An Overview of Teaching a Virtual and Augmented Reality Course at Postgraduate Level for Ten Years

Bernardo Marques[1] and Beatriz Sousa Santos[1] and Paulo Dias[1]

[1]IEETA, DETI, LASI, University of Aveiro, Aveiro, Portugal

Abstract

In recent years, a multitude of affordable sensors, interaction devices, and displays have entered the market, facilitating the adoption of Virtual and Augmented Reality (VR/AR) in various areas of application. However, the development of such applications demands a solid grasp of the field and specific technical proficiency often missing from existing Computer Science and Engineering education programs. This work describes a post-graduate-level course being taught for the last ten years to several Master's Degree programs, aiming to introduce students to the fundamental principles, methods, and tools of VR/AR. The course's main objective is to equip students with the necessary knowledge to comprehend, create, implement, and assess applications using these technologies. This paper provides insights into the course structure, the key topics covered, assessment, as well as the devices, and infrastructure utilized. It also includes a brief overview of various sample practical projects, along the years. Among other reflections, we argue that teaching this course is challenging due to the fast evolution of the field making updating paramount. This maybe alleviated by motivating students to a research oriented approach, encouraging them to bring their own projects and challenges (e.g. related to their Master dissertations). Finally, future perspectives are outlined.

CCS Concepts

• ***Human-centered computing*** → ***Mixed / augmented reality; Virtual reality; Interactive systems and tools;*** • ***Computing methodologies*** → ***Computer graphics;*** • ***Applied computing*** → ***Education;***

1. Introduction

In recent years, Virtual and Augmented Reality (VR/AR) have emerged as transformative technologies with an ever-expanding range of applications. Enhancing training and education, as well as entertainment experiences, optimizing industrial processes, improving healthcare diagnostics and treatment, and revolutionizing marketing strategies, are some of the many applications in which VR and AR may have a significant impact. [SHN19].

One of the main causes of this revolution is its newfound accessibility, thanks to the appearance of affordable devices with substantial computing capacity and a large array of sensors, as well as the emergence of new engines and frameworks, together with content creation tools, have made VR/AR more affordable than ever before [Zar06, HVV21, NJD19]. This has caused not only a democratized access to VR/AR technologies, but also paved the way for a rapid proliferation of these immersive technologies, propelling them into the mainstream. As these technologies advance, their further integration into human daily lives, work environments, among others, can be anticipated. [SDM15, HVV21, Lam16].

However, despite the widespread recognition of VR and AR potential, there is a notable gap in the knowledge and technical skills required to develop applications in these domains. Acquiring the necessary skills to become experienced in this field is a hard undertaking if not guided properly. The complexities of developing immersive and interactive VR/AR applications, the evolving technology landscape, and the rapid pace of innovation contribute to this endeavor; it is a highly interdisciplinary field, and mastering it is no small feat. Regardless, VR/AR remains absent in many Computer Science and Engineering programs. While VR and AR courses are emerging as integral components of modern Computer Graphics education, the specialized skills essential for crafting immersive, real-world applications often remain under-emphasized.

Thus, introductory courses, either in traditional or in more modern formats, are of vital importance. In a field that is continuously evolving and holds immense potential for transforming various industries, nurturing the next generation of VR/AR developers through introductory courses is essential. These courses are the catalyst for innovation and excellence, ensuring that the gap in knowledge and skills is gradually closed, and that the world of VR and AR becomes more accessible to aspiring creators, designers and developers [Cli08, SD17, DH22, HHO13].

This paper describes the main features of an elective course on VR/AR attended by almost two hundred students of distinct Master's Degree programs at the University of over the past ten years. The rest of the paper is organized as follows: section 2 presents the course organization and goals, topics addressed, tools and frame-

DOI: 10.2312/eged.20241000

works, examples of practical assignments, as well as the supporting infrastructure; section 3 includes a reflection on the lessons learned, as well as set of further steps moving forward; last, section 4 draws concluding remarks.

2. Virtual and Augmented Reality Course

Next, the course goals and organization, topics addressed and assessment, as well as the supporting infrastructure, tools/frameworks used by the students, and a sample of practical assignments are briefly presented.

2.1. Objectives and Organization

The Virtual and Augmented Reality course aims at introducing students to the field of Virtual and (VR) and Augmented Reality (AR). Its main objectives consist of giving an overview of the main issues and application areas, as well as a historical perspective of the field, introducing basic concepts, methods, and tools needed to design, implement, and evaluate this type of systems and applications; moreover, it should foster the ability to read and evaluate scientific literature, convey research results to an audience, as well as strengthen teamwork skills.

