ENHANCING TEACHING PRACTICES THROUGH MOBILE AUGMENTED REALITY GAMES: INSIGHTS FROM THE EDUCITY WORKSHOP

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Abstract

Mobile devices can enhance student motivation and learning, particularly when combined with augmented reality (AR). However, there is a gap in teacher training in areas such as mobile and game-based learning. The EduCITY project developed a Smart Learning City Environment to promote sustainability education, including an AR mobile app and a web platform for game creation without programming skills. A 50-hour accredited teacher training workshop was conducted to foster teaching innovation through mobile AR games. Teachers collaboratively designed and implemented educational games, integrating digital resources such as AR, videos, AI-generated images, and 3D models. The study evaluated the impact of this workshop by analysing the quality of the games created and the teachers' reflections on the lessons learned in the training workshop and the applicability to their future teaching practice. Results showed that teachers developed high-quality interdisciplinary AR games addressing sustainability themes and improved their digital skills. They recognized AR games as a valuable teaching tool, particularly for student engagement. Many participants planned to continue using the EduCITY app and platform in their teaching. The workshop successfully encouraged teachers to integrate mobile AR games into their practice, supporting interdisciplinary learning and innovative teaching strategies.

Keywords: Teacher training, mobile learning, game-based learning, augmented reality, digital educational resources, interdisciplinary education.

1 INTRODUCTION

Mobile technologies, particularly smartphones and tablets, have become integral to modern educational environments, offering unprecedented opportunities to enhance student engagement, collaboration, and access to a vast array of learning resources. Among these technologies, augmented reality (AR) has emerged as a transformative tool, superimposing digital information onto the real world and thereby creating immersive and interactive learning experiences. The integration of AR into educational practices has been shown to facilitate the visualization of abstract concepts, promote collaborative learning, and increase student motivation and enjoyment [1]–[3].

Despite the recognised potential of AR to enrich education across various disciplines, its widespread adoption faces significant challenges. A primary obstacle is the lack of adequate teacher training in effectively integrating AR into pedagogical practices. Many educators remain hesitant to incorporate AR technologies due to limited digital competencies and a scarcity of quality educational resources [4]. Furthermore, the absence of sufficient institutional support, such as access to necessary hardware and software, and time constraints for experimenting with new technologies, further impedes the seamless integration of AR into the curriculum [5], [6].

Addressing these challenges needs comprehensive professional development programmes that equip teachers with the requisite skills and confidence to implement AR-based learning effectively. The EduCITY project serves as a pertinent example of such an initiative, offering workshops aimed at supporting teachers in developing innovative outdoor educational practices using mobile devices, AR, and game-based learning approaches. These workshops have been instrumental in providing educators with access to new educational resources, supporting pedagogical change, and fostering interdisciplinary teaching strategies [7].

Building upon the foundation laid by projects like EduPARK [8], [9], the EduCITY project has further advanced the integration of AR in education by developing a Smart Learning City Environment focused on promoting education for sustainability [10], [11]. Central to this initiative is a mobile application that

enables students to engage with AR games in outdoor settings, complemented by a web platform that allows teachers to create their own educational games without requiring programming skills. The EduCITY app (freely available for iOS and Android) supports active, challenging AR games that intend to promote interdisciplinary learning contextualised in outdoor environments. Other similar apps have demonstrated high usability and educational value, particularly when designed to encourage high-level cognitive thinking through interactive questions [12]. To facilitate the effective integration of these tools into classroom practice, a certified 50-hour training workshop was designed for in-service teachers. This workshop provided participants with opportunities to collaboratively design, implement and evaluate mobile AR games, incorporating high-quality digital educational resources into apps such as EduCITY. Moreover, it encouraged critical reflection on their learning experiences and the applicability of mobile AR learning in their future teaching practices.

This type of course is relevant as it creates opportunities for teachers and researchers to collaborate in the development of high-quality open resources, which can be integrated into games made available to all. The quality and relevance of the resources produced are supported by the integration of recommendations from the literature on effective teaching and learning methodologies, particularly those that leverage the potential of technology. These resources are aligned with the National Curriculum and grounded in real educational contexts.

The following sections presents the methods and the results, which integrate the analysis of the AR games produced by the teachers and their reflective reports. These focus on the relevance of the methodology for their own learning and future teaching practices. The final section provides the conclusion, including final remarks, limitations and recommendations for future work.

2 METHODS

This study is conducted within the framework of a case study (Yin, 2014) focusing on the development process of educational resources, specifically mobile AR games, by in-service teachers during a 50-hour workshop (comprising 25 hours of face-to-face sessions and 25 hours of autonomous work). The workshop aimed to enhance the quality of teaching by integrating mobile technologies and games in teachers' practices.

