11th International Conference of the Immersive Learning Research Network
Selected Academic papers for the iLRN Proceedings

DOI: https://doi.org/10.56198/508qgt70

Extended Abstract—Immersive Education: Utilizing the Potential of Immersive Technologies in Computer Science Higher Education

Andrea Horvath[1] and René Goldschmid[1]

[1] FH Campus Wien University of Applied Sciences, Vienna, Austria
andrea.horvath@fh-campuswien.ac.at
rene.goldschmid@fh-campuswien.ac.at

Abstract. The continuous and rapid evolution of immersive technologies, including Augmented Reality (AR) and Virtual Reality (VR), has introduced new possibilities for enhancing computer science education. This extended abstract explores the integration of immersive technologies, with a particular focus on AR and VR in computer science degree programs. By reviewing existing studies and presenting case studies from our bachelor's program, the extended abstract demonstrates how VR and AR bridge the gap between theory and practice, enhancing motivation, engagement, and comprehension through hands-on, interactive learning experiences. It discusses how VR and AR can help visualize complex concepts and allow students to apply theoretical knowledge in controlled, immersive environments that replicate real-world scenarios. The study identifies key benefits of immersive learning, such as improved spatial reasoning, critical thinking, and practical skill application, which are crucial for developing competencies in fields like artificial intelligence, IT security, software development, and digital communications. However, the integration of these technologies is not without challenges; high implementation costs, technical demands, and faculty training requirements present obstacles that institutions must address to ensure their effective use. Ultimately, the findings support a broader adoption of immersive technologies to foster an engaging and effective learning environment that aligns with the evolving demands of modern computer science education.

Keywords: Immersive Learning, Augmented Reality, Virtual Reality, Computer Science, Higher Education.

1 Introduction

Augmented Reality (AR) and Virtual Reality (VR) technologies are transforming educational landscapes by providing immersive and interactive environments that enhance engagement and have been shown to improve learning outcomes. AR overlays digital elements onto the real world, while VR immerses users in a completely simulated environment. These experiences enable students to explore complex concepts in a hands-on manner. Research shows that immersive technologies help improve motivation, emotional engagement, and comprehension, particularly in STEM fields, as these technologies allow students to interact with content, and learn concepts that may be difficult to understand otherwise [1-3].

Especially in computer science education, it is important for students to not only learn about new technologies but also utilize them. AR and VR offer unique tools to facilitate this and increase student engagement. VR allows students to explore simulated environments, visualize algorithms, data structures, and the programming process [1]. Similarly, AR is increasingly applied in computer science courses. This integration fosters engagement and motivation by turning traditionally challenging topics, such as cybersecurity and artificial intelligence, into interactive, hands-on experiences. Furthermore, evidence from educational studies suggests that these immersive and interactive methods encourage critical thinking, collaborative learning, and the development of problem-solving skills among students [2].

Building on findings from different studies on AR and VR in computer science education, the following sections explore how these technologies can be adapted and implemented within the curricula of our bachelor's

program "Computer Science and Digital Communications" (CSDC). By examining effective uses of AR and VR in external case studies, we aim to identify best practices that can enhance student engagement, learning outcomes, and skill acquisition in computer science courses at our institution.

2 Case Studies: Immersive Technologies in Action

In this section, we provide examples of how we either already introduced or plan to use immersive technologies in computer science courses at the FH Campus Wien University of Applied Sciences.

2.1 IT Concepts

One of the core modules of the first semester in our bachelor's degree program is "Computer Science Fundamentals" consisting of the lectures "Operating Systems" and "IT Concepts". While the former teaches basic concepts of operating systems including practical applications using Linux, the latter employs a bottom-up approach, starting with bits, bytes and Boolean algebra with the goal of unraveling the complexities of digital technology, state machines, and computer architectures.

As complex theories and hardware interactions might be difficult to grasp from books and lectures alone, immersive technologies like VR and AR could enhance student comprehension by bridging the gap between theory and practice. As a first approach, existing practical exercises, like the exploration of computer hardware components or the construction of virtual microprocessors, could be extended to VR- or AR-based simulations for expanding (hands-on) immersion and improving deeper engagement on the part of the students.