The course was taught for the first time in 2013/14 as an elective option to Master students in informatics, computer and telematics, as well as electrical and telecommunications engineering; however, it is now offered to a wider range of audiences, namely also Master students in industrial automation engineering, computational engineering, biomedical engineering, digital game development, as well as robotics and intelligent systems. In the latest years, it has become one the most popular elective courses at the Master level in our department, which made us increase the number of students from 16 to 22, making the course management more complex, e.g. regarding equipment and schedule. The students attending the course (almost two hundred over ten years) may have different backgrounds and programming skills. As such, some homogenization is needed during the semester, namely concerning interaction fundamentals, as well as graphics programming libraries, which are new to some of the students and a recapitulation to others; to help this homogenization some materials are provided for self-learning.

The course is organized into 14 three-hour weekly sessions, each one comprising a lecture, a paper presentation by a group of students, and a lab class. Over the years, the syllabus has been evolving, namely, the emphasis has shifted from Virtual Environment (VE) modeling and rendering aspects to the system and application design, a change motivated by the evolution of the field, as well as the technology available. As such, new subjects, and examples were introduced to accompany new trends and topics of interest, resulting in the following topics addressed in the lectures:

- Introduction to the course, assessment, and bibliography;
- Introduction to VR, AR and other types of realities;
- Human-Centered Design for VR/AR;
- Human Factors in VR/AR;
- Interaction in VR/AR;
- Input and Output Devices;
- Guidelines for VR/AR applications;
- Evaluation in VR/AR.

Some sessions also include talks by practitioners and/or researchers (including some alumni), giving students a glimpse into the real-world impact of these technologies.

Currently, the main bibliography consists of four books [Jer15, LaV17,LKM*17,HHO13,SH16]. Slides and other materials to support all sessions are provided at the University e-learning platform, as well as at a course web page.

Students, usually in groups of two, must select a recent paper from renowned conferences or journals (e.g., IEEE VR, IEEE ISMAR, ACM VRST, ACM SUI, ACM CHI, Eurographics, TVCG, Computers & Graphics, Computer Graphics Forum, Computers in Industry, Virtual Reality, International Journal of Human-Computer Studies, among others), as well as present and discuss their choice in class. These presentations ensure that students have access to cutting-edge research work since they have to select and propose the paper they are interested in reading and presenting to the class. These papers may be aligned with their Master's Dissertation, their practical projects, or their personal preferences. Besides the paper presentation and the practical assignment, assessment also includes a test, which in our view is an important component of an assessment strategy, as it motivates students to engage with the material, better understand important concepts, and principles, while promoting critical thinking, and providing a more objective measure of individual performance.

As for the practical assignment, the students, usually in groups of two, perform a mini-project consisting in developing a VR/AR application using a Human-centered approach. The lab classes are used by students to work on their projects, present and discuss their ideas and get the help they need to overcome difficulties. During the first third of the semester students focus on proposing or selecting a project from a list and perform its conceptualization. This includes presenting and explaining to the class their vision of what the final application will be, and a list of main objectives; the approach used involves defining personas, scenarios, a set of illustrative storyboards as well as selecting the necessary hardware, identifying requirements and possible constraints. Based on this work and feedback provided at the first presentation, a low fidelity prototype is developed, tested by other students and used to obtain user feedback and make some improvements. As for the rest of the semester, students must develop their application which could involve finding all necessary 3D models, or create their own (e.g., using Blender), as well as build Virtual Environments (VEs), integrate animations, sound, video, etc. Likewise, navigation/manipulation must be ensured according to distinct interaction paradigms based on the selected project. Most students opt to use Unity that is introduced in the course, although other engines may be used such as Godot or WebXR. Students must integrate all necessary SDKs and libraries (e.g., Vuforia for AR deployment), and guarantee that the final version of the application is able to run in the intended device.

2.2. Infrastructure and facilities

To support the course, students have access to a laboratory equipped with some VR/AR state-of-the-art equipment, namely HTC VIVE, Oculus Quest 2, Microsoft HoloLens 2, several mobile devices, an interactive projector, various external cameras, support for network communication, as well as workstations supporting all existing hardware. This facility is open to students during a standard schedule, although, when possible, each group can borrow the equipment and take it home. In the beginning of the semester students visit the laboratory and become familiar with its types of equipment (see Figure 1), allowing students to experience several demos and take inspiration for their projects.

