A report on the potential of green serious games in higher education

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A **REPORT** ON THE **POTENTIAL** OF **GREEN SERIOUS GAMES** IN **HIGHER EDUCATION**

Prepared by:

PLAY2GREEN

Serious Gaming for Universal Access to Green Education

Zagreb, 2023

Co-funded by the European Union

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CONTENTS

PREFACE

The 21st century is a century of transitions: ecological transitions, societal transitions and, consequently, educational transitions. The Play2Green project provides an answer to Alexandre Lacroix's question (Philomagazine November 2022) "Technology has brought us to the brink. Can we count on it to save us?"

The richness of Play2Green is precisely in not rejecting the tremendous contributions of the digital technologies that surround us, which humans can no longer ignore, but on the contrary, in extracting new ways of learning and thinking green from them. It is in this respect that the inclusion of Green Serious games into courses not initially dedicated to ecological learning can contribute to improving the future of the planet. Thanks to Artificial Intelligence, Augmented Reality and so on, we can enter the complexity of today's environmental issues and put technology to work for the planet.

Furthermore, by choosing to raise ecological awareness among the younger generation in a fun way, Play2Green is in line with 21st century teaching methods where the aim is no longer to dispense knowledge vertically but to develop discernment in our students. Through Green Serious Games, students are entering into a "learning by doing" pedagogy, as they become players in their own training. Will they be able to take advantage of the technologies to learn about themselves at the same time as they learn about the world, as François Taddéi, a researcher in evolutionary genetics in search of new forms of learning, put it? We can only think so, especially as the students from the five partner universities involved also participate actively in the design of the Green Serious Games, working in multicultural groups on 9 projects.

This is another of Play2Green's challenges: not only does it bring together students and teachers/researchers from 4 countries (Croatia, Spain, France, and Hungary), along with a non-governmental association (ASPAS), but the project also helps to break the barriers between disciplines, bringing together people from both the technical sciences and the

humanities. A final intercultural enrichment worth highlighting is the intergenerational collaboration within the project's teaching and research staff, which includes young doctoral students as well as emeritus professors. A very fine example of collective intelligence!

Of course, the introduction of new teaching methodologies is not self-evident: how, and on what terms, can GSGs be introduced into computer science and mathematics courses and so on, without upsetting both teachers and students? Are our higher education institutions ready for such developments?

This report will touch upon these questions. It is the result of collaborative, international work, and we can only hope that reading it will open new windows on the world of education and on our blue planet.

Catherine Sable

IMT Atlantique Bretagne Pays de la Loire

1 Introduction

INTRODUCTION

In today's rapidly evolving world, the urgency to address environmental challenges and promote sustainability has reached critical levels. This necessitates a synergistic relationship between three fundamental components: the green agenda, education, and serious games. The intertwining of these pillars offers a unique opportunity to drive environmental consciousness, foster innovation in education, and provide transformative learning experiences. This comprehensive report delves into the integration of green-themed serious games into non-green-themed higher education (HE) courses, recognizing their potential to instil sustainability values and empower learners to become catalysts of change.

The green agenda represents a broad spectrum of pressing environmental issues, ranging from climate change and resource depletion to biodiversity conservation and waste management. It encompasses a horizontal topic that transcends disciplinary boundaries, emphasizing the interconnectivity and interdependencies of ecological challenges. As sustainability emerges as a global imperative, comprehensive efforts across various sectors of society are necessary. Embedding green principles and sustainability into education is pivotal to equipping students with the knowledge, skills, and mindset needed to navigate complex environmental issues and actively contribute to a sustainable future.

Education stands as a powerful catalyst for societal transformation, shaping minds, fostering critical thinking, and nurturing the next generation of leaders and change-makers. In the digital era, innovation in education has become essential, with digitalization revolutionizing traditional learning paradigms. Advancements in technology offer new avenues to engage learners, enhance educational experiences, and promote active participation. Leveraging emerging technologies enables educational institutions to reimagine the way environmental topics are taught, integrating innovative pedagogical practices and providing learners with the tools to address sustainability challenges effectively.

Serious games have emerged as a potent tool for educational engagement, seamlessly blending entertainment and learning. By combining game mechanics with educational content, serious games create immersive, interactive, and captivating experiences that facilitate deeper understanding and motivation among learners. In the context of environmental education, serious games have the power to simulate real-world scenarios, facilitate hands-on exploration of ecological concepts, and encourage the adoption of sustainable practices. They offer dynamic learning environments where students can experiment, make decisions, and observe the consequences of their actions, fostering a heightened sense of environmental responsibility.

The core focus of this report revolves around the seamless integration of green-themed serious games into non-green-themed HE courses. Incorporating these green-themed games creatively into courses that traditionally do not address environmental topics, the reach and impact of sustainability education can be expanded. This integration requires a comprehensive analysis of existing courses, identifying opportunities to introduce green-themed elements that align with the learning objectives. By doing so, a multidisciplinary approach to sustainability education can be fostered, engaging students across diverse fields and empowering them to apply environmental principles in their respective domains.

Through a systematic analysis of selected HE courses and the development of practical guidelines, this report seeks to provide valuable research of the potential of green-themed serious games as transformative educational tools. It aims to outline modalities and actionable steps for seamlessly infusing serious games into non-green courses, aspiring to bridge the gap between sustainability and traditional disciplines. By harnessing the power of the green agenda, innovative education, and serious games, a paradigm shift can be catalysed in higher education, equipping students with the knowledge, skills, and motivation to address environmental challenges and actively contribute to a sustainable future.

The role of Universal Design for Learning

Didactics and pedagogy which take into account societal transformation outline the need to apprehend learning in a universal way.

What does a „universal learning guide“ mean and why is it so important?

The European Union insists on building an inclusive society, which implies the acceptance of Diversity. Diversity means considering the universal and individual dimension of Human beings. Education and learning are the first steps towards such a society, which is the aim of the researchers of the Universal Design for Learning group (UDL). By introducing some Universal learning Guidelines, they offer a relevant answer as their studies do not neglect the Individual which is part of the Universal:

> *„UDL, on the other hand, treats these individual differences as an equally important focus of attention. In fact, when viewed through the UDL framework these findings are fundamental to understanding and designing effective instruction. “*

Learning, as demonstrated by numerous researchers in the Education Sciences and Developmental Psychology (Piaget, Vygotsky…), takes place in gradual steps: *access*, *build* and *internalize*. To facilitate these steps, UDL presents 3 principle points to produce an effective didactic curriculum, according to the way our brain acts, as outlined by the Neurosciences:

- Representation,
- Action and expression,
- Engagement.

Representation or cognitive studies about comprehension

This section deals with the *„what?“* in learning, drawing on scientific research on the understanding of knowledge and skills, and reminds us of the importance of varying the

sources of information, whether through an auditory or a visual channel. Making people understand implies activating or reactivating knowledge or experience and adapting language to the learners.

Action and expression: strategies and cognitive studies about production

This theme deals with „*How to learn*? ". As Vygotsky and other psychologists have stressed, learning requires real interactions with our social environment: we can thus speak of active learning. In the 21st century, assistive technologies are valuable tools to support the process of understanding in learning.

Engagement or Why learning?

Engagement means developing – and maintaining a high level of interest. It is connected with motivation: In the 21st century, how do we increase student engagement?

- Individual choice and autonomy are fundamental: peer assessment, for example helps students to „*understand where improvements can be made*"
- Value and authenticity: connecting new content to relevant „*real-life contexts* ": the capacity of abstraction being considered as a more complex way of thinking. Learners of the 21st century tend to grasp knowledge through concrete and various challenges, with clarified goals. Furthermore, they were born with technology and are more motivated when it is part of their learning process.

In conclusion, considering that universal guidelines in learning are important is relevant as it has to do with Diversity and Inclusion, two main European objectives. Far from standardisation, this definition of universality is based on variation: varying the methods of information and expression, varying the sources of motivation in order to adapt to the diversity of learners.

Project context

This report is intricately connected to the Play2Green project (https://sociallab.fer.hr/play2green/) and its overarching goals. Play2Green is a collaborative initiative undertaken by a consortium comprising five partners from four EU countries, namely the University of Zagreb, Valencia Polytechnic University, University of Debrecen, IMT Atlantique Bretagne Pays de la Loire, and University of Dubrovnik, along with the Asociación de Familias y Personas Sordas de Valencia. The project is centred around the convergence of the green agenda, education, and serious games, seeking to raise awareness of environmental challenges and combat climate change through innovative learning practices.

As part of the Play2Green project, the consortium aims to stimulate innovative learning and teaching activities in green education. The writing of this report serves as a crucial step in achieving the project's objectives. By exploring the integration of green-themed serious games into non-green-themed higher education (HE) courses, the report seeks to identify modalities and actionable steps for incorporating these games effectively. It aligns with the project's broader mission of promoting innovation in education and leveraging the power of serious games to accelerate environmental education and action.

The consortium's diverse composition reflects the multinational and interdisciplinary nature of the Play2Green project. The University of Zagreb brings expertise in the research and development of serious games, while Valencia Polytechnic University contributes insights from the field of technology-enhanced learning. The University of Debrecen offers valuable perspectives on the use of emerging technologies such as 3D printing in education. IMT Atlantique Bretagne Pays de la Loire brings the expertise of interculturality. The University of Dubrovnik, known for its commitment to sustainability, provides insights into the environmental aspects of the project as well as the potential usage of hologram technology for education. The Asociación de Familias y Personas Sordas de Valencia represents the interests of the deaf community and ensures inclusivity within the project's outcomes.

At the heart of the Play2Green project lies the concept of green-themed serious games. These games combine entertainment and educational content to create immersive and engaging learning experiences. In the context of environmental education, green-themed serious games serve as interactive tools for promoting sustainability, environmental awareness, and the adoption of eco-friendly behaviours. They simulate real-world scenarios, allowing learners to explore and understand complex environmental concepts, make decisions, and observe the consequences of their actions. By integrating green-themed serious games into HE courses, the Play2Green project aims to reach a broader student population and instil a sense of environmental responsibility and activism.

Through this report, the Play2Green consortium highlights the significance of the project's objectives and their alignment with the green agenda, education, and serious games. By investigating the modalities for incorporating green-themed serious games into non-green courses, the consortium aims to revolutionize higher education by infusing innovative and sustainable learning practices. The expertise and collaboration of the consortium partners enable the project to draw upon multidisciplinary perspectives, fostering comprehensive and inclusive approaches to environmental education. Ultimately, the Play2Green project seeks to create a positive impact by empowering learners to become agents of change in the fight against climate change and the pursuit of a greener and more sustainable future.

Research question

Green thinking is a necessity today, being a Citizen of Europe and of the World means that everyone must participate in the green deal. Education is one fundamental dimension in order to inform the citizens of the future. It is obvious to all that education has started and must continue to change in the 21st century.

> *„We live in a fast-changing world, and producing more of the same knowledge and skills will not suffice to address the challenges of the future. A generation ago, teachers could expect that what they taught would last*

> *their students a lifetime. Today, because of rapid economic and social change, schools have to prepare students for jobs that have not yet been created, technologies that have not yet been invented and problems that we don't yet know will arise.“ (**Andreas Schleicher**, OECD Education Directorate)*

Generation Z, born into an innovative and technological world, needs to be skilled at problem solving and to learn how to develop critical thinking. Scientific work has shown that in the 21st century, interdisciplinary and cross-cutting skills are required.

> *“The knowledge world is no longer divided between specialists and generalists. A new group-let's call them “versatilists”-has emerged. They apply depth of skill to a progressively widening scope of situations and experiences, gaining new competencies, building relationships and assuming new roles. They are capable not only of constantly adapting, but also constantly learning and growing in a fast-changing world.” (**Andreas Schleicher**, OECD Education Directorate)*

Green-themed serious games could respond to new learning needs by placing learners in near real-life situations, by asking them to adapt to changing situations.

> *Therefore, is it possible to change the entrenched educational habit that knowledge is best transmitted in a top-down fashion?*
>
> *In other words what are the most suitable ways of including green-themed serious games based on emerging technologies in non-green-themed higher education courses?*

Proposed solution

To address this didactic issue[1], it is important to collect data from those involved in higher education who would be directly concerned by the possible inclusion of green serious games in their non-specialist classes. This means both teachers and students participating in the courses in question. This work aims to understand favourable or unfavourable attitudes to the inclusion of innovative, green-themed serious games.

This work will also enable interviewees to put forward their suggestions relating to the introduction of these green games powered by innovative technologies.

A review of the current course methodologies in higher education is required, particularly in technological courses, where one might assume there would be greater familiarity with new technologies, whether in the form of games or learning tools.

Is this supposition a reality?

First, we position our work against the relevant literature. Afterwards, we explain our research methodology, combining qualitative and quantitative surveys to verify our hypotheses and understand the representations and avenues requiring further investigation.

Next, we present the results of the surveys in relation to the institutional policies of Play2Green's partners. Next, the different modalities of introducing green-themed serious games are discussed, before moving on to address the possibilities offered by emerging technologies, thanks to the expertise of the consortium members.

After that, we imagine an example of a green-themed serious game based on dimensions essential to any learning process that aims to be universal. Finally, we wrap up this report

[1] This research's condensed version has been published in the **Contel 2023 conference**, paper titled "**Inclusion of Green-themed Serious Games based on Emerging Technologies into Non-green-themed Higher Education Courses**" by Iva Zekić (University of Zagreb, Croatia), Jurica Babić (University of Zagreb & Faculty of Electrical Engineering and Computing, Croatia), and Ivana Slošić (University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia).

with the concluding remarks related to green topics, serious games, emerging technologies and universal design for learning.

2 Related Work

RELATED WORK

In the initial stages of preparing the questions for our mixed-method research, our focus was on establishing a comprehensive grasp of both the contextual backdrop of the problem and the potential viability of our proposed methodology. To achieve this, we adopted a multi-faceted perspective that involved a three-fold approach, as depicted in Figure 1, enabling us to thoroughly examine the issue from multiple angles. While some previous research concentrated exclusively on a single domain, our primary interest lay in investigations that sought to bridge and intersect two or more distinct areas. In particular, our objective was to pinpoint pertinent literature that delved into the juncture between higher education institutions (HEI) and green topics (GT).

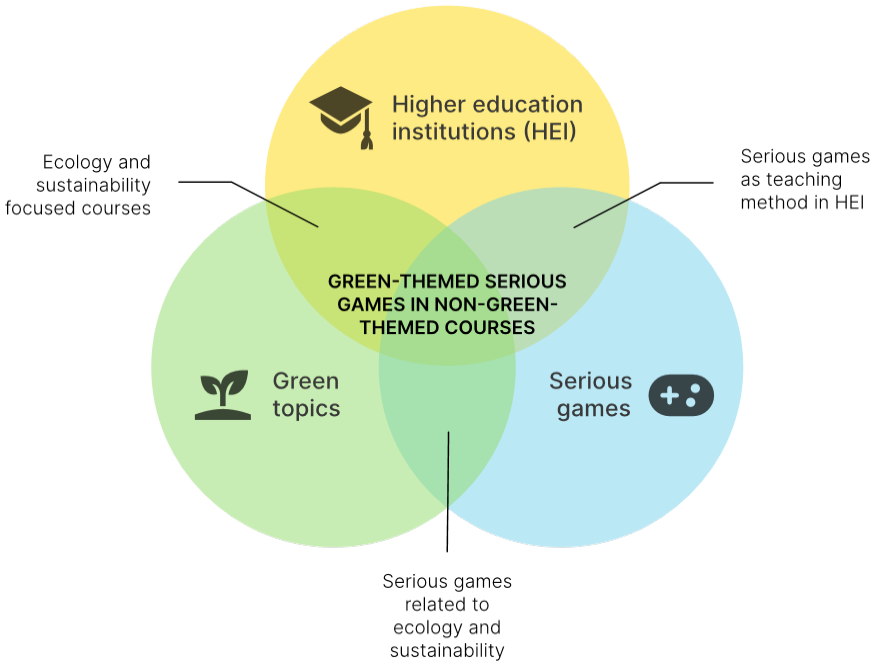

Figure 1: This research is where higher education institutions (HEI), serious games, and environmentally related subjects come together.

The concept of integrating sustainability into higher education has evolved significantly since its initial reference in the Stockholm Declaration of 1972. Over the past two to three decades,

the reorientation of education towards sustainable development, the augmentation of public consciousness regarding environmental matters, and the promotion of environmental training[2] have been identified as crucial factors. Simultaneously, the emphasis on equity among nations has underscored the importance of these efforts in achieving sustainability. Notably, the notion that all academic disciplines should address environmental concerns and that university curricula should adopt a holistic educational approach has gained prominence[3].

Hence, it's unsurprising that a plethora of researchers have explored diverse avenues for integrating HEI curricula with green topics such as sustainability and sustainable development, a process often referred to as curriculum greening. For instance, Mintz and Tal[4] introduced a framework aimed at studying courses dealing with environmental subjects in higher education. Their objective was to enhance comprehension of how different teaching methodologies yield distinct learning outcomes in Education for Sustainability (EfS).

It's important to acknowledge that certain obstacles exist in integrating sustainable development (SD) into HEI curricula. A global study[5] contends that teachers' independence within their disciplines poses a challenge to SD integration, though individual interaction can overcome this hurdle. The study also proposes the establishment of a dedicated group responsible for embedding SD into institutional curricula, advocating for the amalgamation of

[2] United Nations Division for Sustainable Development. (2022). Agenda 21. Accessed: April 14, 2023. [Online]. Available: https://sdgs.un.org/sites/default/files/publications/Agenda21.pdf

[3] Wright, T. S. A. (2002). Definitions and frameworks for environmental sustainability in higher education. International Journal of Sustainability in Higher Education, 3(3), 203–220. https://doi.org/10.1108/14676370210434679

[4] Mintz, K., & Tal, T. (2013). Education for sustainability in higher education: a multiple-case study of three courses. Journal of Biological Education, 47(3), 140-149. https://doi.org/10.1080/00219266.2013.821353

[5] Holmberg, J., Svanstrom, M., Peet, D.-J., Mulder, K., Ferrer-Balas, D., & Segalas, J. (2008). Embedding sustainability in higher education through interaction with lecturers: Case studies from three European technical universities. European Journal of Engineering Education, 33(3), 271-282. https://doi.org/10.1080/03043790802088491

SD-related expertise and disciplinary knowledge to identify connections between SD and specific subjects.