Heba Fasihuddin from the University of Jeddah implemented a prototype for providing an interactive virtual learning environment for teaching/learning computer hardware, based on the use of a VR headset. While such an application can be a cost-effective and manageable way to keep the learning materials up to date, participants of the study found the system satisfactory, useful, and easy to use. However, the initial acquisition and/or implementation of the needed hard- and software might be costly [4].

Not only virtual- but also augmented reality could be used in teaching IT concepts. In their study "Computer hardware course application through augmented reality and QR code integration: achievement levels and views of students", E. Bala and H. Bicen could provide evidence that the integration of AR with QR codes significantly enhances learning achievements in computer hardware courses. Additionally, students in the experimental group believed that the integration makes the process more location- and time-independent [5].

With today's price and short release cycles of new technology, modeling everything for a virtual environment can be a cost-effective alternative. Aside from the initial implementation effort, bringing our practical exercises into an immersive learning environment, using either virtual- or augmented reality, would not only improve our students learning experience, but also allow them to work with up-to-date virtual resources without exceeding our budget.

2.2 Mathematics

In the first and second semester of our bachelor's degree program CSDC mathematics is a fundamental subject. Students acquire foundational knowledge in arithmetic, discrete mathematics, algebra, calculus, number theory, graph theory, probability, and algorithms. Traditionally, abstract concepts such as graph theory or calculus can often be challenging for students when only using static and two-dimensional representations. Immersive technologies like AR and VR offer the potential to transform teaching complex mathematical concepts by adding interactive and multidimensional ways to visualize these concepts. Several studies have found that AR and VR can significantly improve students' spatial reasoning and conceptual understanding of mathematical topics [6-7].

A possible and easy way to incorporate immersive technologies within the mathematics lectures is to utilize existing applications. The Software GeoGebra [8] offers different AR examples for algebra and calculus as well as examples for spatial visualization of graphs and three-dimensional geometrical bodies. Using GeoGebra during classroom activities can provide interactive and real-time visualizations of abstract mathematical concepts. Students could, for example, manipulate algebraic equations and instantly observe the effects on corresponding graphs, or explore geometric transformations in three dimensions. It has been shown that this interactive, hands-on approach enhances comprehension and active learning. Since GeoGebra is accessible through web and mobile platforms, it is a cost-effective and scalable solution [9].

Another way to incorporate it would be to design and develop a solution specifically tailored for the current lecture structure and curricula. Important points to keep in mind when developing such a solution are usability and availability. If using AR, students could use their own mobile phones to access the app or web application,

making it easily available for everyone especially in higher education courses. In terms of usability, it might be necessary to use at least a part of the lecture to familiarize students and professors with the application and allocate time for everyone to ask questions and receive an onboarding session for the application. Some previous studies have shown that students tend to find new apps difficult to use at the beginning, highlighting the importance of adequate design. Notwithstanding, studies over the last few years have shown that students using immersive technologies perform better than students using traditional books and learning materials. Most students liked the experience and stated that it helped them understand some concepts better. Most studies, especially in the field of mathematics, used AR instead of VR. This might be due to availability and costs, since an AR application can easily run on most mobile phones or tablets, which students often have available. For a VR application, students would need a VR headset, which requires a larger investment. Easily available AR applications that work on the students' mobile phones can also be used outside of the lecture and help students learn at home, easing learning and self-learning [7].

2.3 Digital Communications

In the first semester of our study program, we have a strong emphasis on learning the basics of computer science. The lecture “Digital Communications” is fundamental for understanding the essential role of networks in communication and computing, providing the necessary knowledge for further lectures like “Networking Applications”, “Internet of Things”, and “IT Security Fundamentals”. In the first semester, the lecture focuses on the lower layers of the ISO/OSI model: the physical, data link, and network layer, providing students with basic knowledge about how protocols operate across the various layers and how to apply them.

In the field of Digital Communications, signals and network operations are key to understanding the fundamentals. Both concepts are often difficult to understand without proper visual representation. A great example of using AR in this context is an application developed by Drexel University, which allows students to observe wireless network behaviors in real time. Through mobile devices, students can visualize wireless links, antenna radiation patterns, and data throughput, offering an intuitive understanding of how communication systems operate. This approach has shown to significantly enhance student engagement and comprehension by making abstract wireless communication processes more tangible [10].