Figure 1: *Students experiencing various demos at the Lab.*

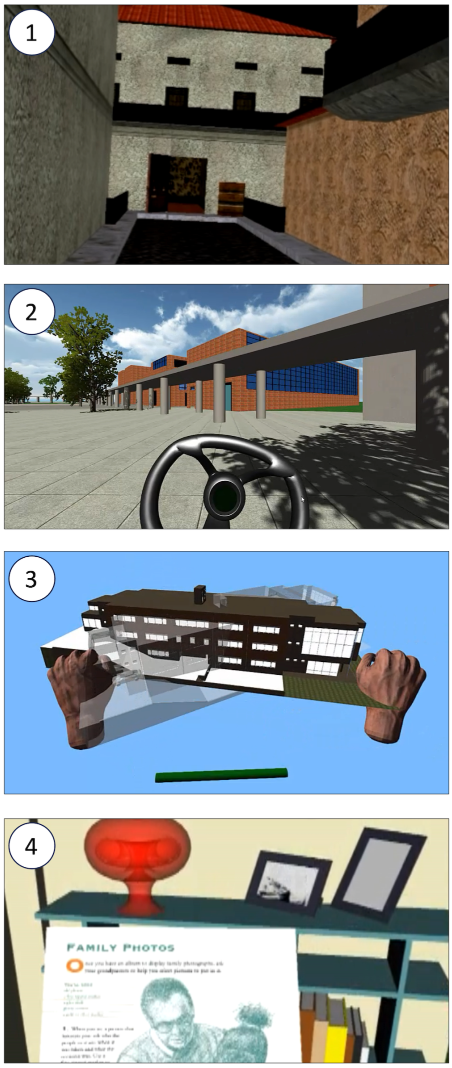

Figure 2: *Illustrative examples of initial projects developed in the course: 1- navigating in a virtual maze; 2- exploring a VE simulating our university campus; 3- manipulating a virtual representation of our building; 4- navigating a VE and visualizing additional information regarding selected objects .*

2.3. Practical Assignments Examples

Next, some examples are given, divided into 4 representative eras.

2.3.1. First prototypes

When the course started, technology was quite different. The available devices were: VR2000 Head-Mounted Display (HMD), Intersense Inertia 3 and Inertia Cube BT orientation sensor, Oculus Rift DK1 and DK2, Microsoft Kinect version 1 and 2, Razer Hydra, Leap Motion, Nintendo Wiimote, Phantom Haptic Interface, Google Cardboard, and several mobile devices. Back then, the lab classes were divided into two main blocks. During the first half of the semester, students focused on 3D creation, visualization, and interaction with virtual worlds using VTK as the main graphics engine. During the other half, students needed to select an interaction technique, as well as the most adequate devices, and then analyze and integrate the devices to enhance the interaction with the VE.

Figure 2 shows representative examples focused on basic functions: navigation, interaction, and manipulation of objects in Virtual Environments (VE). Figure 2 - 1 presents a VR maze that could be visualized through the VR2000 HMD. Navigation was ensured by the use of the Wiimote. Users were placed in a random location and needed to find the way out. The maze was composed by distinct indoor/outdoor spaces (e.g., rooms, corridors, stairs, open spaces).

Figure 2 - 2 displays a virtual representation of our university campus, including several buildings, roads, representative trees, among other objects of interest. This was previewed using a large display, equipped with a Kinect V1, which provided support for gesture recognition, allowing to handle the navigation through the VE. This was one of the first works exploring hand gestures.

Figure 2 - 3 follows a similar approach (Large display + Kinect V1), although in this case, the goal was to use hand gestures to select and manipulate virtual objects. For example, adjust the size and pose of a virtual representation of a building, following the reference model displayed in a transparent mode.

Last, Figure 2 - 4 illustrates a VR 3D floor plan using the VR2000 HMD and the Razer Hydra for interaction purposes. The goal was to augment specific regions of interest with additional information (e.g., displaying images, videos or 3D models associated with a specific element of the room). This additional information was automatically triggered when pointing at an area of interest.

Although several interesting projects were developed, the use of CG APIs such as VTK that do not integrate any physical engine implied a lot of work leaving little time to focus on 3D interaction, a fundamental aspect. The resulting projects were often simple, which motivate the shift to Unity 3D as the engine was becoming more adopted by developers.

2.3.2. Introducing Unity

The introduction of Unity in the lab classes made the creation of VEs easier and quicker, allowing students to commit more time to other aspects of their projects and to pursue more complex projects. By the end of the semester, students were able to deliver richer, more complex and rewarding projects, better illustrating their ideas.

Figure 3 shows representative examples regarding phobias, cultural heritage, physical rehabilitation, and entertainment respectively. Figure 3 - 1 presents an AR serious game created to assist phobic individuals with their fear of spiders. The game, which could be experienced through a standard mobile device, had the goal to motivate the user to capture as many spiders as possible along multiple levels with increasing complexity. This work also explored multi-marker tracking, as well as detection of objects with different shapes taking advantage of the Vuforia library.

Figure 3 - 2 explored the usage of a smartphone as a controller in a Virtual environment replicating a Museum room. The smartphone could be used to navigate inside the environment and to access information about different virtual exhibits. The smartphone location was tracked by the camera and a leap motion stacked on the HMD was used to detect the user's hands allowing to display their avatar in different ways (realistic hands, transparent hands, no hands).

Figure 3 - 3 displays a VR serious game deployed using the Oculus Rift DK2 and a leap motion, with the goal of supporting stroke survivors with upper limb rehabilitation exercises. This work, which was conducted through a Human-Centered Design (HCD) approach with the collaboration of a multidisciplinary team from a rehabilitation center, focused on motivating users to perform specific gestures used in the therapy of stroke survivors.