Despite commendable advancements, the United Nations asserts that further endeavours are necessary to seamlessly mainstream Education for Sustainable Development (ESD) within national education systems, including universities. Correspondingly, the framework outlined in the paper [6] establishes links between pedagogical approaches and Sustainable Development competencies. It highlights that case studies and problem/project-based methodologies correlate with the widest array of SD competencies. Consequently, adopting these approaches presents a means to integrate SD competencies into any course. Additionally, the framework acknowledges the potential of gamification and serious games in enhancing student engagement in learning.

Regrettably, while the pedagogical potential of gaming is substantial[7], its utilization in this context remains limited[8]. Nevertheless, certain efforts have been made to incorporate serious games into teaching methodologies[9], as well as to intertwine serious games with green themes[10][11][12].

[6] Lozano, R., Merrill, M. Y., Sammalisto, K., Ceulemans, K., & Lozano, F. J. (2017). Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education: A Literature Review and Framework Proposal. Sustainability, 9. https://doi.org/10.3390/su9101889

[7] Vlachopoulos, D., & Makri, A. (2017). The effect of games and simulations on higher education: A systematic literature review. International Journal of Educational Technology in Higher Education, 14(22).

[8] Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. Personnel Psychology, 64, 489-528.

[9] Anastasiadis, T., Lampropoulos, G., & Siakas, K. (2018). Digital game-based learning and serious games in education. International Journal of Advances in Scientific Research and Engineering, 4(12), 139–144.

[10] Orduna Alegría, M. E., Schütze, N., & Zipper, S. C. (2020). A serious board game to analyze socio-ecological dynamics towards collaboration in agriculture. Sustainability, 12, 5301.

[11] Herrera, R. F., Sanz, M. A., Montalban-Domingo, L., García-Segura, T., & Pellicer, E. (2019). Impact of game-based learning on understanding lean construction principles. Sustainability, 11, 5294.

[12] Swacha, J., Maskeliunas, R., Damaševičius, R., Kulikajevas, A., Blažauskas, T., Muszyńska, K., Miluniec, A., & Kowalska, M. (2021). Introducing Sustainable Development Topics into Computer Science Education: Design and Evaluation of the Eco JSity Game. Sustainability, 13, 4244. https://doi.org/10.3390/su13084244

While the demand for embedding environmental education into mainstream curricula is considerable, and studies have explored the integration of green topics into non-environmental courses (as referenced[13]), we have yet to come across pertinent literature that employs a data-driven approach to recommend strategies for infusing serious games with environmental motifs into courses that don't exclusively revolve around environmental subjects.

[13] Fisher, D. H., Bian, Z., & Chen, S. (2016). Incorporating Sustainability into Computing Education. IEEE Intelligent Systems, 31(5), 93-96. https://doi.org/10.1109/MIS.2016.76

3

Research Framework A Mixed-Method Research Approach

RESEARCH FRAMEWORK: A MIXED-METHOD RESEARCH APPROACH

To address the core inquiry driving our research, we adopted a mixed-method research approach that seamlessly blends both qualitative and quantitative research components. This strategy allowed us to amass and dissect data from multiple perspectives. The collection process involved the utilization of two distinct methods: an interview and a questionnaire. The interview protocol was exclusively tailored for educators, encompassing lecturers and teaching assistants, whereas the questionnaire extended its reach to encompass student responses as well. Subsequent to data acquisition, we embarked on the meticulous task of data processing, culminating in the encapsulation of responses within our comprehensive report. This culminated in the extraction of strategies for integrating environmentally themed

serious games, grounded in emerging technologies, into non-environmental courses, along with a constellation of additional insights.

Thus, the research unfolded across three distinct phases:

- Interview/Questionnaire design and testing;
- Collecting data; and
- Data processing and analysis.

For a holistic depiction of the research trajectory, refer to Figure 2, which furnishes an all-encompassing overview. Each of these phases is expounded upon extensively in the subsequent subsections, affording a comprehensive understanding of the research journey.

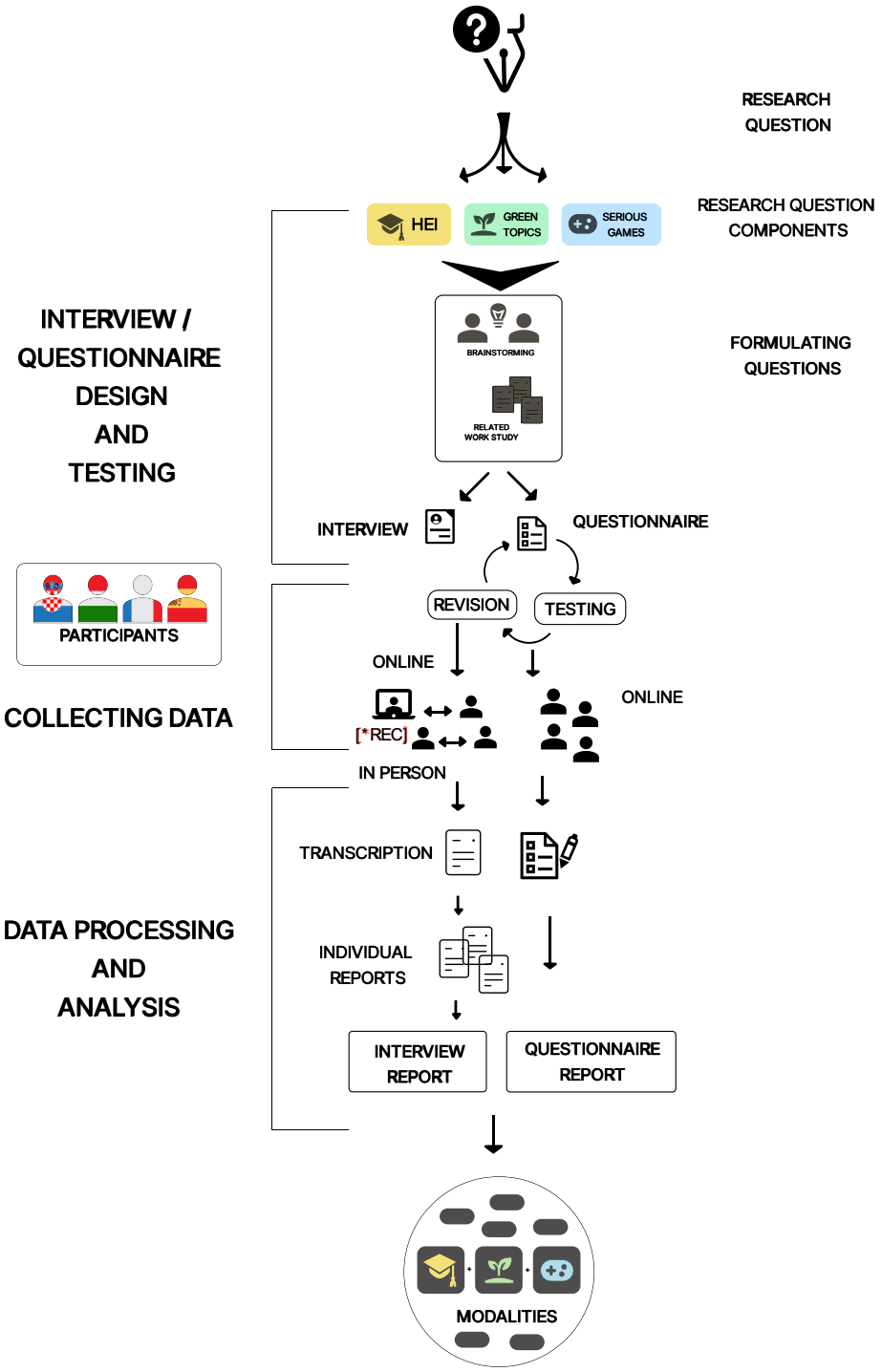

Figure 2: Methodology used.

Interview/Questionnaire design and testing

As mentioned earlier, our research question revolves around the convergence of three distinct areas: higher education institutions (HEI), green topics, and serious games. To delve into this intricate intersection, we approached it through three corresponding elements. Each of these components played a pivotal role in shaping our approach to formulating relevant questions.

Our process commenced with a thorough examination of existing literature related to these three components. We particularly focused on research papers that linked at least two of the aforementioned fields. This literature review provided a foundational understanding that guided us in grasping the problem's context and generating pertinent questions.

To further enhance the question-generation process, we employed brainstorming techniques. This creative exercise allowed us to contribute diverse perspectives to the question proposal. Once we had a collection of questions, we categorized them into several groups, namely: Academic and Demographic Data, Serious Gaming and Emerging Technologies, Motivation and Personal Opinion, and Course Experience. Subsequently, we determined which questions were most suited for each data collection method. This effort culminated in the initial version of our interview, presented in the form of a questionnaire.

To ensure the questions' quality and effectiveness, we subjected the questionnaire to a trial run with a small group of participants. Their valuable insights and feedback guided us in refining and enhancing the questionnaire. Their input was invaluable in making necessary revisions for optimal clarity and comprehensibility.

While we did not formally test the interview process, this was a deliberate decision. By opting for one-on-one interviews, we could swiftly address any confusion or ambiguity that might arise during the conversation, thereby ensuring a more nuanced and accurate exchange of information.

Collecting data

In the second phase of our research, our focus shifted to the process of gathering input using the interview and questionnaire that we had previously designed. Our target participants were individuals who could be either male or female: lecturers, teaching assistants, or students. They were affiliated with one of five institutions located in four different countries: University of Zagreb (Croatia), University of Dubrovnik (Croatia), IMT Atlantique (France), University of Debrecen (Hungary), and Polytechnic University of Valencia (Spain). During this phase, we conducted interviews with lecturers and teaching assistants either in person or via MS Teams. These individuals were chosen due to their significant experience as educators and researchers. The questionnaire, on the other hand, was extended to include students, allowing us to gather insights from both teaching and learning perspectives.

To make participation manageable, we estimated that completing the interview would take approximately 30 to 45 minutes, while the questionnaire would take around 10 to 15 minutes. Over the course of one month, we diligently collected data from our participants.

Prior to conducting the interviews, we took the step of sending our interviewees a brief document. This document contained explanations for key terms related to our research. Additionally, it featured a table where participants could input specific course data, such as the course title (and optionally a link to the course webpage), a concise description, the level of study, the number of ECTS credits assigned, the average number of enrolled students, and the percentage breakdown between theory and practical components of the course. This information gathering exercise helped us better prepare for the forthcoming interviews.

Below, we present a general outline of how we structured both the interview and the questionnaire, outlining the type of data we aimed to generate from each. This overview serves to provide an initial understanding of our approach in this phase of the research process.

Interview

Our interview was thoughtfully divided into three distinct parts, each serving a unique purpose. This comprehensive approach allowed us to delve into various dimensions of the subject matter. The interview encompassed the following segments:

- Academic Data, Serious Games, and Emerging Technologies: In this section, our questions revolved around the participants' academic background, area of expertise, research interests, and their years of experience in the field. Additionally, we explored the extent to which their courses had connections to green topics like sustainable development. Moreover, we delved into their familiarity with gaming, serious gaming, and emerging technologies, seeking to uncover their insights and experiences in these areas.
- Course Experience: The second part of our interview was designed to gain an in-depth understanding of the participants' experiences in their respective courses. We inquired about the number of courses they were involved in, the range of teaching techniques they utilized, and the balance between theoretical and practical components in their courses. We were particularly interested in whether they integrated serious games and the teaching materials they employed. Moreover, we invited them to share their thoughts on how green-themed serious games could be incorporated into courses that were not inherently focused on environmental topics.
- Motivation and Personal Opinion: Lastly, we aimed to capture the motivations and personal perspectives of the participants. We sought to learn about their reasons for considering the inclusion of green-themed serious games in their courses. Additionally, we explored the anticipated difficulties they foresaw in implementing this inclusion. This section also provided insights into the potential impact of integrating such games on the overall course quality and student motivation.

More details regarding the interview design are available in the following appendices at the end of the document:

- Appendix A: Interview preparation document and
- Appendix B: Semi-structured interview layout.

Questionnaire

In a slightly different approach from the interview, our questionnaire was organized into four distinct sections. Additionally, we provided participants with the option to contribute further comments if they wished to share additional insights. The questionnaire encompassed the following elements:

- Academic and Demographic Data: This section aimed to gather basic information about the participants, including their gender, academic institution, role, educational background, and their preferences for the level of innovation in teaching techniques.
- Serious Games and Emerging Technologies: Here, we aimed to explore the participants' familiarity with gaming, serious gaming, emerging technologies, and their exposure to green topics. This section aimed to uncover their level of comfort with these technological advancements.
- Course Experience: In this segment, our questions delved into the specifics of the participants' courses. We gathered data on the number of courses they were involved in, the teaching methods they employed, the extent to which their courses were digitized, the subject group their courses belonged to, and their suggestions for introducing green-themed serious games into non-environmental courses.
- Motivation and Personal Opinion: The final section of the questionnaire provided a platform for participants to express their motivation for considering the inclusion of green-themed serious games in their courses. Additionally, we probed into their predictions about the benefits and challenges associated with this integration. Lastly,

we aimed to understand how they perceived the potential impact of such an inclusion on the overall quality of the course and student engagement.

This structured and comprehensive approach ensured that we captured a wide range of insights from participants, contributing to a thorough understanding of our research objectives. More details on the questionnaire design are available in

Appendix C: Questionnaire.

Data processing and analysis

In the conclusive phase of our research, we dedicated ourselves to the thorough processing and meticulous examination of the data we had diligently collected. Given that our interviews were captured in audio format, our initial task was to convert these audio recordings into written transcripts. This transformation was essential to facilitate a more efficient and focused analysis. To achieve this, we employed the Sonix.ai tool, which enabled us to generate accurate transcripts saved as convenient PDF files. These transcripts became the essential building blocks for crafting our comprehensive report. Each PDF file contained the participant's detailed responses to the specific questions posed during the interviews. We took great care to extract these responses and systematically input them into a meticulously designed report template, ensuring clarity and consistency. Once this step was complete, we seamlessly merged these individualized reports into a coherent master document. This approach not only facilitated a holistic overview of the collected data but also allowed us to compare and contrast the responses across different participants and contexts.

On the other hand, the questionnaire data was already available in a written format, which streamlined the initial stages of analysis. The answers collected from the questionnaire were automatically compiled and organized within an Excel spreadsheet. With this structured foundation in place, we proceeded to carefully process and synthesize the entries, leveraging the spreadsheet to construct a comprehensive and insightful questionnaire report.

In the subsequent stage, we undertook a rigorous comparative analysis of the findings derived from both the interview and questionnaire components. Furthermore, we embarked on a noteworthy exploration of the correlations between the responses provided by educators (lecturers and teaching assistants) and those contributed by students. This juxtaposition of perspectives yielded valuable insights into the convergence and divergence of viewpoints across a range of subjects, including potential challenges and innovative strategies.

Yet, the true apex of our analytical endeavour was the culmination of our efforts into a set of derived strategies - a dynamic compilation that outlined modalities for seamlessly integrating green-themed serious games into higher education courses that did not originally centre around environmental themes. This innovative synthesis, shaped by our extensive data analysis, emerged as the crowning achievement of our study, demonstrating its practical implications and potential for enriching educational practices.

Results and Discussion

4

RESULTS AND DISCUSSION

Institutions

This section outlines the analysis of five higher education institutions that were examined in the research. These institutions are namely the University of Zagreb Faculty of Electrical Engineering and Computing, Universitat Politècnica de València, IMT Atlantique Bretagne Pays de la Loire, University of Debrecen, and University of Dubrovnik. Each institution is introduced with general information, followed by a particular focus on the analysis of their green strategies and innovative teaching practices. It is important to note that these institutions are integral members of the Play2Green consortium.

University of Zagreb Faculty of Electrical Engineering and Computing

General info

The University of Zagreb, founded in 1669, is the oldest and largest university in South-Eastern Europe [14]. With 30 faculties, three art academies, and the Centre for Croatian Studies, it offers diverse academic degree programs across various fields. The University has over 70,000 students and contributes significantly to research output in Croatia.

The Faculty of Electrical Engineering and Computing (FER) is the largest technical faculty within the University of Zagreb. It traces its roots back to 1919 and now excels in electrical engineering, ICT, and computing. FER has modern facilities, including lecture halls, laboratories, a Congress centre, and a central library [15]. It consists of 12 departments with a

[14] University of Zagreb. (2023). About the University. Retrieved from http://www.unizg.hr/homepage/about-university/

[15] University of Zagreb Faculty of Electrical Engineering and Computing. (2023). History. Retrieved from https://www.fer.unizg.hr/en/about/history

team of over 200 professors and 371 teaching and research assistants. The faculty is dedicated to fostering a vibrant environment for teaching, research, and innovation.

FER has established valuable international collaborations with research institutions worldwide, contributing to its global impact. These collaborations enhance research and educational endeavours, elevating FER's status as a leading institution.

The University of Zagreb and FER, with their rich history, comprehensive academic programs, and robust research activities, play a pivotal role in education, innovation, and scientific advancement in Croatia and beyond.