Hands-on lab exercises are an important part of the Digital Communications lecture, where students learn how to configure network switches and routers to build a small network. Until recently, those exercises were conducted in an on-campus networking laboratory. However, with growing student enrollment, the campus infrastructure can no longer accommodate the increased demand, rendering it essential to shift to a digital and remote format. To address this challenge, we propose transitioning to a virtual environment that incorporates gamified elements into the exercise. As part of an ongoing research project, we are developing a VR application to facilitate these lab activities in a fully immersive and interactive format. In this virtual setting, students will engage in exercises focused on building and configuring a company network with a strong emphasis on network switches and routers. The VR experience will transition from the current online setting, which uses Cisco Packet Tracer [11], to a story and level-based game, designed to improve engagement and retention. The VR application’s structure follows a progressive narrative: the user starts as a student in a virtual representation of the networking lab, where they practice cabling and configuring a basic network switch. As they progress through further levels, they work for a small startup that expands throughout the levels, necessitating the creation and expansion of a company network using VLANs, routing protocols, and other advanced configurations. As this research project is ongoing, findings and assessments of the VR application’s effectiveness will be presented in future work.

2.4 Internet of Things

In the third semester the module “Secure Applications” is introduced in the curriculum. This module includes the two lectures “Internet of Things” (IoT) and “IT Security Fundamentals”. IoT describes physical devices that are connected via digital networks like the Internet. Besides a cost-efficient and easy connection of those devices, the development of digital Services to utilize the devices is an important goal of IoT. In the lecture, students learn about IoT network architecture and design, smart objects, different protocols, and data analytics, which are important for IoT Applications.

Besides theoretical input through lectures, students learn how to build their own IoT devices and systems through a project within the lecture. In interactive exercises, students learn the basics of IoT devices and get to build their own using different sensors and Arduino [12] or Raspberry Pi [13] boards. Those boards are often expensive and need to be handled carefully. The boards need constant maintenance, components are added by students during the lecture and then taken off again by the instructors. Especially during the first few exercises,

students often experience hesitation when it comes to working with the hardware, as they are afraid of damaging the small components. Shifting the first few exercises in a virtual environment, like the one proposed for “Digital Communications”, could help students overcome those hesitations. It would significantly reduce maintenance costs and time as students would practice on virtual replicas of the board.

Currently most applications on the market that utilize AR or VR in the context of IoT focus on industrial use cases. Like showcasing digital twins or showing the connection between devices with AR [14-15].

In the context of education, those applications do not offer significant added value. Though possible applications in the context of education could be an AR application that helps students understand the purpose of different sensors and how to connect them to a board. Another possible application would be a VR environment to learn how to program and use different IoT devices. One such application was introduced by Zhu et al with “LearnIoTVR”. In this VR application, students get to build different IoT Applications in a virtual environment. The study showed that most participants enjoyed the virtual learning experience, stating that they could freely modify program and environment parameters while directly experiencing the outcome. The participants in the study stated that this environment deepened their understanding of IoT. Zhu et al propose the virtual learning tool as “a supplement for traditional physical learning media” and not as a replacement. It offers the possibility of making learning IoT more accessible and flexible, since students can easily simulate and change different values within the simulation [16].

2.5 IT Security Fundamentals

In the lecture “IT Security Fundamentals”, students get a comprehensive overview of both the technological and organizational aspects of IT-Security. It covers essential topics such as security objectives, symmetric and asymmetric cryptography, and foundational knowledge on firewalls, intrusion detection, as well as prevention systems. Additionally, there is a strong emphasis on security awareness.

It is often challenging to provide students with practical, real-world experiences in a classroom setting. VR and AR can help with this challenge by offering an immersive and risk-free environment. It is, for example, possible to simulate complex operations of a Security Operations Center in VR. In this setting, a student can perform tasks like intrusion detection, threat analysis, and incident response in a controlled but still realistic setting. Hands-on approaches like this can significantly improve the student’s comprehension of cybersecurity threats and how to counteract them [17].

Another notable example of using VR to teach IT security concepts is the CiSE-Pros VR environment developed by Texas A & M University. The system allows students to perform tasks such as physical access control, hardware security and incident response in a virtual data center. In this interactive environment, students can learn theoretical security principles and implement them in a realistic scenario [18]. Immersive experiences offer a lot of benefits especially for developing critical thinking and problem-solving skills that are necessary for IT Security.