Last, Figure 3 - 4 represents a VR adaptation of the Harry Potter chess game, deployed in the HTC VIVE headset and its controllers. While immersed, users where able to select a given chess piece and visualize the available moves. Additionally, all pieces had animations, triggered when a player conquered an opponent's piece. This work used 3D models identical to the ones used in the movie, as well as thematic sound to increase user engagement.

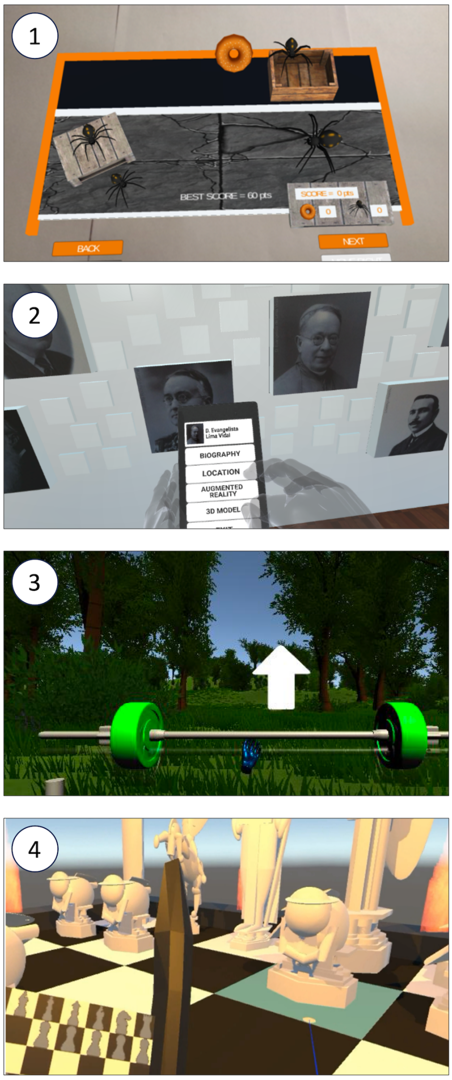

Figure 3: *Illustrative examples of practical projects after the introduction of Unity: 1- AR for spider phobia; 2- VR for cultural heritage at a museum; 3- VR serious game to support stroke survivors rehabilitation; 4- VR to recreate the Harry Potter chess game.*

2.3.3. During the Pandemic

The COVID-19 pandemic has had a significant impact on learning approaches worldwide and this course was no exception. There was a need to shift to remote learning environments. All parties had to adapt to virtual classrooms, which presented unique challenges for teaching and learning immersive technologies. Students were forced to adopt virtual collaboration tools, allowing them to work on projects together, even when physically distant. These tools facilitated teamwork and creative problem-solving. As for restrictions in accessing the hardware, we were lucky enough to have access to the Lab, although with restrictions, which allowed students to collect the necessary devices and take them home. This proved to be a good approach, given that later, a quarantine period was once again implemented. During this period, we also noticed an increase in AR projects, some of them even suggested by the students (in particular, students living in distant locations, which preferred to avoid unnecessary road-trips).

Figure 4 illustrates some representative examples, ranging from addressing phobias, cultural heritage, physical rehabilitation, and entertainment respectively. Figure 4 - 1 presents an AR game using standard mobile devices. Students explored the use of multiple markers through the Vuforia library, aimed to have a villain, i.e., the dragon, and multiple heroes that could have various roles and abilities (e.g., knights, a magicians, etc.). When multiple markers were combined, the skills of the heroes would increase, facilitating defeating the dragon. All characters had animations according to what was happening in the game. Plus, students used medieval sounds to increase the multi sensory experience.

Figure 4 - 2 presents an AR serious game for learning how to control a robotic wheelchair. The user was supposed to follow a miniature AR race car with the wheelchair through out a large space and avoid obstacles. This work explored the ARCore platform, which enabled the creation of this pervasive AR experience without the need for markers; it was developed in the scope of a research project, which allowed having access to target-users who helped with the conceptualization of the serious game developed. The student responsible started by conducting tests at home and, when possible, moved into the robotics laboratory where he attached a standard mobile device to the robotic wheelchair using an articulated support to the final development and user tests.

Figure 4 - 3 displays a VR puzzle. The VE had a large cube at the center of the space, and in each face, a distinct mini-game to be overcome (e.g., solve logic gates, listen to a radio and detect a pattern, use said pattern to open a safe, remove a screw drive from the safe and use it to open a hidden drawer, etc.). Each mini-game had an object of interest, which would affect another game. Users needed to successfully overcome all mini-games in the possible shortest time. This was the only exception, in which the student worked in the Lab given that the HTC VIVE infrastructure was all there and the student was unable to assemble it at at home; however, as he lived near the university, he was able to access the facilities.