Green strategy

The "Development Strategy 2019-2023"[16] outlines FER's commitment to implementing green strategies and fostering sustainability. FER recognizes the pressing need to address environmental challenges and endeavours to make significant contributions towards a greener future. This strategy encompasses various areas, including energy efficiency, resource conservation, and environmental education. It is worth noting that research and innovation activities from FER are divided into the following five clusters which are in line with the relevant EU-level and national strategic documents: Health, Inclusive and Secure Society, Digitalization and Industry, Climate, energy and Mobility, and Food and Natural Resources.

FER aims to enhance energy efficiency throughout its operations. The organization will invest in modern technologies and infrastructure to reduce energy consumption and minimize its carbon footprint. By optimizing energy usage, FER seeks to promote sustainability while achieving cost savings. Furthermore, the strategy emphasizes the adoption of renewable

[16] University of Zagreb Faculty of Electrical Engineering and Computing. (2019). Strategija razvoja 2019-2023 [PDF file]. Retrieved from https://www.fer.unizg.hr/_download/repository/Strategija_razvoja_2019-2023_final-web.pdf

energy sources, such as solar and wind power, to drive a transition towards cleaner and more sustainable energy generation.

FER recognizes the importance of responsible resource consumption and plans to implement measures to conserve resources. This includes optimizing water usage, reducing paper consumption through digitalization, and implementing sustainable procurement practices. By promoting resource efficiency, FER aims to minimize its ecological footprint and contribute to the preservation of natural resources for future generations.

Education and awareness play a pivotal role in FER's green strategy. The organization is dedicated to raising environmental consciousness among its employees, students, and the broader community. FER will develop educational programs, workshops, and awareness campaigns to promote sustainable practices and encourage behaviour change. By fostering a culture of environmental responsibility, FER aims to create a lasting impact on individuals and empower them to contribute to a greener society.

In conclusion, FER's "Development Strategy 2019-2023" demonstrates a strong commitment to implementing green strategies and promoting sustainability. Through these efforts, FER wants to minimize its environmental impact and inspire positive change within its organization and the wider community.

Innovative teaching practices

The teaching strategy outlined in the "Development Strategy 2019-2023" document focuses on ensuring high-quality education for students at FER. The strategy emphasizes the integration of teaching, research, and innovation, aiming to enhance the regional and European recognition of the study programs in the fields of electrical engineering, computer science, information and communication technology, and related multidisciplinary areas. It also aims to increase student and staff mobility and develop lifelong learning and training programs.

The teaching strategy at FER also incorporates innovative approaches to education. FER recognizes the importance of staying at the forefront of technological advancements and pedagogical methods to provide a cutting-edge learning experience for students. By embracing innovation in teaching, FER aims to enhance student engagement, promote critical thinking, and develop practical skills that are relevant to the evolving demands of the industry.

One of the innovative aspects of teaching at FER is the implementation of blended mobility. This approach combines traditional face-to-face teaching with online and remote learning methods. Blended mobility enables students to access educational resources and participate in interactive learning experiences both on-campus and remotely, fostering flexibility and adaptability in the learning process. It allows students to benefit from the convenience of online learning while still having opportunities for in-person interactions and practical hands-on activities[17].

Additionally, FER encourages the use of innovative teaching techniques and tools. This includes leveraging technology in the classroom, such as interactive digital resources. These technological advancements provide students with immersive and interactive learning experiences, enabling them to gain practical skills and problem-solving abilities in a dynamic and engaging manner.

Furthermore, FER promotes a student-centred approach to teaching, where students are actively involved in the learning process. This includes project-based learning, group work, and collaborative activities that encourage teamwork and critical thinking. By engaging students in practical projects and real-world challenges, FER fosters creativity, innovation, and the application of theoretical knowledge in practical contexts.

[17] SocialLAB. (2023). The INNOSID project. Social Computing Laboratory, Faculty of Electrical Engineering and Computing, University of Zagreb. Retrieved from http://sociallab.tel.fer.hr/innosid/

Overall, the teaching strategy at FER embraces innovation by incorporating blended mobility, utilizing technology-enhanced learning, and promoting student-centred approaches. By embracing these innovative methods, FER aims to provide students with a dynamic and forward-thinking educational experience that prepares them for the challenges and opportunities of the rapidly evolving technological landscape.

Universitat Politècnica de València

General info

UPV is a public Higher Education Institution actively involved in international cooperation and mobility projects. UPV hosts nearly 30,000 students and employs over 4,000 people (teaching, research, and administrative staff). It is the first technological university in Spain according to international rankings (e.g., Shanghai Ranking of World Universities) and offers 39 undergraduate programmes, over 80 official master's degrees and 30 Doctorate programmes. Even though UPV focuses mainly on engineering and technical studies, it also hosts a Faculty of Fine Arts and a Faculty of Business Administration and Management. Yearly UPV enrols over 1,800 exchange students and sends over 1,400 of their own students abroad under different mobility programmes.

UPV has repeatedly ranked amongst the top 5 European Universities in student exchange figures under the Erasmus+ Programme. UPV has experience in the management of European projects and takes part in different actions: Erasmus+ (Capacity Building in Higher Education, Knowledge. Specifically, Telecommunications School (ETSIT) at UPV has participated in several European projects, as TEMPUS, etc, and it has not only received the National and European accreditations, but also the prestigious ABET accreditation for the Master and Bachelor programmes. ETSIT has also coordinated an EU Intensive Program (IP) in the topic of Sustainability for 3 consecutive years (SUSCOMTEC 2012, 2013 and 2014), and it is a partner, as a member of the Steering Committee, of the ERAMUS+ KA2 projects INNOSOC, TEAMSOC21 and INNOSID, coordinated by the University of Zagreb.

Green strategy

UPV has an "Environmental Unit ", that oversees all the issues related to „green topics "[18]. It ensures that UPV abides by all the Spanish and European regulations concerning the environment, as the ISO 14001:2015 or the „Eco-Management and Audit Scheme (EMAS) "[19]. The unit oversees policies concerning: Water consumption, Consumption of materials, Wastewater discharge, Paper, and cardboard waste, Sanitary waste, or Mobility.

UPV makes a commitment to know, assess, and minimize any environmental impacts that may derive from its activities, to be able to control, prevent and reduce the adverse effects, but also to promote and disseminate the positive ones. As a university it meets any legal environmental requirements or other requirements concerning environmental matters that could be applicable to the institution.

All the members of the university community are informed and trained on the current issues and topic of environmental regulations, so the UPV can raise the level of environmental awareness. This extends to the students by teaching them and allowing them to foster the appropriate environmental training.

However, the UPV has taken initiative not only to train the people inside the UPV, but to help improve environmental actions for those persons from outside the University. Enabling them to carry out their activities in offices or centres belonging to the university, as well as other public and private entities. UPV also constantly improves their environmental management systems to optimize the environmental performance of the University.

[18] Universidad Politécnica de Valencia. (2023). Environmental Unit. Retrieved from https://www.upv.es/entidades/AMAPUOC/indexi.html

[19] Universidad Politécnica de Valencia. (2020). El sistema de gestión ambiental de la UPV. Retrieved from https://www.upv.es/entidades/AMAPUOC/infoweb/ov/info/1026233normalc.html

Innovative teaching practices

The UPV has numerous plans to improve teaching practices. Among the most important we can highlight the traditional ones of recent years:

1. Recording of classes.
2. Repositories with teaching videos (usually 10 minutes)[20]
3. Virtual laboratories[21]
4. Repositories with teaching material for the subjects.

In addition, at the UPV there is the "Instituto de Ciencias de la Educación" (ICE[22]) which offers a multitude of courses every year aimed at teachers to improve their teaching skills. The courses can range from voice techniques for better vocalisation to stress control, video preparation, teaching material, quality presentations, etc. Finally, we would like to highlight the "PLAN INTEGRAL DE ACOMPAÑAMIENTO AL ESTUDIANTE" (PIAE+[23]). It is a programme with many years of operation that seeks to guide students who have recently arrived at the university, to introduce them to the new stage they are starting.

In particular:

1. It facilitates academic, personal, and social integration at UPV in the centre and in the UPV.
2. To carry out academic monitoring of first-year students.
3. Identifies their needs and/or problems.

[20] Universidad Politécnica de Valencia. (2020). ¿Qué es Polimedia?. Retrieved from https://www.upv.es/entidades/ASIC/catalogo/522359normalc.html

[21] Peñaranda Foix, Felipe Laureano (2022). Newton-Raphson Method Calculator. Retrieved from https://labmatlab-was.upv.es/webapps/home/Newton_Raphson.html

[22] Universitat Politècnica de València. (2023). Instituto de Ciencias de la Educación. Retrieved from https://www.ice.upv.es/

[23] Universitat Politècnica de València. (2020). PLAN INTEGRAL DE ACOMPAÑAMIENTO AL ESTUDIANTE. Retrieved from https://www.upv.es/perfiles/futuro-alumno/integra-piaeacom-es.html

4. Orientates them in their academic progress: study skills and strategies.
5. Promotes the development of the transversal competences of the UPV.
6. Offers guidance in their insertion in the work/professional environment.

University of Debrecen

General info

The University of Debrecen is the oldest higher education institution operated continuously in Hungary. The current form was established by integration of several universities operating in the city in 2000 [24]. The student community of 30,000 can study in 13 faculties, in institutions of excellent scholarly standards. It has outstanding educational, researcher, and innovation capacities in comparison with international educational institutions as well. Based on this it plays a major role in the realization of objectives of national strategy. As a leading university it is known in Hungary as an intellectual centre, providing the widest spectrum of educational programs while also closely cooperating with the private sector, the business sphere, and the local government [25].

The university has been an excellent partner for the city of Debrecen from the very beginning and it is one of the main driving forces behind the city's development. It is the mission of the university to play an active role in the economic life of the Northern-Great Plain region and to be present as a service provider in the innovation activities of regional companies, primarily in the fields of the health industry, biotechnology, agriculture, IT, and technology[26].

[24] University of Debrecen. (2021). From the Reformed College to the University of Debrecen. Retrieved from https://unideb.hu/en/reformed-college-university-debrecen
[25]University of Debrecen. (2021). Education. Retrieved from https://unideb.hu/en/reformed-college-university-debrecen
[26] University of Debrecen. (2019). University of Zagreb. Dr. Zoltán Szilvássy (Ed.). Dr. Mónika Rőfi & Anita Nánási-Molnár (Eds.). Printart-Press Kft. (Graphic design and print). Archives of the University of Debrecen (Photography). ISBN: 978-963-490-119-8.

The independent Faculty of Informatics was founded in 2004 to continue and maintain bachelor's and master's programs in information technology. The faculty with its five departments and its off-site departments fulfils an important role regarding higher education and scientific research in the region[27].

Green strategy

University of Debrecen (UD) has recognized the importance of implementing the green strategy, thus the Green Future Research Centre started operating at the end of year 2022[28]. As a part of the plan a monitoring system is being developed in the Debrecen region to map biodiversity, which will later be expanded into a national network. Artificial intelligence is also used in the evaluation of the collected data and in the development of scientific findings and responses to them. Nevertheless, efforts have been made in this field much earlier to support different activities, collaboration according to the national initiatives[29]. UD collects and organizes them in its website[30], and regularly shares news about related projects as well[31].

Students' Union of UD has an Environment Committee that organizes regularly different events. Green Expo offers colourful programs with themes that touch on different global issues. A community garden is also maintained to support movement 'Think globally, act locally!'. Common garbage collection, eco evenings are organized where topics on steps for a greener future can be discussed with invited lecturers.

[27] University of Debrecen. (2023). Faculty of Informatics. Retrieved from https://inf.unideb.hu/

[28] University of Debrecen. (2023). University Research Centre for a Green Future. Retrieved from https://hirek.unideb.hu/en/university-research-centre-green-future

[29] European Environment Agency. (2023). Green infrastructure. Retrieved from https://biodiversity.europa.eu/countries/hungary/green-infrastructure

[30] University of Debrecen. (2021). Implementation of Sustainable Development Goals at the University of Debrecen. Retrieved from https://unideb.hu/fenntarthato-fejlodesi-celok-megvalosulasa-debreceni-egyetemen

[31] University of Debrecen. (2021). Green Energy Cooperation in Higher Education. Retrieved from https://unideb.hu/en/green-energy-cooperation-higher-education

The university operates a shared bike service called UniBike that enables students and employees to move between the campuses[32]. There is a lot of green space around the buildings. The Botanical Garden with its nearly 6000 plant species is one of the largest in Central and Eastern Europe[33].

The Faculty of Informatics also makes efforts to become green: the heating system of the third floor is eco-friendly, solar panels are set on the roof of the building; the windows are equipped by automatic shading. In front of the building a large park called Green Waves provides recreation for the students.

Innovative teaching practices

It is a priority for the University of Debrecen (UD) to become a student friendly university[34]. To earn this recognition, electronic administration systems in all areas of administrative duties are introduced, and a large growth in the scope of electronic curriculum development is witnessed too. The UD runs a Talent Management Programme for students to promote the identification and unfolding of talents in any fields[35]. The University of Debrecen's stUDinnovate Innovation Scholarship Programme supports innovative ideas. During this programme experts of the university and mentors with business experience help students to develop their ideas and prepare for entrepreneurship[36].

[32] University of Debrecen. (2023). Unibike. Retrieved from https://unideb.hu/en/green-energy-cooperation-higher-education

[33] Hungary.com. (2023). Debrecen Parks and Gardens. Retrieved from https://hungary.com/debrecen/debrecen-parks-gardens/

[34] University of Debrecen. (2021). STUDENT FRIENDLY UNIVERSITY. Retrieved from https://unideb.hu/en/student-friendly-university

[35] University of Debrecen. (2023). University of Debrecen Talent Management Program (DETEP). Retrieved from https://detep.unideb.hu/en/words-welcome

[36] University of Debrecen. (2022). Would you do something for a better future? The innovator lives in you. Retrieved from https://hirek.unideb.hu/index.php/en/would-you-do-something-better-future-innovator-lives-you

Teaching has moved toward digitalization: the online eLearning system is used effectively in several faculties, the Department of Botany at UD has digitalized its four botanical collections, and integrated data into a special database that can be used in distance learning as well[37].

At the Faculty of Informatics an automatic assessment system (ProgCont) is used for evaluating the programming exercises of the students[38], textbooks written by the staff members are stored digitally and available for the students for free[39]. In the labs Veyon is installed to help monitoring the student's activities[40]. It also results in less usage of the projectors.

The different research labs make it possible to implement project-based learning[41].

The Faculty of Informatics is a recognized member of Microsoft's Learn for Educators Program since they have effectively integrated the results of the cooperation with Microsoft into their academic and educational activities. The business certificate issued by Microsoft can be obtained free of charge by the students[42]. The faculty is also an authorized testing centre for Certiport exams[43].

[37] University of Debrecen. (2020). Unique botanical collection. Retrieved from https://hirek.unideb.hu/index.php/en/unique-botanical-collection

[38] Procgcont.hu (2023). Programming contests. Retrieved from https://hirek.unideb.hu/index.php/en/would-you-do-something-better-future-innovator-lives-you

[39] University of Debrecen – Faculty of informatics. (2023). Béla Gyires Informatics Curriculum Repository - Completed course materials. Retrieved from 6. https://inf.unideb.hu/node/346

[40] Veyon. (2023). Welcome to Veyon. Retrieved from https://veyon.io/en/

[41] University of Debrecen – Faculty of informatics. (2023). Research labs. Retrieved from https://inf.unideb.hu/en/research-labs

[42] University of Debrecen. (2022). The Faculty of Informatics is ranked among the best of the international elite. Retrieved from https://hirek.unideb.hu/index.php/en/faculty-informatics-ranked-among-best-international-elite

[43] University of Debrecen Faculty of informatics. (2022). CERTIPORT. Retrieved from https://inf.unideb.hu/en/certiport

IMT Atlantique Bretagne Pays de la Loire

General info

IMT Atlantique is an elite technical University, spread over 3 campuses: Brest, Nantes, and Rennes, each with its own incubators. It is ranked as one of the 44th best young Universities. IMT Atlantique is part of the Institut Mines-Télécom and comes under the aegis of the Minister of industry and digital technology. The school awards two apprenticeship engineering diplomas, master's degrees, specialized master's degrees, and doctorates. 250 Lecturers and Associate Professors work at IMT Atlantique. There are 13.400 students, considering all trainings. IMT Atlantique covers a large range of topics, combining digital technology, energy, and the environment to transform society through training and research. The fields of application covered by the research conducted at IMT Atlantique are: Energy, Industry of the future, Health, Security and safety of systems, Defence, Sea, Telecoms, Transportation, Environment, Cities and territories. The research is carried out in 6 joints research units: GEPEA? IRISA? LATIM? LABSTICC, LS2N and SUBATECH. In a context where sustainable development and social responsibility have become imperative, IMT Atlantique asserts its commitment with a formally approved "Label DD&RS" approach since 2016. Through partnering with major stakeholders, we strive to constantly improve our positive impact on the environment, the quality of life and the sustainability of the economy.

IMT-Atlantique contributes to the achievement of the 17 Sustainable Development Goals (SDGs) adopted in September 2015 by the 193-member countries of the United Nations through all its businesses: training, research, finance, human resources, etc. and that is the reason why IMT Atlantique has established 5 strategic actions oriented and equipped itself with a Sustainable Development and Social Responsibility Policy, which places sustainable development and social responsibility at the heart of its strategy. The actions below illustrate some of the initiatives carried out at IMT Atlantique:

1. Strategy and governance: through this annual initiative, the President asks each of his collaborators to report on at least one SDSR (Sustainably development and social responsibility) action implemented during the year and to define at least one SDSR objective for the coming year.

