual reality for active and visual object-oriented programming. In *Proceedings of the ACM Conference on Global Computing Education*, CompEd '19, 2019.

[34] M. Webb. Affordances of ict in science learning: Implications for an integrated pedagogy. *International Journal of Science Education - INT J SCI EDUC*, 27:705–735, 05 2005.

[35] J. Wing. Computational thinking. *Communications of the ACM*, 49:33–35, 03 2006.

[36] M. Wolff and L. Wills. Satsim: A superscalar architecture trace simulator using interactive animation. In *Proceedings of the 2000 Workshop on Computer Architecture Education*, p. 6–es. ACM, 2000.

[37] C. Zapponi. Sorting, an attempt to visualize and help to understand

how some of the most famous sorting algorithms work, 2014. [Online; accessed August 23, 2019].