Figure 4 - 4 showcases a VR rehabilitation version to the traditional 'Whac-a-mole' game. This was developed for stroke survivors upper limb rehabilitation. The user could play the game in two modes: grabbing the hammer with the affected hand to train movements directly as a rehabilitation exercise, or use the non affected hand to control the hammer while seeing the affected hand in VR. This mirror version was developed as it helps rehabilitation. The repetitive nature of the game made the users perform necessary therapeutic gestures in a more entertaining way. Despite the limitations of the pandemic, it was possible to conduct several virtual meetings with a physiatrist doctor from a rehabilitation center, as well as some stroke survivors, which guided the student during the design and development of this practical assignment.

Despite some challenges, all students submitted their practical assignments with positive results. The pandemic highlighted the potential for collaboration, and in a way, this was positive for students, given that they started to view new emerging platforms using VR/AR. The consequences of COVID-19 helped to accelerate innovation, adoption and adoption of VR/AR applications for various areas of application all over the world, and may have contributed to a better perception of the potential of immersive technologies.

2.3.4. Adopting real-life problems

Due to ongoing collaborations with the industry sector and other entities interested in transfer of knowledge, we have been also exploring projects based on real-life scenarios, which can have an impact on their intended target users.

Figure 5 illustrates some representative examples, ranging from addressing logistics, environmental awareness, education, and rehabilitation. Figure 5 - 1 displays the use of AR in a continuous manner for a logistic shop floor environment. Through the use of Microsoft HoloLens 2, human operators could be guided to the next picking location through a directional arrow, indicating the type and number of items that needed to be collected. All interaction with the virtual content was done using hand recognition. This allowed to validate how many times an operator passed their hands over a specific region of interest. This was conducted following an HCD methodology, in which the students had the opportunity to visit a factory and discuss with operators and other stakeholders.

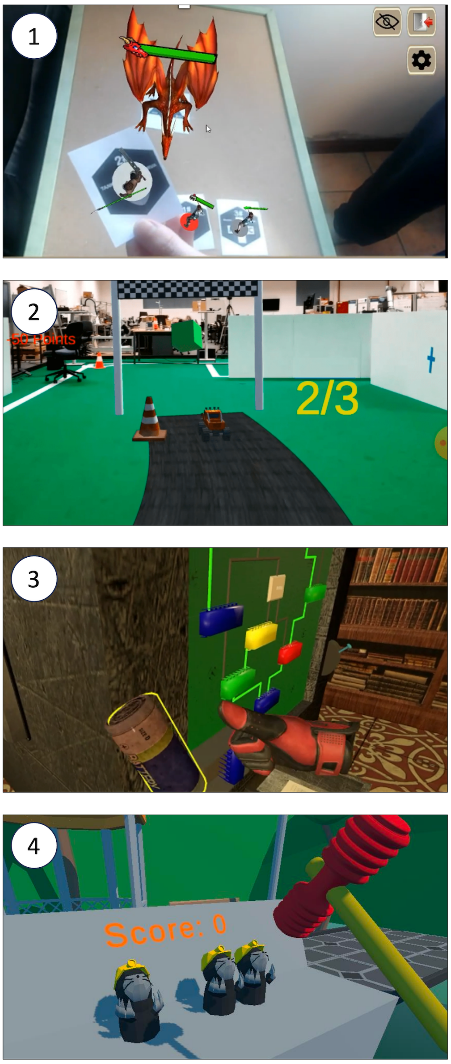

Figure 4: *Illustrative examples of practical projects created during the COVID-19 Pandemic: 1- AR to enhance a typical card game; 2- AR and a serious game to facilitate learning how to control a robotic wheelchair; 3- VR puzzle box; 4- VR and a serious game to support stroke survivors upper limb rehabilitation.*

Figure 5 - 2 illustrates a virtual representation of a real-life location, enhanced with air pollution data. The goal was to allow users to immerse in a VR experience (using a Oculus Quest 2) in which they could explore and have a better understanding of the levels of

Proceedings published by Eurographics - The European Association for Computer Graphics.

pollution in streets they usually walk by. As such, the pollution concentration data were represented using 3D glyphs. This collaboration with the Environmental department targeted visiting students at our university with the goal of increasing their awareness concerning this topic of interest, as well as encourage best practices.

Figure 5 - 3 presents a VR environment for Geosciences education. Students started by capturing real-life structures using a 3D reconstruction sensor (a Google Tango enable Lenovo device). Later, the resulting models could be exported to the VR application, and a teacher, using the Oculus Quest 2 headset and its controllers, could explain specific concepts, e.g. highlight specific areas of interest like fractures on a rock. Likewise, it was possible to leave notes to emphasise important information. The ultimate goal was to allow students to visit remote locations, and learn from realistic 3D models, instead of the traditional images and video materials. During their project, students had contact with distinct audiences of the Geosciences department at our university, to help guide their work.

Last, Figure 5 - 4 proposes the use of a VR supermarket for assisting stroke survivors rehabilitation. This work, which follows previous projects combines a serious game with a virtual setting in which users must move throughout the environment and grab selected products following a predefined list of products. As before, the device selected was the Oculust Quest 2, taking advantage of its hand-tracking recognition abilities for interaction and navigation. Once more, a HCD methodology was used, having the collaboration of a multidisciplinary team from a rehabilitation center.