2. Education and training: the engineering education at IMT Atlantique includes a compulsory 80-hour module for first year engineering students. The competences targeted by this module are: responsibility, anticipating and evaluating impacts, developing, and implementing a systemic approach, working and learning together, developing and implementing foresight.
3. Research: IMT has applied for the European Commission's "HR Excellence in Research" accreditation, "HRS4R" ("Human Resources Strategy for Researchers") to become more attractive to of foreign researchers and to position itself in terms of European funding. IMT Atlantique has therefore geared its research towards the H2020 programme by aiming to coordinate projects in connection with our interdisciplinary research themes on water, air, energy, waste, health, environment, ocean, and by fostering incoming and outgoing mobility for both researchers and PhD students.

4. Environmental management: first, the information systems department has installed thin-client workstations: the virtualized servers carry out the processing, with the client workstation only providing display functions. Controlling our water consumption was, along with that of energy and recycling, one of the very first actions of the Sustainable Development approach, with the aim of reducing our water consumption by 20%.

5. Social policy and local roots: our strong belief that in the importance of quality of life has led to the implementation of support measures for staff (Social Diagnosis, Assistance Unit); prevention/awareness measures (e.g., the "Quality of Life at University" programme); the development of a new approach to the quality of life at IMT.

Green strategy

In line with the roadmap for ecological transition adopted by the Institut Mines-Télécom, the school has chosen to emphasise the ecological cornerstone of sustainable development. This does not mean giving up the "societal" aspect or the economic dimension. The various UN Sustainable Development Goals (SDGs) are difficult to reconcile - even though they are highly interdependent. IMT's strategy thus retains a systemic approach, which is essential in view of the gigantic transformation project awaiting our societies.

IMT Atlantique has identified four main areas of work, which will be the focus of future actions. Firstly, acting to mitigate the impact of climate change, with an emphasis on reducing energy intensity. Secondly, preserving the diversity of species and resources. Thirdly, inventing sustainable modes of production and consumption. And finally, facilitating the adaptation of societies to change, and build a sustainable, resilient, responsible world.

These choices reflect a particular focus on three SDGs: combating climate change (SDG 13), access to quality education (SDG 4), responsible consumption and production (SDG 12). To these were added SDGs 14 and 15 on marine and terrestrial biodiversity - two goals that may seem far removed from the concerns of a technical university like IMT Atlantique, but which are essential for the long term.

Innovative teaching practices

IMT university is actively involved in diverse forms of pedagogical innovation (MOOCs, serious games, the QPES colloquium on pedagogical issues in Higher Education, etc.).

IMT Atlantique is drawing on its expertise with MOOCs to increase its international influence. The pioneering phase now behind us, several MOOCs are produced every year and deployed on FUN (the French national online education platform), Coursera or edX. English versions are also produced to increase distribution. These MOOCs are also widely used in certified training courses because they develop students' skills, particularly through peer-to-peer exchanges.

In addition to these measures, the university has also designed several teaching tools to stimulate learning by helping students “learn through doing”. This is the case of the Pyrat project, in which students must design a video game to develop their computer skills; the “build your robot” project concludes the first semester with a competition between student teams; and the Ice-cream "serious game" which illustrates the bullwhip effect as players set up a supply chain.

University of Dubrovnik

General info

The University of Dubrovnik (UNIDU) is a public university founded in 2003 and located in Dubrovnik, Croatia. It was founded based on a very long tradition dating back to the 17th century and decades of modern higher education. UNIDU's vision and mission is to become an internationally recognised institution that actively contributes to the local, national, and international academic community through education and scientific work consistent with the highest standards of excellence.

Over the years, UNIDU has participated in numerous international academic initiatives. It is one of the few higher education institutions in Croatia offering double degree master’s programmes. All programmes are compatible with the Bologna Declaration and follow the 3+2+3 scheme.

The main goal of UNIDU is to further develop international cooperation programmes, which include exchange and mobility projects for students and professors, development of joint foreign language study programmes with international partners and creation of a small but high-quality university with its own identity.

UNIDU consists of 6 departments (Aquaculture, Art and Restoration, Economics and Business Economics, Electrical Engineering and Computing, Maritime and Mass Communication) and 2 institutes (Institute for Marine and Coastal Research, Institute for Mediterranean Plants).

UNIDU educates students in the following fields: Maritime Affairs, Economics, Electrical Engineering, Computing, Aquaculture, Mass Communication, Art and Restoration, History, Nursing and Finance.

UNIDU has about 243 permanent staff (including 147 academics), about 1500 full-time students and more than 110 exchange students per year.

Green strategy

The University of Dubrovnik (UNIDU) does not have a specific green strategy document, but is involved in numerous projects and other activities.

At the University of Dubrovnik, several projects in the field of environmental protection have been implemented by LARIAT (Laboratory in the Department of Electrical Engineering and Computing) and the Department of Applied Ecology. For example, UNIDU is the project holder of the tender "A Scheme for Strengthening Applied Research for Climate Change Adaptation Measures" (in Croatian: "Shema za jačanje primijenjenih istraživanja za mjere prilagodbe klimatskih promjena"). UNIDU projects such as MARLESS, InnovaMare and SeaClear address marine environmental protection issues.

In UNIDU Strategy Document[44] „STRATEGIJA RAZVOJA SVEUČILIŠTA U DUBROVNIKU (2016. – 2025.)", chapter 6.1. "Obrazovanje i istraživanje za održivi razvoj", it is mentioned that: UNIDU supports the policy of sustainable development, which extends from the protection and wise use of natural resources to all spheres of human existence and activity. The University of Dubrovnik, through its procedures and programs, must lead such a development policy, which not only does not question the principles of sustainable development, but also promotes and implements them with all available means. Therefore, it is necessary to unite all capacities at the University of Dubrovnik, both students and teachers, programmatic and planning, to form

[44] University of Dubrovnik. (2016). Strategija razvoja Sveučilišta u Dubrovniku 2016-2025 [PDF file]. Retrieved from https://www.unidu.hr/wp-content/uploads/2020/03/STRATEGIJA_RAZVOJA_SVEUCILISTA_U_DUBROVNIKU_2016-2025.pdf

a single coordinating body that, together with the City of Dubrovnik and Dubrovnik-Neretva County, will be involved in the implementation of the sustainable development policy at all levels and in all areas.

Innovative teaching practices

The Development Strategy for E-Learning at the University of Dubrovnik ("Strategija razvoja Sveučilišta u Dubrovniku (2019-2022)") [45] supports the creation, development and assessment of e-content and repositories and emphasises the importance of teachers as mentors, coordinators, and promoters of the educational process.

The aforementioned strategy is in line with the University of Dubrovnik Development Strategy document („Strategija razvoja Sveučilišta u Dubrovniku (2016. – 2025.)") and the National Strategy for Education, Science and Technology (Official Gazette No. 124/2014) ("Strategija obrazovanja, znanosti i tehnologije")[46], which emphasises in several places that teachers in higher education must assume obligations related to the creation, development and review of e-learning content and tools for the needs of all levels of education.

The e-learning development strategy at UNIDU aims to achieve the strategic goals of improving the quality of higher education, increasing the competitiveness of the university and university programmes through the development of ICT-enabled courses and programmes, and training students for independent education and lifelong learning using ICT. The strategy envisions four groups of tasks to achieve the goals: human resources and organizational environment development, support to teachers and students, infrastructure development, and development of educational content. One of those groups relates to the design, development, and evaluation of educational content. Within this group, three

[45] University of Dubrovnik. (2019). Strategija razvoja e-učenja na Sveučilištu u Dubrovniku 2019-2022. Retrieved from https://www.unidu.hr/wp-content/plugins/quarascope/download.php?file=2126

[46] Narodne Novine. (2014, October 10). Strategija obrazovanja, znanosti i tehnologije. Official Gazette. Retrieved from https://narodne-novine.nn.hr/clanci/sluzbeni/2014_10_124_2364.html

operational actions are mentioned: the definition and creation of standards and recommendations for e-learning materials, the definition of guidelines for the evaluation process of e-learning materials, and the creation and maintenance of the university repository for e-learning materials.

Respondents

As we highlighted earlier, distinct approaches were adopted for processing the data originating from interviews and the data garnered through questionnaires. The rationale for this separation stemmed from the distinct formats of these data sources, necessitating specialized procedures for data extraction from recorded interviews.

Our objective was to draw meaningful and comprehensive conclusions from both the interview responses and the questionnaire answers. Below, in each section, we present a portion of our findings in parallel, systematically aligning them with their corresponding topics.

Academic and demographic structure

During our interviews, we engaged with a diverse group of 11 lecturers and 1 teaching assistant. This group comprised 7 males and 5 females. The interviews were conducted in varying formats, 10 of them were held in-person and the remainder as online meetings via the MS Teams platform. An intriguing aspect of our approach was our interaction with experts spanning different fields. These fields encompassed social sciences (Didactics in Languages; Interculturality), natural sciences (Microwaves; Signal Processing), and engineering (3D Interaction with User Interface; 3D Printing and Modelling; Accessibility; Algorithms and Data Structures; Computer Vision in Robotics; Emerging Technologies for Communication, Education, and Increasing Awareness; Geographic Information Systems; Interactive Multimedia; Network Traffic Modelling and Analysis; Optical Networking; Programming; Technology in Education). While some of our interviewees possessed expertise in multiple domains, it was noteworthy that the same research area was rarely covered by more than

one expert. This intentional approach aimed to capture diverse perspectives from a varied expert population. As future work, a compelling avenue could involve comparing the viewpoints of experts contributing to the same field.

Conversely, the questionnaire enjoyed significantly broader participation, with a total of 224 individuals taking part. This contrast in numbers can be attributed to the user-friendly nature of the questionnaire, which facilitated swift and structured data collection. Among these participants, the majority hailed from the University of Debrecen (45.1%) and the University of Zagreb (33.9%), as depicted in Figure 3. The remaining institutions - Technical University of Valencia (9.4%), IMT Atlantique (6.3%), and University of Dubrovnik (5.4%) - had a comparatively smaller representation. In terms of academic roles, as depicted in Figure 4, our respondents spanned both students and lecturers (including teaching assistants), constituting 74.1% students and 25.9% lecturers. Figure 5 shows that across all institutions, a male predominance emerged, which could be attributed to the prevalence of technical colleges where male students still constitute a majority[47].

[47] Botella, C., Rueda, S., Lopez-Iñesta, E., & Marzal, P. (2019). Gender Diversity in STEM Disciplines: A Multiple Factor Problem. Entropy, 21, 30. https://doi.org/10.3390/e21010030

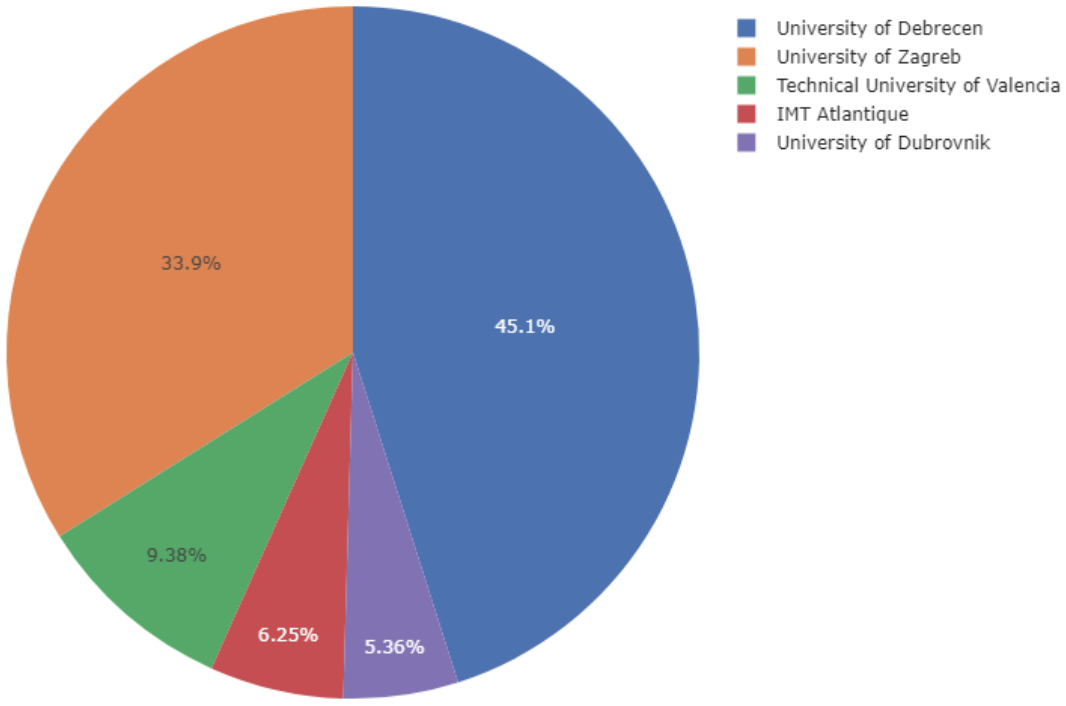

Figure 3: Institutional distribution of respondents (questionnaire)

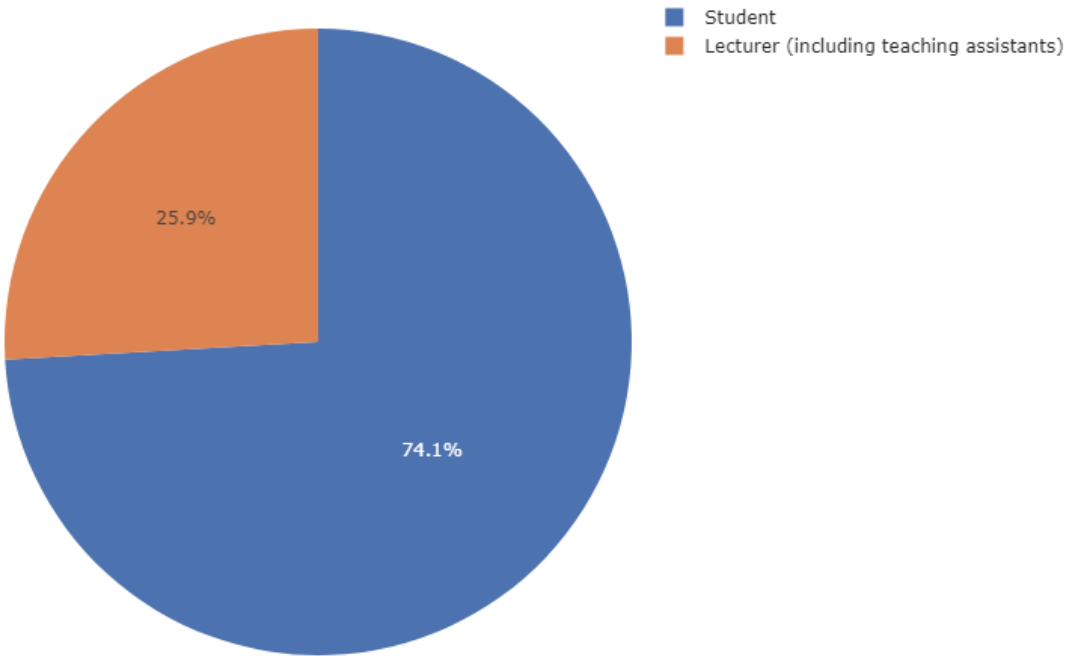

Figure 4: Role distribution of respondents (questionnaire)

This comprehensive overview of our data sources and participants provides a foundational understanding of the diverse perspectives contributing to our study.

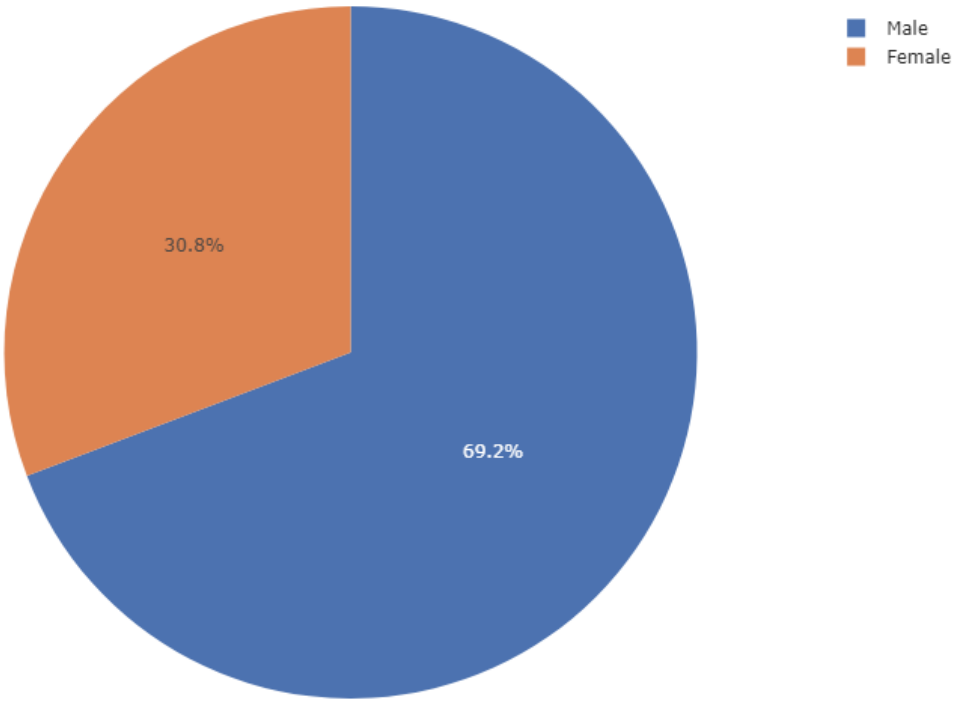

Figure 5: Gender distribution of respondents (questionnaire)

Gaming and emerging technology experience

Exploring participants' engagement with the realm of games and emerging technologies (ET) was a central aspect of our research focus. To delve into this aspect comprehensively, we posed several questions to understand their habits and knowledge concerning emerging technologies, gaming, including serious gaming, and environmental topics. The exploration began with the analysis of the questionnaire data, which yielded several intriguing insights that provide a rich tapestry of understanding.