Studies have shown that VR enhances students’ engagement and retention of cybersecurity knowledge. Through interactions, students can experiment with different security measures and receive immediate feedback. They can learn the consequences of their actions in a virtual environment without any risks. This active learning process has shown an increase in motivation of the students and better long-term retention of information [18].

Incorporating immersive technologies in the IT Security Fundamentals course would provide a more engaging and effective learning experience for students.

2.6 Introduction to AI and Data Science

In "Introduction to AI and Data Science", another lecture of the CSDC study program, students of the third semester are provided with essential mathematical and conceptual foundations of artificial intelligence (AI) and data science. Beginning with core mathematical areas such as linear algebra, probability theory, and statistics, introducing key mechanics behind AI and machine learning algorithms. Building upon that, students are introduced to fundamental AI principles, including problem-solving techniques, heuristic search, and decision-making under uncertainty. Ultimately, the course shifts over to data science, where students explore the process of collecting, cleaning, and filtering data, as well as building and evaluating machine learning models. When our students are confronted with Convolutional Neural Networks (CNNs) for the first time during lab exercises, they often feel overwhelmed by the complex nature and math behind them. Unfortunately, our approach, letting the students apply a CNN as a practical example, occasionally leads to confusion and a lot of questions in the forums. We could improve their understanding by incorporating visualization techniques for CNNs, using resources available on the web, like CNN Explainer [19].

This brings forth the idea of further improving the student's motivation and understanding by visualizing CNNs using immersive learning environments. In "Using Visualization of Convolutional Neural Networks in Virtual Reality for Machine Learning Newcomers", N. Meissler et al. explored, as the title suggests, the possibilities of using VR to visualize the structure and functionality of CNNs. Their exploratory study with a group of 14 participants led to the conclusion that the learning experience was well received overall and warrants further improvement and investigation [20].

For the "Introduction to AI and Data Science" lecture, we discovered the topic's complexity was one of the main concerns of our students at the beginning of the course, leading to a lack of motivation. The integration of immersive learning environments for visualizing structures and algorithms, especially in the introductory phase of each topic, could be a valuable addition to this course.

3 Discussion

In this study, we explored the possibilities of incorporating immersive technologies, such as VR and AR, within the curricula of the Computer Science and Digital Communications study program. The integration of immersive learning environments across different courses, from foundational IT concepts to specialized topics like the Internet of Things, demonstrates the potential to enhance both student engagement and academic performance. Our findings emphasize the various benefits of immersive technologies in areas like spatial reasoning, interactive learning, and the transition of theoretical concepts to practical applications.

Courses like "IT Security Fundamentals" and "Digital Communications" heavily rely on the simulation of real-world scenarios, often restricted by limited physical resources and the complex nature of their setups. A recurring approach in the case studies presented in this paper is the use of immersive environments to reduce the need for physical setups and abstract complex concepts. This aligns with research findings that show the use of immersive technologies enhances conceptual understanding, as well as student engagement and motivation, which helps in tackling subjects like network protocols or machine learning algorithms. Using AR and VR technology allows students to experience practical exercises in a more immersive way, letting them deeply engage with the course content. In courses like "Introduction to AI and Data Science", we can make use of those findings to, for example, flatten the learning curve of complex concepts like Convolutional Neural Networks, mitigating barriers and finally improving the overall learning experience of our students.

The study also highlights key challenges, which mostly involve the technical requirements and cost of integrating immersive learning environments into academic programs. Acquiring hardware like VR headsets and developing new software can be costly and time-consuming, creating barriers for institutions with limited budgets.

4 Conclusion and Future Research

This extended abstract explored the integration of immersive technologies in computer science at higher education level. The presented case studies demonstrate how VR and AR environments can improve accessibility of complex concepts by bridging the gap between theory and practice. The findings of this study suggest that immersive technologies can enhance the learning experience, student engagement, and skill development.

However, the integration of an immersive learning environment into higher education computer science courses poses a few challenges, despite the aforementioned advantages, mostly related to initial cost and time investment. Future investigations should focus on developing immersive applications in a reusable and cost-effective way. A relevant example of such research is currently in development at our institution for the "Digital Communications" network laboratory exercises, where students practice network configuration tasks in a VR-based lab environment. As this project progresses, it will provide new data and insights on the effectiveness of immersive technologies in supporting the student's skill development and engagement, potentially enabling the integration of similar VR-based applications in the various other fields of computer science education.