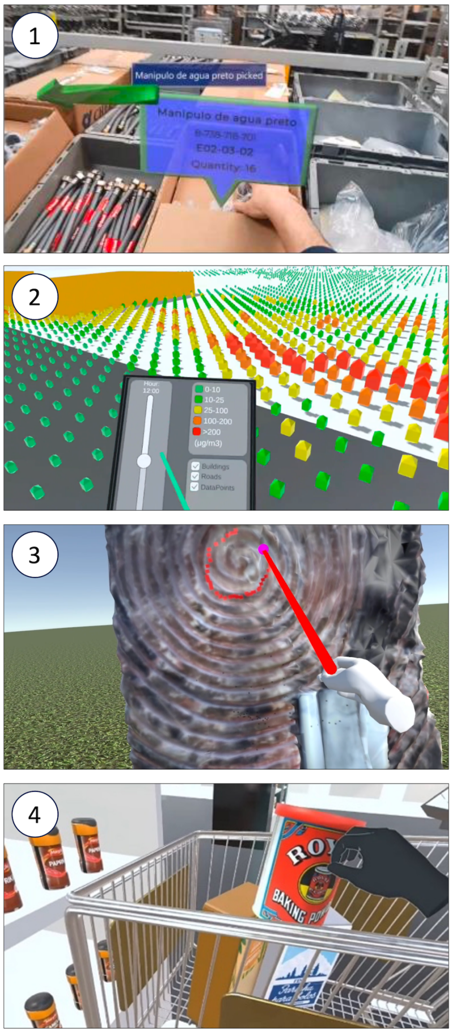

Figure 5: *Illustrative examples of practical projects based on real-life scenarios: 1- AR to support operators in logistics; 2- VR to raise air pollution awareness; 3- VR in teaching Geosciences; 4- VR and a serious game to support stroke survivors rehabilitation.*

3. Reflection and Future Perspective

This section presents some reflections on the course and lessons learned over the past ten years. We also outline the main challenges and draw ideas for the future.

3.1. Understanding the audience

One key aspect that has been confirmed over time, is the fact that understanding and catering to students' interests has been crucial. Students who are engaged tend to learn more effectively. They are more likely to absorb and retain information when they are enthusiastic about the subject. This is why all students can select their practical assignment from a predefined list of projects, or propose their own themes. We strongly believe that a deeper understanding of VR/AR technologies often comes from personal interest and exploration. When students are genuinely interested in the subject matter, they are more motivated to actively participate in class, complete assignments, and explore the topic further, i.e., experiment with novel ideas and push the boundaries of what can be achieved with immersive technologies. This enthusiasm can drive them to go beyond the basic requirements of the course.

Furthermore, recognizing students' interests allows to tailor assignments (both paper presentation and mini-projects) to align with what motivates them most. Encouraging students to further explore some topics based on their preferences can make the learning experience more enjoyable and relevant. Naturally, this comes with a price, requiring further preparation by the teaching team. Overall, recognizing and incorporating students' interests into a VR/AR course can lead to a more meaningful and enjoyable educational experience, equipping students with the skills and enthusiasm needed for successful careers spanning numerous industries.

3.2. Using a Human-Centered Design Methodology

Over time, as the focus of the practical assignments shifted towards more complex projects, as well as more often based on real cases, the adoption of an HCD methodology has become even more important. To contextualize, HCD prioritizes the needs, preferences, and experiences of users. Whenever the goal involves creating immersive and interactive experiences, understanding user needs is paramount for creating applications that are engaging, intuitive, and effective. This way, by designing with users in mind, it is possible to obtain better results from a user experience point-of-view and being capable of using this approach is a fundamental learning outcome of the course. This is especially important in VR/AR, where technology is evolving very rapidly.

In addition, HCD involves an iterative approach to design, and students are asked to evaluate their prototypes involving participants who are representative of targets users whenever possible. Using HCD allows for continuous improvement and adaptation as new technologies and user needs emerge, thus providing students with tools that they can apply later when moving into industry-related jobs. Also relevant, HCD promotes ethical design by considering the impact of VR/AR applications on users' privacy, well-being, and digital rights. It is important that students leave the course with these principles in mind, allowing them to make more ethical choices throughout the design process in the future.

In summary, we deem that incorporating an HCD approach into the practical assignments of a VR/AR course is essential to educate students on how to create user-focused, effective, and innovative applications. This ensures that VR/AR technologies are not just technically impressive but also genuinely useful and enjoyable for the target users, which is particularly important when they are vulnerable people, as is the case of stroke survivors.

3.3. Keeping updated

Since this is an elective course, most students choose it based on their personal interests and motivations, which means that during the semester, it is natural for questions to arise regarding latest developments and trends in the VR/AR landscape. As such, each year, there is a concern about updating the existing materials to reflect this fact, either the theoretical lectures with the introduction of new examples, videos, and research publications, as well as including new demonstrations and hardware whenever possible to maintain students' interest and engagement.