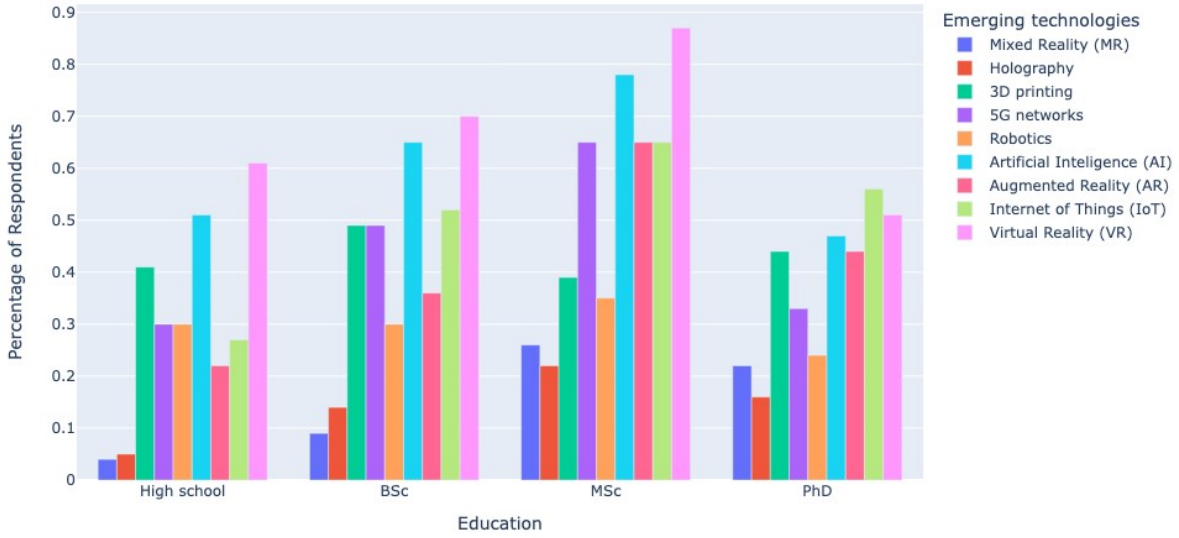

Figure 6: Percentage of participants experienced in various ET, grouped by level of education.

Firstly, as we correlated the awareness of emerging technologies with participants' educational levels, a clear pattern emerged. Notably, individuals with a "High school" education level exhibited the lowest familiarity with emerging technologies, with only 46.8% recognizing the term "emerging technologies" before completing the questionnaire. However, as educational levels progressed, so did the percentage of participants who recognized the term ET. Specifically, 74.0% of "BSc" participants were acquainted with the term, and this percentage increased further for "MSc" (87.0%) and "Ph.D." (84.4%) participants. Furthermore, respondents who indicated even a modest familiarity typically labelled themselves as "Slightly" or "Moderately" acquainted. Intriguingly, the majority of "MSc" participants categorized themselves as "Very" acquainted. Upon examining Figure 6, a trend became evident where higher levels of education correlated with a greater proportion of participants having experience with various emerging technology options. This implies that students, over the course of their undergraduate and postgraduate studies, tend to

encounter a diverse array of emerging technologies, fostering a sense of familiarity. It's important to acknowledge that Ph.D. participants deviated from this pattern. Notably, the most prevalent emerging technologies identified were Virtual Reality (VR) and Artificial Intelligence (AI). Different institutions excelled in distinct areas - the University of Zagreb stood out in VR, while the University of Dubrovnik led in AI. Additionally, the University of Debrecen, Technical University of Valencia, and IMT Atlantique demonstrated prominence in 3D printing. However, it's imperative to consider the uneven distribution of participants across institutions, underscoring the need for more nuanced analysis.

Another fascinating insight relates to participants' experiences with gaming and serious gaming. We inquired about the frequency of their engagement with video games (VG) and serious games (SG), employing a scale of 1 ("Never") to 5 ("Very often"). Delving deeper into the responses unveiled a notable trend. Lecturers exhibited a tendency to engage in both regular video games and serious games less frequently compared to students. On average, lecturers reported scores of 2.41 for VG and 1.88 for SG, whereas students reported scores of 3.42 for VG and 2.28 for SG. This pattern was echoed in our interview findings as well. Interestingly, only a quarter of the interviewed lecturers indicated playing games during their leisure time, while the majority either engaged rarely or not at all. One lecturer offered a perceptive perspective, noting that "Scientists generally do not like to play (games) because they play at work all the time." This observation underscores the demanding and creative nature of their professional commitments.

In essence, our exploration into participants' interaction with emerging technologies and gaming nuances has unveiled multifaceted insights, allowing us to better understand the intricate relationship between these domains and our research objectives.

Motivation and personal opinion

One of the pivotal aspects of our research journey was to delve into the motivations and viewpoints of participants regarding the integration of green-themed content into courses

that were originally designed without an environmental focus. This section unveils a comprehensive analysis of the insights garnered from these intriguing facets of our study.

Within the realm of interviewed lecturers, an overwhelming majority expressed a notable motivation for the inclusion of serious games in their courses. A subset even found this concept to be not just educational but also genuinely entertaining and engaging. While their enthusiasm shines through, a fraction pointed out that their motivation might waver if the process of integrating these games proves to be excessively demanding or if a collective approach isn't adopted. An interesting alignment emerged when we probed the questionnaire data. A deeper dive into this data illuminated a moderate negative correlation between lecturers' enthusiasm for inclusion and their perception of the inherent difficulty in incorporating serious games (Pearson's r: -0.5156; p-value: 0.0000). However, this correlation didn't emerge in the students' responses, potentially attributable to the fact that lecturers are chiefly tasked with the process of integrating serious games. Thus, increased complexity might not necessarily translate into heightened enthusiasm for them.

Moreover, during our interviews, participants articulated their concerns regarding the complexities of embedding green-themed serious games into courses with a non-green focus. One substantial concern echoed through these discussions: while the aspiration to integrate environmental topics is commendable, lecturers who are not well-versed in ecological matters might not possess the necessary competence to effectively convey such content. A probable solution is additional training to empower lecturers to confidently disseminate green-related material. Another insightful observation was the need for coherence between the existing course content and the introduced serious game. A thought-provoking point arose, cautioning against shoehorning green themes into courses that lack a strong foundational connection, which could potentially dilute the intended impact.

Several thought-provoking perspectives enriched the discourse:

- The lecturers' plates are already brimming with teaching, research, and project commitments. Consequently, unless external motivators like financial incentives or substantial support are provided, their willingness to embrace inclusion might wane.
- A reluctance to adopt technology could influence some lecturers' decision-making. Hence, it's of paramount importance that the inclusion material is user-friendly, catering to a broad spectrum of technological proficiency.
- A prevalent lack of understanding about the nature of serious games exists. Moreover, many harbour negative perceptions about integrating games into educational contexts, citing concerns about students' excessive exposure. This intricately woven web of opinions indicates that the adoption of serious games might not be immediately welcomed.

Delving into the responses from the questionnaire, it emerged that participants displayed a moderate level of interest in the prospect of inclusion. Their envisaged benefits were twofold: "Improving skills and knowledge on green topics" and "Increasing motivation through interactive learning." On the flip side, they envisaged "Difficulties connecting the green topics with the existing course" as a major challenge.

Furthermore, insights gleaned from interviewed lecturers suggested that student receptiveness hinged on individual preferences. Diligent students were inclined to be motivated by the perceived benefits of a class and the approachability of the instructor.

In summation, this comprehensive exploration into participants' motivations and opinions on embedding green-themed serious games into diverse educational settings uncovers a rich tapestry of insights, providing a holistic perspective on the multifaceted dynamics at play.

Table 1 provides more insights into potential differences between lecturers and students based on their average responses on a 5-point Likert scale[48].

Table 1: Summary of average results for 5-Point Likert-based questions based on roles.

Attribute	Lecturer (including teaching assistants)	Student	Total
Teaching innovation preference	3.07	3.49	3.38
Knowledge level on emerging technologies	3.22	2.89	2.97
Video game playing frequency	2.41	3.42	3.16
Serious game playing frequency	1.88	2.28	2.18
Familiarity on green topics	3.38	2.83	2.97
Digitalization level (case study)	3.5	3.36	3.39
Interest for green-themed serious game (case study)	3.03	3.02	3.03
Integration difficulty level of green-themed serious game (case study)	2.95	3.13	3.08
Impact of green-themed serious game on quality of case study course	3.62	3.47	3.51
Motivation for case study course after inclusion of green-themed serious game	3.59	3.66	3.64

[48] Unless explicitly stated otherwise in this report, a rating of 1 on the 5-point Likert scale corresponds to "very low," while a rating of 5 indicates "very high".

Key findings for each of HEIs from the consortium

Table 2 presents the key findings from 23 non-green-themed courses offered by 5 HEIs within the consortium.

Table 2: A summary table with non-green-themed HEI courses which were analysed in this report.

Institution	Course name	Summary	Identified modality	Practical implementation
University of Zagreb	Popularization of Science	The course covers techniques of creating workshops, lectures, and exhibitions on scientific topic to pupils and non-professional audience.	Using a game as a starting point for practical assignments	Create workshops for pupils based on serious game (playing or any other way).
	Object Oriented Programming	Students are introduced to the fundamentals of object-oriented modelling and programming.	Learn-to-code game development	A series of laboratory assignments that gradually builds the game: sketch the class diagram, implement classes, refactor, design graphical user interface etc.
	Network Performance and Traffic	Architectures and technologies of today's networks, analysis and modelling of network traffic at the packet, burst and flow level, metrics for network performance,	Explaining the green aspects of course-related concepts	Serious game that is used by lecturer to design an efficient system to reduce the number of backup devices.

		network traffic modelling, etc.		
	Networked Games	Networked virtual environments, distributed physics simulations, networked game architectures, network parameter effects on quality of experience, delay compensation mechanisms, etc.	Project-based green-themed serious game development	Project assignment for team of students in a dedicated game development course
			Using a game as a starting point for practical assignments	A task that as an input provides a source code of the game and expects the optimized code that will consume less energy when more players are playing
	Human Factors in Computing	Introduction to the field of ergonomics, recognizing the principles of ergonomics in daily life in the context of workplaces with emphasis on computer equipped workplaces.	A case study for universal design, accessibility, new technologies	Example of the game that follows UDL guidelines.
	Network and Distributed Systems Reliability	Students gain knowledge of reliability, availability, and security of systems and networks, the impact of testing on software reliability, and analysis of	Manually testing a green-themed serious game	As a part of the laboratory assignment, test the game and find bugs.

		distributed systems performance.		
	Management in Engineering	Within this subject, students must acquire knowledge of the economic, legal and project environment.	Creating situations	During lectures use the game as an example of responsible engineering to teach students how to be responsible towards society.
	Communication Software Development	Within the scope of the subject students gain knowledge on software product life-cycle processes and software development models.	Project-based green-themed serious game development	Make a game prototype to complete one laboratory assignment.
Universitat Politècnica de València	Multimedia Equipment	The course deals theoretically and practically with the main features of today's multimedia equipment.	Examining knowledge on green topics	Include questions related to the game into the exam.
			Create multimedia content	Create videos or animations about the game as part of the content creation process.
			Explaining the green aspects of course-related concepts	Serious game that is used by lecturer to teach about the proper way of recycling various multimedia equipment.

	Microwaves	Students are familiar with the scattering matrix (S parameters), their meaning, how to calculate them, the benefits at high frequencies and applying theoretical knowledge to higher modes.	Measuring game outputs	As a part of the laboratory assignment, measure the power that the device radiates when the game is played.
University of Debrecen	Database Systems	Students study about designing ER models, relational databases, basics of database managing systems.	Explaining the course-related concepts	Use database scheme related to the green topics in order to explain the basic course concepts.
	3D Printing and Modelling	During the course the basic principles of 3D printing technologies (through illustrative samples), requirements of 3D printable models, settings and functionality of slicer programs are discussed.	Content adaptation towards green topics from the game	3D models that are being printed during the classes can be inspired by the game.
			Collecting points by playing a game	Solving a game for homework or during the lecture to gain extra course points.
	Descriptive Geometry	Descriptive geometry is a branch of geometry in which the three-dimensional spatial objects are represented on a plane using one of projecting methods.	Content adaptation towards green topics from the game	Take some objects from the game, simplify them, and try to project them into 2D space.

IMT Atlantique Bretagne Pays de la Loire	Programming of Robotic Systems	This course introduces both at a theoretical as well as practical level elements that are required for autonomous operation of robots.	Development of a game aspect	Development of a game component that relies on computer vision to recognise different objects related to green topics (e.g. various plants)
			Explaining the green aspects of course-related concepts	Serious game that is used by lecturer to teach about efficient robotic programming.
	Optical Networks	This course deals with optical networks, presenting optical networking techniques and methods. The links between the telecom business, the technologies and the regulation are also explained.	Explaining the green aspects of course-related concepts	Serious game that is used by lecturer to teach about the energy usage in networks.
	French as Foreign Language	Developing communication, teamwork and intercultural skills facilitates the integration of future international engineers into research and innovation teams.	Learning a foreign language	A homework assignment that includes playing the game to learn the green-themed vocabulary.
	Intercultural Training	The objectives of this course are to understand what an intercultural	A case study for universal design, accessibility,	A practice that discusses the key universal design for learning guidelines

		approach is to better adapt, collaborate in a complex and international world.	new technologies	implemented in the game.
			Creating situations	Using the game during the lecture for putting students in situations that are discussed at class from an ethical viewpoint.
University of Dubrovnik	Project	Mentored project/paper.	Creating scenarios for green-themed serious games	Create game experience as a task for the project.
			Using a game as a starting point for practical assignments	Use the game data to get initial input for programming, prototyping etc.
			Project-based green-themed serious game development	Develop a green-themed serious game as a task for the project.
	Object Oriented Programming	Students are introduced to the fundamentals of object-oriented modelling and programming.	Explaining the course-related concepts	Slides with the code snippets from the serious game that showcases the programming concepts.
			Content adaptation towards green topics from the game	Programming tasks that are adapted from the general themes (e.g. trigonometry) towards the green themes (e.g. electric vehicles) from the game available as the lecture resource.

			Learn-to-code game development	A series of laboratory assignments that gradually builds the game: sketch the class diagram, implement classes, refactor, design graphical user interface etc.
	Introduction to Data Science	Students are introduced to definition of data science, how to collect, format and storage data, definition of data concepts and examples.	Using a green-themed dataset used by the game	Exploratory analysis of weather data used as an input for the game.
	Hardware Ergonomics	Students are introduced to the field of ergonomics and its principles in daily life, analysis of human-computer interaction, user capabilities, concept of Universal Design, definition of accessible software solution, assistive technologies, and possibilities of new technologies.	A case study for universal design, accessibility, new technologies	A seminar that discusses the key universal design for learning guidelines implemented in the game.
	Distributed information Systems	Students are introduced to basics of distributed information	Measuring game outputs	If a game is connected to some sensors, measure their output and use

		systems, different ways to implement them, and different technologies used in these systems.		that data for further processing.
	Technical Writing	Students are introduced to the basics of writing academic papers and documents in technical professions.	Practice academic writing	Students write a scientific paper based on some concept or anything demonstrated in the game.
			Giving examples of academic papers	Students review scientific papers that are connected to the topics explored in the game.

Modalities for inclusion of green-themed serious games in non-green-themed higher education courses

The pivotal segment of both the interview and the questionnaire delved into the extraction of the aforementioned modalities. However, before embarking on the unveiling of these modalities, it's imperative to underscore the findings related to teaching techniques. This adds a contextual layer to the subsequent insights. Notably, our exploration into the preference for innovation in teaching techniques revealed a noteworthy distinction between students and lecturers. Students exhibited a greater affinity for innovative methods. However, both groups reported that traditional lecturing (95% lecturers; 94% students) and project-based learning (83% lecturers; 66% students) constituted the primary teaching techniques employed in their respective courses. Intriguingly, gamification emerged as the least employed technique for both categories. Specifically, only 14% of lecturers and 9% of

students incorporated this innovative teaching method into their instructional approach. This signifies a fertile ground for advancement within this realm.

With this understanding as a backdrop, we proceed to unveil the modalities that surfaced through our study, along with their tangible implementations into existing courses. These modalities offer a structured framework for the integration of green-themed serious games into educational contexts that might not inherently possess environmental themes.

Derived modalities

Following a meticulous analysis of both the interview transcripts and the responses gathered from the questionnaires, we successfully identified a total of 19 distinct modalities that effectively facilitate the integration of green-themed serious games into higher education courses that originally lack environmental themes. To enhance clarity and organization, we have systematically categorized these modalities into 7 separate groups, each aligned with specific teaching techniques or aspects of the course. You can find an overview of these modalities presented in Table 3.

Notably, an interesting trend emerges when assessing the most prevalent modalities across both the interview and questionnaire data. Remarkably, the top 5 most frequently mentioned modalities are consistent between the two methods. These include "Explaining the green aspects of course-related concepts," "Explaining the course-related concepts," and "Project-based green-themed serious game development." However, the interviews further established the significance of the "Content adaptation towards green topics from the game" modality. On the questionnaire side, "Collecting points by playing a game" and "Using a game as a starting point for practical assignments" emerged as particularly noteworthy. This divergence in priorities could potentially be attributed to the opposite perspectives of students and lecturers. Students may have a stronger focus on achieving successful course completion, while lecturers are primarily concerned with efficiently delivering lectures and transmitting knowledge. Essentially, altering the phrasing of an assignment might require less

effort compared to crafting entirely new laboratory exercises grounded in green-themed serious games – a point of lesser relevance to students.