Future research could also analyze the broader impacts of using immersive learning environments on academic outcomes and job readiness, so institutions can fully utilize the potential of immersive education, contributing to a dynamic and motivating learning environment for students of computer science.

Acknowledgements

We want to express our sincere gratitude to the FH Campus Wien, University of Applied Sciences, for providing us with the essential resources, such as time, and equipment, to conduct this research.

References

1. Pirker, J., Kopf, J., Kainz, A., Dengel, A., Buchbauer, B.: The potential of virtual reality for computer science education—engaging students through immersive visualizations. In: 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), pp. 297–302. IEEE (2021).
2. Lampropoulos, G., Keramopoulos, E., Diamantaras, K., Evangelidis, G.: Integrating augmented reality, gamification, and serious games in computer science education. Computers in Human Behavior 13(6), 618.
3. Resnyansky, D., İbili, E., Billinghurst, M.: The potential of augmented reality for computer science education. In: IEEE Conference Proceedings, pp. 350–356.
4. Fasihuddin, H.: Virtual reality technology in teaching computer hardware: A prototype and assessment from user perspectives. TEM Journal 12(2), 899–907 (2023).
5. Bal, E., Bicen, H.: Computer hardware course application through augmented reality and QR code integration: Achievement levels and views of students. Procedia Computer Science 102, 267–272 (2016).
6. Coimbra, M.T., Cardoso, T., Mateus, A.: Augmented reality: An enhancer for higher education students in math's learning? Procedia Computer Science 67, 332–339.
7. Buentello-Montoya, D., Lomelí-Plascencia, M., Medina-Herrera, L.: The role of reality-enhancing technologies in teaching and learning of mathematics. Computers & Education 94, 107287.
8. GeoGebra GmbH.: GeoGebra. https://www.geogebra.org, last accessed 2025/02/25.
9. Iparraguirre-Villanueva, O., Paulino-Moreno, C., Chero-Valdivieso, H., Espinola-Linares, K., Cabanillas-Carbonell, M.: Integration of GeoGebra Calculator 3D with augmented reality in mathematics education for an immersive learning experience. International Journal of Engineering Pedagogy (iJEP) 14(3), 92–107 (2024).
10. Sahin, C., Nguyen, D., Begashaw, S., Katz, B., Chacko, J., Henderson, L., Stanford, J., Dandekar, K.R.: Wireless communications engineering education via augmented reality. In: 2016 IEEE Frontiers in Education Conference (FIE), pp. 1–X. IEEE (2016).
11. Cisco.: Cisco packet tracer. https://www.netacad.com/cisco-packet-tracer, last accessed 2025/02/25.
12. Arduino.: Arduino. https://www.arduino.cc, last accessed 2025/02/25.
13. Raspberry Pi Foundation.: Raspberry Pi. https://www.raspberrypi.com, last accessed 2025/02/25.
14. Subramania, J.: Experience robots, flying objects, and shooting stars in virtual reality. Tech Insights.
15. Chansanchai, A.: Quicker fixes, hands-free, when Thyssenkrupp elevator's service technicians use Microsoft HoloLens. Microsoft Blog.
16. Zhu, Z., Liu, Z., Zhang, Y., Zhu, L., Huang, J., Villanueva, A.M., Qian, X., Peppler, K., Ramani, K.: LearnIoTVR: An end-to-end virtual reality environment providing authentic learning experiences for internet of things. In: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, pp. 1–17. ACM (2023).
17. Wagner, P., Alharthi, D.: Leveraging VR/AR/MR/XR technologies to improve cybersecurity education, training, and operations. Cybersecurity Research 2024(1) (2024).
18. Seo, J.H., Bruner, M., Payne, A., Gober, N., McMullen, D.R., Chakravorty, D.K.: Using virtual reality to enforce principles of cybersecurity. Cybersecurity Journal 10(1), 81–87.
19. POLO Club.: CNN Explainer. https://poloclub.github.io/cnn-explainer/, last accessed 2025/02/25.
20. Meissler, N., Wohlan, A., Hochgeschwender, N., Schreiber, A.: Using visualization of convolutional neural networks in virtual reality for machine learning newcomers. In: 2019 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR), pp. 152–1526. IEEE (2019).