While a University course should mainly provide solid fundamentals, VR/AR technologies are evolving at an astonishing pace and what was cutting-edge 2 years ago may now be outdated; thus, an effort should be made to keep track of the latest developments, ensuring that students are working with current tools and techniques. This has particular interest for the industry, given that companies tend to value professionals who are knowledgeable about the latest breakthroughs. Being up-to-date can enhance students' competitive advantage in the job market. Moreover, keeping tabs on the news can inspire them to think creatively and develop new applications or solutions. This innovation is critical for the growth of the field and should be introduced from an early stage.

Naturally, this also means that the teaching team has to stay informed as well. The course content can be updated to reflect the most current knowledge and industry best practices, ensuring students receive the most relevant education. Thus, we argue that in the ever-evolving world of VR/AR, staying informed is not merely an advantage, it's a necessity.

3.4. Motivating a research-oriented approach

Every year some of the students have a Master dissertation related to VR or AR; in these cases, they are encouraged to propose an assignment aligned with and inspired by their dissertation, conduct a literature research previous to starting their assignment, and present in class a paper related to the topic. Students who submit high quality work have been encourage to disseminate their work; an effort has been made to help them write a conference paper or poster, or to participate in events showcasing their work. Overall, the outcomes have been very positive, and each year there have been works resulting in publications and even awards [OMA*24, MAP*23, PMA*22, MAM*22, BRFM*20]

3.5. Open challenges

Despite the aforementioned examples, lecturing a VR/AR course presents several ongoing challenges, as this field continues to evolve and expand rapidly. Technology is constantly evolving, which means educators must keep up with the latest hardware, software, and trends to ensure that the course content remains relevant. Additionally, although it is paramount to ensure that students have access to the necessary equipment for hands-on learning, maintaining access to high-quality VR/AR hardware can be a substantial challenge, especially for educational institutions with limited budgets. Moreover, ensuring that VR/AR education is accessible and inclusive for students of diverse backgrounds and abilities is not straightforward. In particular, given that unlike more established fields VR/AR lacks universal standards, which can make it challenging to guide students on best practices. In this vein, a considerable effort to bridge these interdisciplinary gaps is necessary, while providing a comprehensive education and an inclusive learning environment. This has become more challenging lately, as the course has become an elective in more Master's programs, and the number of students has increased, as previously mentioned. Last, evaluating students' work when each group of students has a different project is challenging. As such, it is paramount to consider appropriate evaluation criteria to measure student progress effectively.

4. Concluding remarks

The VR/AR elective course has been offered for ten years, working at maximum student capacity. At the end of all editions, students were asked to fill out questionnaires provided by the quality assurance system of the University, as well as by the teaching team on more specific topics. These questionnaires allowed to gather students' feedback and the general impression has been quite positive; students generally reported having enjoyed the course and found the topics and projects interesting to their programs; students' answers also provide a clearer understanding of their motivations and background, as well as difficulties in using the technology, which may be used to improve the following editions of the course.

Despite this, it is important to reflect and plan the next steps to keep the success of previous editions. For example, the use of multimodal interaction (e.g., hand recognition, multi-touch, eye tracking, voice commands, etc.) has been growing due to the support provided by some of the existing devices. Multimodal interaction leverages various sensory modalities to engage target users more deeply and improve their experiences. This engagement can result in a larger adoption of the technology through more natural/familiar interaction approaches. Yet, thus far, only a reduced number of students have selected projects that explore this kind of paradigm. In the future, it may be relevant to further push this kind of interaction, given the ability to enhance user experiences and expand the potential applications of VR/AR technologies.

Another topic that deserves further attention is user evaluation within the scope of VR/AR applications. Even though the lectures cover this subject, not all groups have the opportunity to conduct their final evaluations during the practical project. Conducting a user evaluation of the submitted prototype is usually done by the more advanced groups, where a strong development component is already established. Regardless, an effort must be made to make this a mandatory milestone in the design and development cycle of the practical project. Students may not always recognize issues in their creations. User evaluations help uncover issues, glitches, or design flaws that might not be apparent to the creators. In the future, we intend to ask students to use the feedback collected and make improvements in their applications for the final presentation. This will make students more effective designers and developers.

As VR/AR technologies become more pervasive and used by non-technical people, it is important to devote more time addressing ethical considerations, as well as privacy and security issues in the use of these technologies, ensuring that students are well aware of the implications of their work.

Last, given the rise of new Artificial Intelligence (AI) tools, and students enthusiasm towards using them, its role in a VR/AR course must also be considered. In the near future, students may be able to use AI to assist in creating VR/AR content more quickly and efficiently, to generate 3D models, textures, and environments, making it easier to develop prototypes and applications. AI may also be used as an assistant or a non-player character, as well as a way to adjust content and pace based on users' engagement and emotions. Besides, AI may improve the accessibility of VR/AR applications, providing features for individuals with disabilities, such as voice-controlled navigation or customized visual experiences.