This synthesis of modalities and their nuanced implications offers a comprehensive roadmap for integrating green-themed serious games into the curriculum of non-green-themed courses. The diversity of these modalities reflects the multifaceted nature of education and highlights the dynamic interplay between teaching techniques, course content, and the incorporation of innovative pedagogical tools.

Table 3: Identified modalities for inclusion of green-themed serious games into non-green-themed higher education courses and examples of their practical implementation.

Category	Identified modality	Practical implementation	
		Course	Modality implementation
Teaching concepts	**Explaining the green aspects of course-related concepts**	Optical Networks	A serious game used by the lecturer to teach about the energy usage in networks.
	Explaining the course-related concepts	Database Systems	Use database scheme related to the green topics in order to explain the basic course concepts.
Game development	**Project-based, green-themed serious game development**	Networked Games	Project assignment for a team of students in a dedicated game development course.
	Learn-to-code game development	Object Oriented Programming	A series of laboratory assignments gradually builds the game: sketch the class diagram, implement classes, refactor, design a graphical user interface, etc.
	Manually testing a green-themed serious game	Network and Distributed Systems Reliability	As a part of the laboratory assignment, test the game and find bugs.
	Development of a game aspect	Programming of Robotic Systems	Develop a game component that relies on computer vision to recognize different objects related to green

			topics (e.g., various plants).
Data sourcing	**Using a green-themed data set used by the game**	Introduction to Data Science	Exploratory analysis of weather data used as an input for the game.
	Using a synthetic data set from the game	Distributed Information Systems	If a game is connected to some sensors, measure their output, and use that data for further processing.
Case study	**Using a game as a starting point for practical assignments**	Popularization of Science	Create workshops for pupils based on a serious game (playing or any other way).
	A case study for universal design, accessibility, new technologies	Hardware Ergonomics	A seminar discusses the key universal design for learning guidelines implemented in the game.
Academic writing	**Practice academic writing**	Technical Writing	Students write a scientific paper based on some concept or anything demonstrated in the game.
	Giving examples of academic papers	Technical Writing	Students review scientific papers that are connected to the topics explored in the game.
Course grading	**Examining knowledge on green topics**	Multimedia Equipment	Include questions related to the game in the exam.
	Collecting points by playing a game	3D Printing and Modelling	Solve a game for homework or during the lecture to gain extra course points.

Creative applications	**Creating scenarios for green-themed serious games**	Project	Create a game experience as a task for the project.
	Creating situations	Intercultural Training	Use a game during the lecture to put students in situations discussed in class from an ethical viewpoint.
	Learning a foreign language	French as Foreign Language	A homework assignment that includes playing the game to learn green-themed vocabulary.
	Content adaptation towards green topics from the game	Descriptive Geometry	Take some object from the game, simplify it, and try to project it to 1D space.
	Creating multimedia content	Multimedia Equipment	Create videos or animations about the game as part of the content creation process.

Practical implementation to the courses

In addition to deriving modalities, our objective encompassed establishing tangible connections between these modalities and real-world scenarios. Essentially, we aimed to uncover the practical applications of these modalities within the existing curriculum of the participating Higher Education Institutions (HEIs). During the interview phase, we successfully identified 34 instances of these concrete case scenarios. Each instance correlated a specific course with a modality, further augmented by a detailed account of its practical implementation. This illuminating process allowed us to gain insights into how these modalities could seamlessly integrate into diverse courses across different HEIs.

For clarity and comprehensiveness, each course-modality pairing was accompanied by an elaborative description of its practical execution, as well as the respective HEI where the course is conducted. It's worth mentioning that we did not employ the same mapping approach for the questionnaire answers. This distinction was due to the inherent limitations of the data-gathering method, which often lacked the depth required for comprehensive explanation.

To exemplify our discoveries, we've chosen to showcase the case of "Object Oriented Programming." This particular course, conducted at the University of Zagreb, is distinctly centred around programming. Drawing from insights gathered during interviews, we paired it with the "Learn-to-code game development" modality. Delving deeper into practical implementation, we learned that this modality could be manifested as "A series of laboratory assignments that gradually build the game: sketch the class diagram, implement classes, refactor, design graphical user interface..." This real-world example vividly illustrates how the modality aligns with course content and could be effectively incorporated into the curriculum.

Furthermore, Table 3 serves as a repository of illustrative course examples, one for each derived modality, originating from one of the participating HEIs. These practical cases provide tangible demonstrations of the seamless integration of modalities into actual courses, exemplifying the dynamic synergy between theory and application.

Additional insights

Beyond the already unveiled findings, our interviews yielded a trove of additional insights that shed light on the intricacies of integrating green-themed serious games into the fabric of higher education. These unanticipated revelations emanate directly from the valuable commentary provided by lecturers, offering a rich tapestry of perspectives that went beyond the explicit questions posed.

To start, a consensus emerged among most lecturers: if they possess sole responsibility for a course, they maintain the autonomy to integrate green-themed serious games at their discretion. However, the scenario becomes notably intricate when multiple colleagues share the course responsibilities. In such instances, unanimous agreement is requisite before incorporating these novel materials into the curriculum. Adding a layer of complexity, some lecturers emphasized the significance of university politics. This is attributed to the alignment of course topics and learning objectives with broader university or faculty programs, potentially necessitating approval from higher institutional authorities.

Interestingly, the feedback further illuminated the notion that discussions surrounding green topics should commence from the very outset of the curriculum. The consensus is that green subjects should be woven into course content right from the first year, tailored to the complexity level corresponding to the students' study stage. Simplicity for freshmen gradually evolving into greater intricacy as they progress. In this regard, lecturers expressed the belief that the inclusion should be pervasive across numerous courses, serving as a universal thread that can be seamlessly woven into diverse subjects.

A yearning for solidarity surfaced among some lecturers, reflecting a desire for collective involvement in integrating green-themed serious games. The prospect of like-minded colleagues joining the journey resonated as a reassuring notion, fostering an environment where collaboration would lessen the individual burden. Moreover, while the lecturers demonstrated considerable interest in green-themed serious games, several pointed to the necessity for tangible examples. These examples need not be confined to their own disciplines; instead, they emphasized the value of any demonstration that offers insight into such games or courses, complete with syllabi and information about expected student engagement. These exemplars would serve as guiding beacons through the integration process. Nevertheless, even in the presence of well-crafted examples, lecturers underscored the crucial need for patience. Realistically, a process involving 2-3 iterations is essential to

gather feedback, recalibrate, and fine-tune the approach to effectively integrate green-themed serious games.

In summation, these untapped insights emanating from the interviews provide a holistic perspective on the multifaceted considerations and dynamics that underlie the endeavour to infuse green-themed serious games into higher education curricula.

The potential of emerging technologies for green-themed serious games

Artificial Intelligence (AI)

Potential for serious games

Artificial intelligence (AI) has significant potential for enhancing serious games. By leveraging AI technologies, serious games can offer more immersive, adaptive, and intelligent experiences, making them highly effective tools in various domains.

Adaptive Gameplay [49] : AI enables serious games to dynamically adapt to the player's behaviour, skills, and learning progress. By employing machine learning algorithms, games can analyse player actions and make real-time adjustments to provide personalized challenges and content. For example, in educational games, AI can assess a student's performance, identify areas of weakness, and tailor the game's difficulty level or content to suit the individual's needs.

Intelligent Agents[50]: AI-powered intelligent agents can enhance the realism and complexity of serious games by simulating human-like behaviours. These agents can act as virtual characters, opponents, teammates, or instructors, offering interactive and engaging

[49] Dobrovsky, A., Borghoff, U. M., & Hofmann, M. (2019). Improving adaptive gameplay in serious games through interactive deep reinforcement learning. Cognitive infocommunications, theory and applications, 411-432.
[50] Wooldridge, M. (1999). Intelligent agents. Multiagent systems: A modern approach to distributed artificial intelligence, 1, 27-73.

experiences. For instance, in medical simulations, AI-driven virtual patients can exhibit realistic symptoms, respond to treatments, and provide valuable feedback to trainees.

Natural Language Processing[51]: AI techniques like natural language processing (NLP) enable serious games to understand and generate human language, facilitating communication and interaction. NLP can be utilized in language learning games, virtual simulations with conversational agents, or in scenarios where players need to give verbal commands to control the game environment.

Data-driven Decision Making[52]: AI algorithms can process large amounts of data generated during gameplay, providing insights and informing decision-making processes. This data-driven approach can be applied in various contexts, such as business simulations, military training, or healthcare scenarios, where analysing player performance and decision patterns can lead to improved strategies and outcomes.

Emotion Recognition and Adaptive Feedback[53]: AI can analyse player facial expressions, gestures, or speech to recognize emotions and adapt the game's feedback accordingly. This capability enhances the emotional engagement and personalization of serious games. For example, in mental health interventions, games can use AI to detect signs of stress or anxiety in players and adjust the gameplay or provide supportive feedback accordingly.

[51] Picca, D., Eberlé, G., & Jaccard, D. (2015). Natural Language Processing in Serious Games: A state of the art. International Journal of Serious Games, 2(3).
[52] Hooshyar, D., Yousefi, M., & Lim, H. (2018). Data-driven approaches to game player modeling: a systematic literature review. ACM Computing Surveys (CSUR), 50(6), 1-19.
[53] Frommel, J., Schrader, C., & Weber, M. (2018, October). Towards emotion-based adaptive games: Emotion recognition via input and performance features. In Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play (pp. 173-185).

The research on AI in games can be explored in many publications, including IEEE Transactions on Computational Intelligence and AI in Games[54] and IEEE Transactions on Games[55].

Potential for green-themed serious games

AI has significant potential for green-themed serious games, offering unique opportunities to raise awareness, educate, and promote sustainable behaviours. Here are some aspects of AI's potential in this context:

Realistic Simulations[56]: AI can power realistic simulations of environmental systems, enabling players to experience the impact of their actions on the environment. By incorporating AI algorithms, serious games can simulate the effects of pollution, deforestation, climate change, and other environmental factors, allowing players to understand the consequences of their decisions and encouraging them to make environmentally conscious choices.

Personalized Feedback[57]: AI algorithms can analyse players' actions and provide personalized feedback based on their environmental impact. This feedback can help players understand the specific implications of their choices, guiding them towards more sustainable behaviours. AI can adapt the game's challenges and content to the player's skill level and knowledge, ensuring an engaging and educational experience.

Behaviour Change[58]: AI can contribute to behaviour change by leveraging techniques such as reinforcement learning. By tracking and analysing player behaviour, AI algorithms can identify

[54] IEEE Computer Society. (2017). Past Issues - 2010. IEEE Computer Society Digital Library. Retrieved from https://www.computer.org/csdl/journal/ci/past-issues/2010/2017

[55] IEEE Xplore. (2023). Recent Issues - IEEE Transactions on Games. IEEE Xplore Digital Library. Retrieved from https://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=7782673

[56] Camargo, C., Gonçalves, J., Conde, M. Á., Rodríguez-Sedano, F. J., Costa, P., & García-Peñalvo, F. J. (2021). Systematic literature review of realistic simulators applied in educational robotics context. Sensors, 21(12), 4031.

[57] Bontchev, B. P., Terzieva, V., & Paunova-Hubenova, E. (2021). Personalization of serious games for learning. Interactive Technology and Smart Education, 18(1), 50-68.

[58] Tanenbaum, T. J., Antle, A. N., & Robinson, J. (2013, April). Three perspectives on behavior change for serious games. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 3389-3392).

patterns, reinforce positive actions, and suggest alternatives to unsustainable practices. This personalized approach can motivate players to adopt greener habits in their daily lives beyond the game.

As for a possible future game, imagine an AI-powered serious game called "EcoVille." In EcoVille, players are tasked with building and managing a sustainable city. The game incorporates AI algorithms to simulate various aspects, such as energy systems, waste management, transportation networks, and urban planning. Players make decisions regarding infrastructure, resource allocation, and policies to balance environmental sustainability, economic growth, and the well-being of citizens. The AI analyses players' choices, provides feedback on the ecological impact of their decisions, and offers suggestions for more sustainable approaches. Through immersive gameplay and personalized guidance, EcoVille educates players on the challenges of sustainable urban development and encourages them to apply these lessons in real-world contexts.

Augmented Reality (AR)

Potential for serious games

Augmented Reality (AR) is one of the emerging technologies that is being applied in more and more different fields. For example, it has great potential in developing immersive and interactive serious games aimed at education and learning purposes. The basic idea of AR is to superimpose graphics, audio, and other sensory enhancements over a real-world environment in real time, which blurs the lines of reality. In the most uncomplicated cases, smartphones or tablets are the primary platforms for AR applications, making them popular. However, sometimes additional equipment, devices, and sensors are needed, which can be a barrier for some user groups.

Using AR in a serious game means that the physical environment around us is used to frame the applications. Therefore, the application's user interface is not artificial anymore, and fewer efforts should be made to create a realistic background.

SkyMap is a hand-held planetarium that overlays information about constellations, planets, and more as you point the camera of your smartphone or tablet toward the heavens [59]. Chinese researchers have developed an AR serious game prototype with a vibrotactile feedback jacket[60]. The jacket is equipped with fourteen vibration actuators to generate an immersive AR experience. The game pulls you inside a fictional world with amazingly giant plants and insects. Some virtual characters are friendly, whereas others are aggressive to gamers. The players can interact, touch, or even fight with the virtual characters. Serious games offer a good opportunity to train and asses different skills such as spatial skills[61]. Traditional paper based test can be pushed into the digital world which make them more attractive for youngsters.

Potential for green-themed serious games

Sustainability awareness and commitment were put in the focus of a serious game, which resulted in a multiplayer AR game. The developers also evaluated their app using data from game analytics, questionnaires and video recordings, and found that players' attitudes towards sustainability issues have changed[62]. This idea and the basic structure of this game could be adopted and used for other green-themed topics including how 3D printed objects can result in a greener future.

[59] Sky Map Devs. (2021). Sky Map [Mobile application software]. Retrieved from https://play.google.com/store/apps/details?id=com.google.android.stardroid&hl=hu&gl=US

[60] Zhu, L., Cao, Q., & Cai, Y. (2020). Development of augmented reality serious games with a vibrotactile feedback jacket. Virtual Reality & Intelligent Hardware, 2(5), 454-470.

[61] Tóth, R., Zichar, M., & Hoffmann, M. (2021). Improving and Measuring Spatial Skills with Augmented Reality and Gamification. In L. Y. Cheng (Ed.), ICGG 2020 - Proceedings of the 19th International Conference on Geometry and Graphics (ICGG 2021) (Vol. 1296, Advances in Intelligent Systems and Computing, pp. 68). Springer, Cham. https://doi.org/10.1007/978-3-030-63403-2_68

[62] Strada, F., Lopez, M. X., Fabricatore, C., Dos Santos, A. D., Gyaurov, D., Battegazzorre, E., & Bottino, A. (2023). Leveraging a collaborative augmented reality serious game to promote sustainability awareness, commitment and adaptive problem-management. International Journal of Human-Computer Studies, 172, 102984. https://doi.org/10.1016/j.ijhcs.2022.102984

AR & VR is a software company whose mission is continuously develop smart and innovative technological solutions across different verticals: marketing, retail, education, tourism, art, entertainment, and others. They have an AR serious game called Entropy that integrate Internet of Things (IoT), Advanced Data Modelling and Analysis techniques, a Recommendation mechanism and Gamification to facilitate the deployment of innovative energy-aware IT ecosystems for motivating end-users' behavioural changes towards energy consumption reduction in buildings[63]. The ARvatar serious game came into the world when the FI-content project consortium and AR & VR company joined forces. The aim was to raise awareness on air pollution and other environmental issues by using concepts of Augmented Reality[64]. Their challenge was to develop a specific enabler (SE) that uses SLAM algorithm for marker-less tracking applied to Augmented Reality in serious gaming. In addition, a specific enabler had to be developed that offers features and functionalities for creating and deploying AR applications.

Virtual Reality (VR)

Potential for serious games

Virtual Reality (VR) has immense potential and value for serious gaming, revolutionizing the gaming experience by immersing players into fully interactive and lifelike virtual worlds[65]. One of the key benefits of VR in serious gaming is its unparalleled ability to provide realistic simulations and training environments. Industries such as healthcare [66], defence, and

[63]ARVR Tech. (2023). Innovations. Retrieved from https://arvrtech.eu/innovations/

[64] ARVR Tech. (2023). SERIOUS GAME WITH AR – FI CONTENT. Retrieved from https://arvrtech.eu/portfolio-items/fi-content-serious-gaming-augmented-reality/

[65] Checa, D., & Bustillo, A. (2020). A review of immersive virtual reality serious games to enhance learning and training. Multimedia Tools and Applications, 79, 5501-5527.

[66] Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. Computers & Education, 127, 252-266.

education can leverage VR to create lifelike scenarios for medical training, military simulations, and skill development, respectively. This not only enhances the learning process but also allows individuals to practice and refine their skills in a safe and controlled environment, reducing the risk associated with real-life training.

Moreover, VR offers a heightened sense of presence, making it a powerful tool for emotional and psychological engagement. Serious games designed with VR can evoke strong emotional responses and foster empathy, as players experience events from a first-person perspective. For instance, VR experiences can educate players about historical events or raise awareness about social issues by putting them directly in the shoes of relevant characters. This emotional connection enhances the impact of serious gaming, making it an effective platform for education, behaviour change, and fostering a deeper understanding of complex topics. Overall, VR's potential to provide realistic simulations, promote emotional engagement, and create tailored experiences makes it a valuable asset in the realm of serious gaming, with a multitude of applications across various fields.