The aforementioned topics together with the previous list of open challenges represent important steps to take into consideration moving forward. All in all, with the evolution of the field, other important topics may arise. Having an open mind and keeping a track of emerging topics for a VR/AR course can enhance the educational experience for educators and students. As a consequence, it ensures that the course remains relevant, inspires innovation, and prepares students for successful careers in the ever-evolving world.

Acknowledgments

To Beatriz and Paulo. Your course was the beginning of a new reality for me! Thanks for everything. I hope the next 10 years can follow the current success. We would like to recognize the contribution of all the students who attended the Virtual and Augmented Reality course and gave us their feedback, as well as all the people who have provided motivation and support to the students' projects; without their enthusiasm, this course would not have been as motivating for students and educators. This research was supported by IEETA, funded through the Foundation for Science and Technology (FCT), in the context of the project [UIDB/00127/2020].

References

[BRFM*20] BARROSO REGO J. P., FONSECA L., MARQUES B., DIAS P., SOUSA-SANTOS B.: Remote collaboration using mixed reality: Exploring a shared model approach through different interaction methods. In *European Conference on Computer-Supported Cooperative Work (ECSCW)* (2020), pp. 1–4. 7

[Cli08] CLIBURN D. C.: A virtual reality laboratory for undergraduates. *Journal of Computing Sciences in Colleges 24*, 2 (2008), 57–63. 1

[DH22] DOERNER R., HORST R.: Overcoming challenges when teaching hands-on courses about virtual reality and augmented reality: Methods, techniques and best practice. *Graphics and Visual Computing 6* (2022). 1

[HHO13] HÄFNER P., HÄFNER V., OVTCHAROVA J.: Teaching methodology for virtual reality practical course in engineering education. *Procedia Computer Science 25* (2013), 251–260. 1, 2

[HVV21] HÁCHA F., VANECEK P., VÁŠA L.: A virtual reality platform for immersive education in computer graphics. In *Eurographics (Education Papers)* (2021), pp. 9–14. 1

[Jer15] JERALD J.: *The VR book: Human-centered design for virtual reality*. Morgan & Claypool, 2015. 2

[Lam16] LAMBERS M.: Lowering the entry barrier for students programming virtual reality applications. In *Eurographics (Education Papers)* (2016), pp. 33–36. 1

[LaV17] LAVALLE S.: *Virtual Reality*. Cambridge University Press, 2017. 2

[LKM*17] LAVIOLA J., KRUIJFF E., MCMAHA R., BOWMAN D., POUPYREV I.: *3D User Interfaces: Theory and Practice*. Addison-Wesley, 2017. 2

[MAM*22] MAIO R., ALVES J., MARQUES B., DIAS P., LAU N.: Exploring an augmented reality serious game for motorized wheelchair control. In *International Conference on Advanced Visual Interfaces (AVI)* (2022), pp. 1–3. 7

[MAP*23] MARQUES B., ALVES J., PEDROSA E., CABRAL R., SILVA S., SANTOS B. S.: Robartics: Using ar to enhance robotics competitions. In *International Workshop on Virtual, Augmented, and Mixed-Reality for Human-Robot Interactions, ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (2023), pp. 1–7. 7

[NJD19] NGUYEN V. T., JUNG K., DANG T.: Creating virtual reality and augmented reality development in classroom: Is it a hype? In *IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)* (2019), pp. 212–2125. 1

[OMA*24] OLIVEIRA S., MARQUES B., AMORIM P., DIAS P., SANTOS B. S.: Stepping into recovery with an immersive virtual reality serious game for upper limb rehabilitation: A supermarket experience for stroke survivors. In *International Conference on. Human-Computer Interaction (HCII)* (2024), pp. 1–12. 7

[PMA*22] PARAENSE H., MARQUES B., AMORIM P., DIAS P., SANTOS B. S.: Whac-a-mole: Exploring virtual reality (vr) for upper-limb post-stroke physical rehabilitation based on participatory design and serious games. In *IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)* (2022), pp. 716–717. 7

[SD17] SANTOS B. S., DIAS P.: What should a virtual/augmented reality course be? In *Eurographics (Education Papers)* (2017), pp. 59–62. 1

[SDM15] SANTOS B. S., DIAS P., MADEIRA J.: A virtual and augmented reality course based on inexpensive interaction devices and displays. In *Eurographics (Education Papers)* (2015), pp. 15–22. 1

[SH16] SCHMALSTIEG D., HOLLERER T.: *Augmented reality: principles and practice*. Addison-Wesley Professional, 2016. 2

[SHN19] SPEICHER M., HALL B. D., NEBELING M.: What is mixed reality? In *Proceedings of the CHI conference on Human Factors in Computing Systems* (2019), pp. 1–15. 1

[Zar06] ZARA J.: Virtual reality course—a natural enrichment of computer graphics classes. In *Computer Graphics Forum* (2006), vol. 25, pp. 105–112. 1