AR and VR allow the expansion of knowledge on any proposed topic, in such a way that the visual information is amplified, providing details that may not be noticeable at first. Additionally, it provides a virtual environment that facilitates to include a very high learning component[67].

Furthermore, the use of VR/AR has positive effects on learning, as the use of VR/AR devices and systems is associated with more motivation, more time spent on the learning task and better acquisition of cognitive, psychomotor, and affective skills[6869].

[67] Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. Education and Information Technologies, 23(4), 1515–1529.
[68] Ajit, G. (2021). A Systematic Review of Augmented Reality in STEM Education. Studies of Applied Economics, 39(1).
[69] Garzón, J., Pavón, J., & Baldiris, S. (2019). Systematic review and meta-analysis of augmented reality in educational settings. Virtual Reality, 23(4), 447-459.

Potential for green-themed serious games

The use of AR/VR in educational games with a green theme facilitates sustainable aspects linked to the UN SDGs such as saving paper, saving trips, etc., because elements (places, objects, ...) that may be difficult to access in real life are shown in a virtual environment, with all that this implies in terms of energy savings, carbon footprint, etc.

3D printing

Potential for serious games

Three-dimensional (3D) printing is a process of creating a 3D object by fusing one layer on another according to information generated by slicing a 3D model. The model can be designed using a wide range of modelling software, but we need a 3D printer as well. Even home-printed tangible objects can be used in many fields, from medicine to education[70].

Mobile applications could teach the basics of the 3DP technology in the frame of a serious game. The acquired knowledge provides a new point of view for people to consider if they need to find an innovative and sustainable solution for some problems. For example, an application can aim to provide help in creating the model of an existing object that should be 3D printed. Such an app can reconstruct the object based on a series of photos captured by the device. The device does all the computations; thus, the model is generated using only the device's resources[71,72]. Smartphones or tablets can be turned into a 3D scanner, so users do not need to purchase one. An additional service of such an application could be to compare

[70] Babic, J., Car, Z., Gace, I., Lovrek, I., Podobnik, V., Topolovac, I., Vdovic, H., Zilak, M., Gourves, A., Sable, C., & et al. (2020). Analysis of Emerging Technologies for Improving Social Inclusion of People with Disabilities. Zagreb, Croatia: University of Zagreb, Faculty of Electrical Engineering and Computing.
[71] Xplorazzi Tech. (2021). 3D Scanner Pro - PDF Document Scanner [Mobile application software]. Retrieved from https://play.google.com/store/apps/details?id=com.xplorazzi.scannerpro
[72] Smart Mobile Vision. (2017). Scann3D - 3D Scanner App [Mobile application software]. Retrieved from https://play.google.com/store/apps/details?id=com.smartmobilevision.scann3d

the generated model to the 3D printed one. That means that the generated 3D model would be 3D printed and then scanned again to make the comparison.

Potential for green-themed serious games

The potential and value of 3D printing in green-themed serious games lie in its ability to promote sustainable practices and foster eco-consciousness. By integrating 3D printing technology into these games, players can virtually design, create, and interact with environmentally friendly objects and structures, encouraging innovative solutions for green living. Players can explore renewable energy sources, sustainable architecture, and eco-friendly product designs through hands-on experiences in the virtual world. Additionally, 3D printing empowers players to bridge the gap between virtual and real-life applications, as they can bring their in-game creations to life, inspiring them to implement sustainable practices in their everyday lives and contributing to a greener and more sustainable future.

Holograms

Potential for serious games

The emergence of holographic projection technology is set to revolutionize various fields, including education, science, art, and health. To comprehend the functioning of a holographic projector, one must first understand what a hologram is. Essentially, holography involves recording patterns of light and reproducing them as a three-dimensional image known as a hologram. There are three types of holograms: Reflection, Transmission, and Hybrid, with each type having distinct characteristics that determine its suitability for representing different objects[73].

[73] Elmorshidy, A. (2010). Holographic Projection Technology: The World is Changing, 2(2).

According to authors[74], holographic technology offers numerous benefits in education, including the ability to engage in risk-free activities, facilitate communication between students and teachers, and visualize abstract ideas and concepts. Furthermore, teachers have expressed positive attitudes towards the potential use of this technology in the classroom. A study of 400 teachers in the United Kingdom revealed that most of them believed that holographic technology would enhance learning and could serve as an effective supplement to traditional teaching in the future[75]. Despite the positive experiences associated with holographic technology, further research is required to maximize its educational potential[76].

An examination of the application of holograms in education[77] suggests that holographic projections can enhance cognitive development in students by allowing them to view subjects from various angles, leading to an improved understanding of the material. However, the use of this technology is limited by factors such as infrastructure, implementation costs, and a lack of expertise[78]. In response, authors from the paper[79] present an example of a pyramidal hologram made of glass that could be used for educational purposes. The hologram is placed on the screen of a smartphone, which displays a three-dimensional object that is reflected from the mirror of the pyramid and is projected as a hologram. Additionally, they propose using hand gesture control for hologram manipulation. Holograms are often combined with augmented reality[80], enabling people with learning or reading difficulties to visualize and

[74] Eschenbrenner, B., Nah, F. F.-H., & Siau, K. (2011). 3-D Virtual Worlds in Education. Journal of Database Management, 19(4), 91–110.
[75] Ghuloum, H. (2010). 3D Hologram Technology in Learning Environment. Proceedings of the 2010 InSITE Conference, 693–704.
[76] Fokides, E., & Bampoukli, I. A. (2022). Are hologram-like pyramid projections of an educational value? Results of a project in primary school settings. Journal of Computer Education, (0123456789).
[77] Barkhaya, N. M. M., & Halim, N. D. A. (2017). A review of application of 3D hologram in education: A meta-analysis. In 2016 IEEE 8th International Conference on Engineering Education (ICEED), pp. 257–260.
[78] Kalansooriya, P., Marasinghe, A., & Bandara, K. M. D. N. (2015). Assessing the Applicability of 3D Holographic Technology as an Enhanced Technology for Distance Learning. IAFOR Journal of Education, 3(SE).
[79] Awad, A. H., & Kharbat, F. F. (2018). The first design of a smart hologram for teaching. 2018 Advances in Science, Engineering and Technology International Conference (ASET), pp. 1–4.
[80] Klamma, R. (2019). Perspectives on Wearable Enhanced Learning (WELL).

understand objects or locations described in books by using wearable devices such as HoloLens virtual reality glasses.

Overall, holographic technology has great potential for serious games as it allows users to interact with virtual objects in a more natural and realistic way. By creating immersive and engaging simulations, holographic technology can enhance learning and training in a variety of fields.

Potential for green-themed serious games

Holographic technology has significant potential for green-themed serious games, i.e., games designed to promote environmental awareness and sustainable behaviour among players. Holograms can create immersive and interactive environments that allow players to experience and understand complex ecological systems and sustainability concepts.

One possible game that could be implemented in the future is a holographic simulation of a city's ecosystem. Players could observe and interact with different aspects of the city, such as the transportation system, waste management, and energy system, and make decisions that affect the environment and the well-being of the community. By illustrating the interconnectedness of these systems, players could learn how their individual decisions and actions affect the environment and work toward sustainable solutions.

Another potential use of holographic technology in green-themed serious games is in educational content creation. Holograms could be used to illustrate environmental phenomena and concepts in more engaging and memorable ways, such as the effects of climate change or list of endangered species (e.g. IUCN Red List). By using holographic technology, game developers could create more immersive and interactive experiences that encourage players to act for sustainability and raise awareness of a critical condition of the health of the world's biodiversity.

Guidelines for implementing Universal Design for Learning principles in green-themed serious games

As mentioned in the beginning of this study, UDL has identified 3 major didactic points, which can be broken down into 9 principles, as shown in the taxonomy from the figure below.

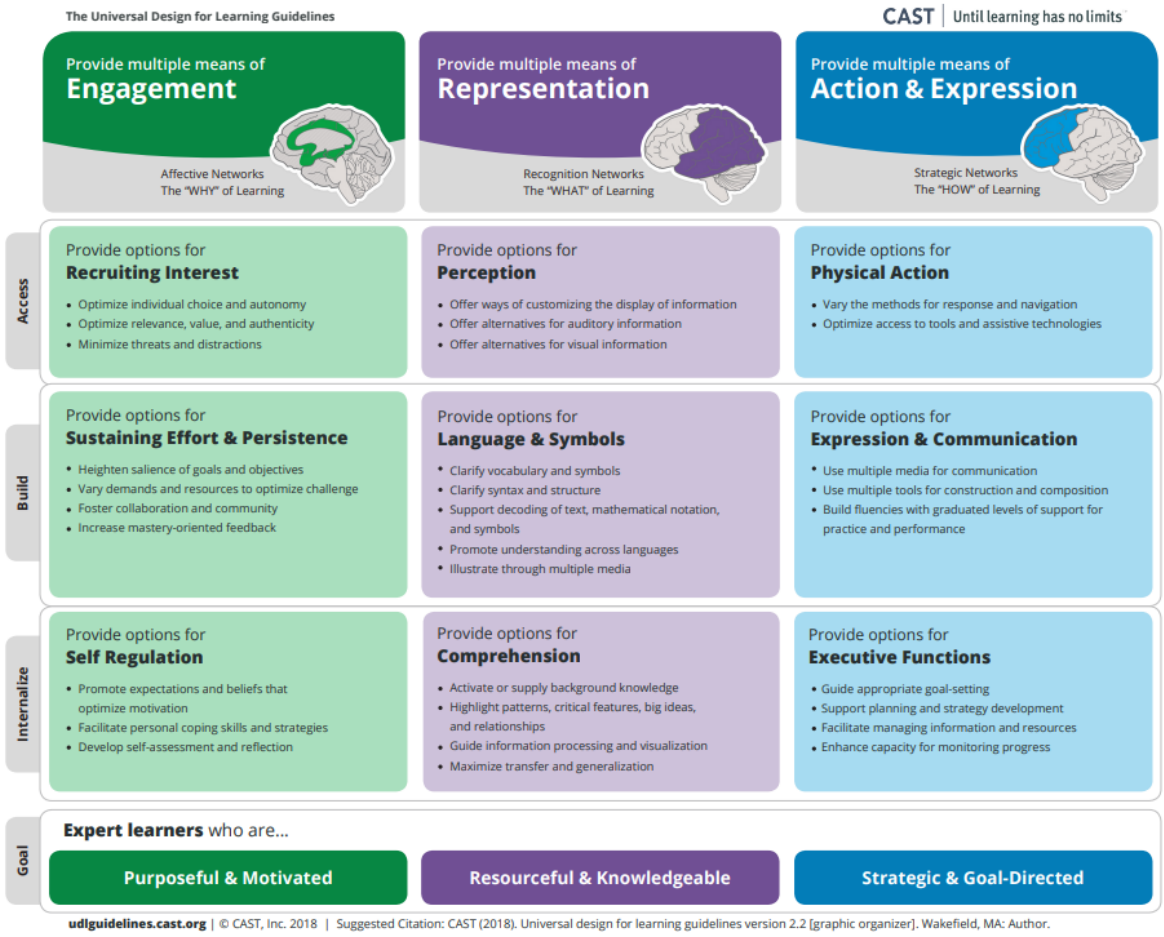

Figure 7: Universal design for learning guidelines version 2.2[81]

[81] CAST (2018). Universal Design for Learning Guidelines version 2.2. Retrieved from http://udlguidelines.cast.org

3 dimensions can be extracted from this taxonomy:

- **Cognitive dimension**: raising mental and learning processes through some goal-directed strategies, through the adaptation of varied pedagogical activities.
- **Affective dimension**: focusing on the interest of the learners and their motivation.
- **Psychomotor dimension**: involving language and communicative skills

Based on an imaginary Serious Game, "Ocean Rescue", we will identify ways of making the game more accessible particularly for deaf users, to be able to take full advantage of the educational opportunities offered by green-themed serious games. For the purpose of the analysis, imagine that the “Ocean Rescue” game is an immersive VR educational game that raises awareness about the impact of pollution on the ocean and marine life. Players embark on underwater missions to clean up pollution, save endangered species, and restore the health of the ocean ecosystem. Through interactive experiences, stunning visuals, and informative storytelling, the game empowers players to become ocean conservation heroes.

Ocean is an attractive and mysterious world with its marine animals, but a world in danger!

The game features a series of "mini challenges" linked to different animals.

Thanks to the wide variety of challenges, motivation remains intact. The diversity of requirements is one important element in universal learning design.

Furthermore, the game resembles a kind of formative quest, like Choose Your Own Adventure books designed for children, in which the hero must make decisions that always have consequences. The pedagogy becomes active insofar as the player is responsible for his or her own learning:

> *“By navigating the obstacles presented in each mini-game, your critical thinking and problem-solving skills flourish”.*

By addressing directly to the player, the game becomes intimate and motivating.

This maritime world is brought to life thanks to innovative technologies (virtual reality and holograms). These innovative media will also make it possible to diversify representations to make Serious Games accessible to as many people as possible.

Representation deals with cognitive and psychomotor skills: language and symbols allow the learner to understand his environment, especially in a Serious Game: the Ocean has to be drawn or created in AR, VR and so on.

Attention must first and foremost be focused on perception: how can we respond to the perceptive difficulties of an audience of deaf or hearing-impaired learners?

The world of the ocean is not a silent one: ocean is full of noise, coming from maritime animals and from human activities.

> *„Marine animals use underwater sound in many important ways. Just as people talk to each other, marine animals use sound to communicate. However, also like people, vocal marine species hear much more than the sounds they use to communicate with one another. Marine species use their hearing to find food and mates, avoid predators, and navigate. Sound is critical to the survival of a great many marine species.*[82]*“*

As the challenges involve interacting with dolphins and turtles, using emerging technologies, should the virtual ocean be as noisy as the real one when the target has to do with deaf or hearing impaired?

Interviews with members of ASPAS-VALENCIA, the Spanish association for deaf and hearing-impaired, have highlighted the essential elements of perception, language and symbols that need to be put in place to facilitate understanding.

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[82] National Oceanic and Atmospheric Administration. Soundcheck: Ocean noise, https://www.noaa.gov/explainers/soundcheck-ocean-noise, retrieved 11.9.2023.

The first point to bear in mind is that 98% of deaf people are equipped with hearing aids, which enable them to hear. Deaf students therefore play video games in the same way as young students without hearing impairs. Data from France confirms that young deaf people are equipped and go to HE[83].

However, it is still important to use subtitles to make the listening experience more comfortable.

Thanks to advancements in AI, it will be easy to introduce speech bubbles into the Serious game and thus introduce a visual that will facilitate comprehension for a more diverse audience.

Furthermore, in order not to slow down comprehension and to maintain the pace of the game, the subtitles or "speech bubbles" should be simple, avoiding complex syntax. The illustration of how to implement such practical guidelines is presented in Figure 8.

Figure 8: The concept for alternative representation of information with speech bubbles.

[83] Des chiffres autour de la surdité, https://www.surdi.info/bibliographie/des-chiffres-autour-de-la-surdite/, retrieved 11.9.2023.

As it is easily adaptable to the deaf and hearing-impaired, GT Serious Games appear to be a relevant and universal solution for educating people about the ecological issues facing the world today.

Furthermore, Table 4 presents the practical guidelines for implementing UDL principles in the "Ocean Rescue" game that can be generalized for any other green-themed serious game.

Table 4: Practical guidelines for implementing UDL principles in green-themed serious games, instantiated on the imaginary serious game "Ocean Rescue"

Multiple means of Engagement	Multiple means of Representation	Multiple means of Action and Expression
Text-Based Instructions: Alongside spoken instructions, provide text-based instructions and objectives that appear on-screen to ensure deaf players can understand their missions and goals.	Visual and Textual Information with Subtitles: Provide visual representations of marine life, pollution effects, and other important elements within the VR game. Additionally, include subtitles for all spoken content and audio cues to ensure deaf players can access the information.	Text-Based Communication: If the game includes communication with other characters or players, offer text-based chat or messaging options in addition to voice chat to facilitate communication for deaf players.
Provide Feedback and Support: Offer real-time feedback on player actions and decisions and provide additional information or hints if players are struggling to progress. This supports individualized learning.	Sign Language Interpretation: Offer the option for sign language interpretation within the VR environment to support players who use sign language as their primary mode of communication.	Alternative Sound-Based Challenges: For challenges that involve sound recognition, provide alternative visual or haptic (vibration) cues that allow deaf players to participate and demonstrate their understanding.

Set Meaningful Goals: Establish clear objectives and goals for players to achieve within the game, providing motivation and purpose for learning about ocean conservation.	Visual Clues for Audio Information: When there are audio cues or environmental sounds related to pollution or marine life, incorporate visual cues (e.g., vibrating controllers, on-screen indicators) to convey this information to deaf players.	Flexible Assessment: Assess player knowledge and comprehension through a variety of means, such as quizzes, interactive challenges, or even creative activities like designing pollution prevention strategies.
Offer Player Choice: Allow players to choose from different missions or scenarios related to pollution and its impact, catering to their individual interests and preferences.	Use Varied Perspectives: Offer different viewpoints within the VR environment to help learners gain a comprehensive understanding of the ocean ecosystem. This could include the ability to see the ocean from the perspective of different marine creatures.	Diverse Interaction Modes: Enable players to interact with the game and demonstrate their understanding through various means, such as using hand gestures, voice commands, or traditional controller input, to accommodate different physical abilities.

CONCLUSIONS

In this report, the complexity of interdisciplinarity has been analysed in order to find relevant solutions. The pedagogy adopted here follows the fundamental changes of our 21st century world, where each of the partner universities recognizes "the pressing need to address environmental challenges and endeavors to make significant contributions towards a greener future". In Zagreb, Dubrovnik, Debrecen, Brest (IMT Atlantique) or Valencia, ecological transition is part of the strategic plan for the coming years. Similarly, each of the partner universities is interested in introducing more inclusive, more universal ways of learning. This is why it was important to include a clear understanding of the universal guide to learning. This enabled us to analyse the complexity of interdisciplinary problems in order to find relevant solutions.

The question explored by Play2Green involving the possibilities of introducing "green themed serious games based on emerging technologies in non-green-themed higher education courses" has met with a generally favorable response, as shown by the results of interviews and surveys. However, this study has highlighted the need to develop the degree of familiarity with emerging technologies among those involved in this project (lecturers). This is particularly necessary as the enthusiasm shown by a large proportion of our informants (survey and interview) is accompanied by questions about how to introduce green-themed serious games into courses that are not dedicated to ecological and societal transition. For IT courses or courses in the Humanities, there is a real desire to innovate, to develop attractive teaching methods for an audience brought up in the digital age.

Emerging technologies are making games, and therefore Serious Games, more accessible to a wider audience: inclusion is at the heart of Play2green. AI, to take just one of the emerging technologies, enables people with hearing difficulties to play Serious Games like everyone else, and to take part in the green effort.

While Play2Green has chosen to focus on introducing green-themed Serious Games into higher education courses, it would be highly relevant to extend such a project to secondary school classes to raise awareness as early as possible for the urgent need to adopt good habits, from recycling to clean oceans and cities, but also smart ones. The EU's 2050 climate-neutrality objective does indeed call for a renewal of educational practices. Our Consortium has strived to take this into account, with an additional focus on interdisciplinarity, intergenerational cooperation and inclusion.

APPENDICES

Appendix A: Interview preparation document

Inclusion of green-themed serious games in non-green-themed higher education courses

This document is a part of the preparation for the upcoming interview. Before conducting an interview, we would like to list keywords as well as their explanations, give you examples of questions, and to get an insight in nature of your courses.

The document is organized in two parts. The first part contains definitions of keywords and a few questions which should help you to prepare for the interview.

In the second part there is a table containing the required course data. We kindly ask you fill out the table for **at least 3 of your courses**, the ones you find the most relevant. After you fill it out, please send it to us, but not later than **XXX.**

Part 1: General information regarding the interview

The interview is being held as a part of the course Research Seminar (FER, University of Zagreb), and is serving as a support to Erasmus+ project “Play2Green” activities.

The general objective of the "Play2Green" project is to raise awareness of the environment and fight against climate change among all learners. To contribute to the general objective, the project identified the following two specific objectives: **(i) increase the number of higher education students and lecturers who covered green topics within their studies**; and **(ii) provide innovative, green-themed educational resources to everyone**.

To achieve our goals, we need to find a way to integrate innovative, green-themed material (serious games) in courses that are usually not related with the green topics.

Hence, the research question was raised: "*What are the modalities for inclusion of green-themed serious games based on emerging technologies in non-green-themed higher education courses?*"

The keywords in this research are:

- **modality** = way in which a serious game can be included in a teaching process, for example, a programming laboratory assignment whose task deals with some aspect of a serious game

- **green-themed** = any topic connected to sustainability, environment, green concepts, etc.

- **serious games** = games whose primary goal isn't just entertaining a player; those games can be used in various industries; in our case we use it as an educational tool

- **emerging technologies** = technologies that are characterized by radical novelty, relatively fast growth, coherence, prominent impact, and uncertainty and ambiguity (for example: VR, AR, holography, ML, 3D printing, etc.)

During the interview we will ask you questions considering your prior experience with serious games, innovative technologies, etc. (e.g., *Do you have any experience with using serious games for your lectures? Are your courses or lectures connected in any way to SD themes?*).

Additionally, we will ask you about your motivation and your students' attitude towards integration of green-themed serious games in your courses (e.g., *What do you think how motivated your students would be for learning your courses/lectures from materials in which green-themed SG has been integrated?*).

The focus of the interview will, after all, be on your teaching and inclusion of serious games in HEI courses. Please try to think how you would use (green-themed) serious games in your teaching. The questions will try to derive some modalities, i.e., ways how we could integrate green-themed serious games in HEI courses (e.g., *How would you use (green-themed) SG in your courses & lectures? Do you think it is possible?*).

Thank you in advance for participating. We believe your answers will be a valuable resource to this research.

Part 2: Your data

In this part, we would like to ask you fill out your **name and surname**, as well as some basic data about the courses you teach. Please fill out data for **at least 3 courses** you teach, and send it **by XXX**.

In the first row there is an example of how it should be filled out. If there are any questions regarding the table data, feel free to contact us, we would love to help.

Your Name and Surname: _____

Course title (insert a link to the course if possible)	Short description	Level of study	Number of ECTS credits	Average number of enrolled students per semester	Percent of theory*	Percent of practice*
e.g., Social Networks	The course offers students the opportunity to acquire knowledge and skills in the interdisciplinary field of social networks. Social networks are not only the most popular service based on the Internet infrastructure, but also a true global phenomenon that greatly affects the modern way of life and doing business.	Master's	5	80	25	75

	Students will acquire theoretical knowledge about the structure and processes in social networks, as well as practical knowledge and skills about application of social networks or achieving individual user or business goals.					

* Defines approximately how theoretical, i.e., practical course is. (Social Networks is mostly based on projects and student seminars, with some lectures included. That's why it is approximately 75% practical, and 25% theoretical course.)

Percent of theory and Percent of practice sum must be equal to 100.

Appendix B: Semi-structured interview layout

GENERAL QUESTIONS

- Gender / Male, Female, Other
- Institution / FER, UNIDEB, UNIDU, UPV, IMT Atlantique

PREVIOUS EXPERIENCE - poznato koje kolegije održavaju

- Can you summarize: what is Your area of expertise and Your research interest?
- How many years of work experience do You have?
    - How long have You been working as a teacher?
    - What is Your primary course, the one You are most experienced at?
- Are your courses or lectures connected in any way to SD themes?
- How often do You play video or mobile games: very often, often, sometimes, rarely, never?
- Would You say you're keen to innovative technologies? How familiar are You with the term emerging technologies, from "not at all" to "extremely"?
- Do You have any experience with using serious games for Your lectures?
    - What kind of game did You use and in which way?
    - Were students satisfied with it?
    - Were You satisfied with the learning outcomes?

CURRENT STATUS

- How many different courses do You teach now (academic year 2022. /2023.)?
- What are the practical components of those courses (if there are any)? And theoretical ones? // specifically ask for the courses they entered in the pre-interview doc
- Which technique do You use for teaching Your courses?

- For example: brainstorming, case studies, lecturing, flipped-classroom, projects, research, visits, discussion and debates, etc.
- Do You usually use SG in your courses & lectures?
- If not, do You think it is possible? What about green-themed serious games?
- How would You use (green-themed) SG in your courses & lectures (or if You already use them, how do You use them in Your teaching)?

PERSONAL OPINION & MOTIVATION

- On a scale from 1 to 5, how motivated are You to integrate green-themed SG in Your courses/lectures? (one is “Not motivated at all”, 5 is “Highly motivated”) ○
  Why is that so, can You explain?
- On a scale from 1 to 5, what do You think how motivated would Your students be for learning Your courses/lectures from materials in which green-themed SG has been integrated? (one is “Not motivated at all”, 5 is “Highly motivated”)
- Would that make a difference? // as in would they be more/less motivated for learning course content
  - Why is that so, can You explain?
- On a scale from 1 to 5, what do You think how hard would it be to integrate green-themed SG in Your courses?
    - Why?
  - Would integrating affect students and help them subconsciously learn about sustainability? // would they actually learn something about SD
  - Could that content (sustainable development, serious games) help them master Your course or You find it as an unnecessary addition?

Appendix C: Questionnaire

Short Survey: Inclusion of Green-Themed Serious Games in Non-green-Themed Higher Education Courses

Dear participant,

the goal of this survey is to look into participants' game and emerging technologies experience as well as to derive ways of including green-themed serious games in courses that are not focused on green themes.

The survey is a part of the course Research Seminar taken by Iva Zekic, a MSc student at the Faculty of Electrical Engineering and Computing, University of Zagreb. The research is conducted within the Erasmus+ project **Play2Green: Serious Gaming for Universal Access to Green Education** (*2022-1-HR01-KA220-HED-000088675*) and supervised by associate professor Jurica Babic and assistant Ivana Slosic.

For any additional information on the project, please visit the page https://sociallab.fer.hr/play2green/.

Thank you for participating, we appreciate it!

* Indicates required question

Personal data collection and processing consent *

By accepting this statement, it is considered that you voluntarily, knowingly and without coercion give the permission to collect and process your personal data for the purposes expressly stated here: researching experience related to (serious) gaming, emerging technologies usage and course implementation; deriving possible ways of including green-themed serious games in non-green-themed courses.

The survey is anonymous, therefore no name, e-mail address or any kind of contact will be collected. The data collected will be: **demographic/academic data** (your gender, academic role and institution, level of education), **experience data** (level of familiarity

with the emerging technologies / serious games / green topics), **course data** (educational materials, teaching techniques, number of courses), **motivation data** (beliefs regarding integration of the green-themed serious games in non-green-themed courses).

Your personal data will be handled in accordance with the relevant legal regulations, using the appropriate technical and security measures to protect personal data from unauthorised access, misuse, disclosure, loss, or destruction.

You have the right to request access, correction, deletion, and restriction of personal data processing related to you. You also have the right to the portability of personal data and can object to the processing of personal data.

An objection to the processing of personal data can be submitted by e-mail at **iva.zekic@fer.hr**.

Check all that apply.

☐ I consent to the personal data collection and processing

General questions

2. Gender *

Mark only one oval.

Male

Female

Other:

3. Institution *

Mark only one oval.

IMT Atlantique

University of Debrecen

University of Dubrovnik

University of Zagreb

Technical University of Valencia

Other:

4. Your role *

Mark only one oval.

Student

Lecturer (including teaching assistants)

5. Acquired level of education * *Mark only one oval.*

High school

BSc

MSc

PhD

Other:

6. What kind of teaching techniques do you prefer? *

1 - Highly traditional, 2 - Mostly traditional with innovative elements, 3 - Balanced traditional and innovative, 4 - Mostly innovative with traditional elements, 5 - Highly innovative

Mark only one oval.

1

2

3

4

5

Serious games and emerging technologies

This section is consisted of a few questions related to emerging technologies and (serious) game usage.

Emerging technologies are technologies characterised by radical novelty, relatively fast growth, coherence, prominent impact, and uncertainty and ambiguity (for example: VR, AR, holography, ML, 3D printing, etc.).

Serious games are games whose primary goal isn't just entertaining a player. Those games can be used in various industries and range from simple quiz-based educational games to advanced simulators such as Microsoft Flight Simulator. In this case we use it as an educational tool.

Green-themed topic is any topic connected to sustainability, environment, or green concepts, such as waste separation, renewable energy production, endangered species conservation, etc.

7. Did you know what term "emerging technologies" stands for prior to filing out this questionnaire? *

Mark only one oval.

Yes

No

8. How well acquainted are you with emerging technologies? *

1 - Not at all, 2 - Slightly, 3 - Moderately, 4 - Very, 5 - Extremely

Mark only one oval.

- 1
- 2
- 3
- 4
- 5

9. Which emerging technologies do you have experience with? *

Check all that apply.

- Virtual Reality (VR)
- Artificial Intelligence (AI)
- Internet of Things (IoT)
- 3D printing
- 5G networks
- Augmented Reality (AR)
- Robotics
- Holography
- Mixed Reality (MR)
- None
- Other:

10. Did you know what term "serious games" stands for prior to filing out this questionnaire? *

Mark only one oval.

Yes No

How often do you play video or mobile games for non-professional related reasons (e.g. entertainment)? *

1 - Never, 2 - Rarely, 3 - Occasionally, 4 - Often, 5 - Very often Mark only one oval.

1

2

3

4

5

How often do you play serious games? *

1 - Never, 2 - Rarely, 3 - Occasionally, 4 - Often, 5 - Very often Mark only one oval.

1

2

3

4

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How familiar are you with green topics? *

1 - Not at all, 2 - Slightly, 3 - Moderately, 4 - Very, 5 - Extremely

Mark only one oval.

1

2

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14. Did you ever play a green-themed serious game? *

Mark only one oval.

Yes

No

I'm not sure

15. If answered yes to previous question, how did you like that game? What was it about?

Course experience

In this section, you will be asked to enter information about your courses. Additionally, we ask you to enter a concrete way of integrating green-themed serious games in your courses (*e.g. playing a green-themed game that explains some concept for that course, designing or programming such a game, explaining some programming concepts using examples from game, etc.*).

16. Which educational materials do you usually use in your higher education courses? *

Check all that apply.

- Slides
- Videos
- Relevant reading materials
- Textbooks
- Workbook exercises (e.g. program examples, math problems)
- Interactive exercises (e.g. quizzes, simulations)
- Recordings Video
- games Other:

17. Have you ever used serious games in your courses? *

Mark only one oval.

- Yes
- No

18. If answered yes to previous question, how did you like it? Was it a useful teaching/learning tool?

19. Which teaching techniques are usually used in your courses? *

Check all that apply.

- Lecturing (lecturers explain terms and concepts, students mostly listen and ask questions)
- Project-based learning (students working together with one another to achieve shared goals)
- Self-learning (students are independently exploring some area)
- Design thinking (resolving real-life cases through group analysis, brainstorming, and creative ideas)
- Learning tools usage (creating mind maps, using flashcards, solving quizzes, etc.)
- Flipped classroom (students prepare for the lecture before the class and then elaborate learned material)
- Gamification (learning through the use of games) Other:

20. How many courses do you have in this academic year (2022. /2023.) *

21. Name the title of one non-green-themed course in which a green-themed serious game * could be integrated.

Note that the chosen course shouldn't be primarily focused on green topics (e.g. Object Oriented Programming course is a correct choice, while Environmental Sustainability and Climate Change Mitigation course is an incorrect choice).

22. In which of the following groups does that course belong? *

Mark only one oval.

- Mathematics, physics, and other natural sciences
- Software engineering and programming
- Computer science
- Computer engineering

Electrical engineering

Data science

Telecommunications and ICT

Social sciences Other:

23. Which teaching/learning technique is used in that course? *

Check all that apply.

Lecturing (lecturers explain terms and concepts, students mostly listen and ask questions)

Project-based learning (students working together with one another to achieve shared goals)

Self-learning (students are independently exploring some area)

Design thinking (resolving real-life cases through group analysis, brainstorming, and creative ideas)

Learning tools usage (creating mind maps, using flashcards, solving quizzes, etc.)

Flipped classroom (students prepare for the lecture before the class and then elaborate learned material)

Gamification (learning through the use of games)

Other: How would you rate the current level of the digitalisation of that course (online collaboration, digital exams, digital educational materials...)?
1 - Very poor, 2 - Poor, 3 - Moderate, 4 - Good, 5 - Excellent *Mark only one oval.*

1

2

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In this question we want to identify the concrete ideas on how to use the green-themed serious games in non-green-themed courses.

Think about the way you are currently learning/teaching the chosen course. Lectures, laboratory exercises, seminars, project assignments, homework, consultations, online collaboration...
Regarding the educational materials, there may be slides, videos, textbooks, online resources, additional materials for advanced students etc.

Now, suppose that you have available the free-to-use educational material for your course in form of the SERIOUS GAME for PC or mobile. Such a game is designed to be used by students to interactively learn about a certain green topic, for example, about the benefits and concerns of electric vehicles.

In your opinion, **what would be the best way to include green-themed serious games in your course**? Please share at least one idea on how to use such games in your course.

Motivation and personal opinion

How interested are you in using green-themed serious games in your non-green themed courses?
1 - Not at all, 2 - Slightly, 3 - Moderately, 4 - Very, 5 - Extremely

Mark only one oval.

1

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27. What benefits do you foresee with the inclusion of green-themed serious games in your * existing non-green-themed courses?

Check all that apply.

Improving skills and knowledge on green topics

Increasing motivation through interactive learning

Increasing the students' interest for enrolling the course due to the innovative teaching method

Facilitating the process of mastering the course content

None

Other: What concerns do you foresee with the inclusion of green-themed serious games in your existing non-green-themed courses?

Check all that apply.

Difficulties connecting the green topics with the existing course

The lecturers are not keen on using innovative teaching methods

The course loses primary focus due to the integration of green topics

The students are not interested in green topics

Lack of the necessary hardware equipment such as computer

It becomes harder to learn/teach the course content with that educational material

None

Other:

28. How difficult would it be to integrate green-themed serious games in your non-green-
* themed courses?
1 - Not at all, 2 - Slightly, 3 - Moderately, 4 - Very, 5 - Extremely *Mark only one oval.*

1

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29. Please explain your answer to the previous question. *

30. Suppose that the green-themed serious games are now integrated into your existing
* non-green-themed course.

In your opinion, how would that affect the overall QUALITY of your course?

The quality would:
1 - Significantly deteriorate, 2 - Slightly deteriorate, 3 - Stay unchanged, 4 - Slightly improve, 5 - Significantly improve *Mark only one oval.*

1

2

3

4

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31. Can you explain why?

32. Suppose that the green-themed serious games are now integrated into your existing * non-green-themed course.

In your opinion, how would that affect your MOTIVATION for the course?

My motivation would:
1 - Significantly deteriorate, 2 - Slightly deteriorate, 3 - Stay unchanged, 4 - Slightly increase, 5 - Significantly increase *Mark only one oval.*

1

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33. Can you explain why?

Additional comments

We thank you for your time in completing this survey. If you have some more feedback on the questionnaire please use the comment box below. In case you would like to get in touch concerning this research, feel free to reach us via e-mail at **iva.zekic@fer.hr**.

34. Additional comments box

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