The research question guiding this research was: How does a 50-hour teacher training workshop may impact on teaching practices? Specifically, it examines: (i) the quality of the AR games produced by teachers and (ii) teachers' perspectives on their own learning and the applicability of the newly acquired skills to their future practices.

A qualitative approach was employed, including document analysis of the games produced and the individual reflections written by the teachers at the conclusion of the training.

To analyse the quality of the AR games produced by the teachers, the performance descriptors for achieving the top performance (a score of 10) were established as follows. An informative initial and final game message, providing relevant information regarding the learning objectives and context, contributed with 0.5 points. All points of interest within the game were required to have clear and appropriate instructions to assist players in locating them, also contributing with 0.5 points. Each group member was expected to include at least two creative questions, valued at 2.0 points. Constructive and explanatory feedback had to be provided for all responses, with differentiated feedback for correct and incorrect answers, contributing further with 2.0 points. The game was expected to address sustainability by integrating the environmental, social, and economic pillars, adding another 1.0 point. Evidence of an interdisciplinary or multidisciplinary approach within the game and/or its questions contributed also with 1.0 point. The inclusion of original and edited resources created by the group was required, accounting for 1.5 points. Finally, the Digital Educational Resources needed to be creative, engaging, and educationally appropriate, earning an additional 1.5 points.

To analyse the teachers' perspectives on their own learning and the applicability of the newly acquired skills to their future practices, a qualitative thematic analysis [13] was conducted to identify key sub-themes. The analysis followed an inductive approach, with coding conducted manually in MAXQDA software [14]. Initial codes were generated from close readings of the reflective texts, then grouped into broader topics through an iterative process. Sub-themes were refined and validated through repeated comparisons with the data to ensure trustworthiness and consistency of interpretation.

2.1 The case: Teacher Training Workshop

The primary aim of the workshop was to encourage teacher trainees to implement meaningful changes in their educational practices in order to foster teaching innovation. This was to be achieved through the integration of mobile technologies, AR experiences, and games into their teaching strategies, ultimately enhancing student learning.

The workshop focused on the collaborative design, implementation and evaluation of interdisciplinary mobile games, supported by the EduCITY app, and integrating digital educational resources such as AR, videos, audio, images, and 3D models.

The quality and relevance of the educational resources produced during the workshop were ensured by aligning the games and digital materials with the Portuguese National Curriculum and by implementing and evaluating them within the real educational contexts of the teacher trainees.

To this end, the workshop aimed to create a training environment that fostered innovation in teaching practices by promoting the effective use of mobile devices, games, and digital educational resources to support contextualised, interdisciplinary learning. It also sought to address curricular topics where students often had learning difficulties, as identified by teacher trainees, demonstrating how these challenges could be effectively approached through mobile game-based learning. Additionally, the workshop involved designing, building, and implementing interdisciplinary digital educational resources within real educational contexts, with the potential for integration into apps such as EduCITY. These resources were continuously evaluated and refined throughout the process. Finally, all games and digital educational resources developed were made openly and freely available to the educational community.

The training content focused on the educational potential of mobile game-based learning and Digital Educational Resources with the aim of promoting contextualised interdisciplinary learning. The EduCITY project was explored as an example of innovation in educational practices within the realm of mobile game-based learning, particularly in an interdisciplinary framework. The course also explored the use of games as a tool for engaging students through contextualised questions that could be framed within various cognitive levels. Additionally, trainees examined the use of digital platforms for creating and sharing games and Digital Educational Resources, promoting open access and collaboration in educational resource development.

The training course was conducted within a socio-constructivist framework, where teacher trainees were encouraged to take an active role in their professional development, with trainers acting as facilitators of this process. The approach emphasised collaboration, critical reflection, and the practical application of knowledge in authentic educational contexts. During the face-to-face sessions, the working methodologies involved discussions to systematise the trainees' perspectives, field trips to explore the EduCITY app in real-world contexts, and collaborative work in small groups to design, develop, test, and refine a game and its associated Digital Educational Resources, aimed at promoting interdisciplinary learning and integration into platforms such as EduCITY. Additionally, there were opportunities to present and discuss group work, explore platforms for the creation and open sharing of Digital Educational Resources, and complete individual questionnaires to gather feedback and reflections. The autonomous work sessions focused on document analysis to support informed resource development, collaborative group reflections guided by a structured reflection tool, and also group work to co-create a game and Digital Educational Resources with the possible involvement of students as co-creators. Moreover, the teacher trainees implemented the educational game they had developed with their own student groups, ranging from primary to secondary education. During this phase, they collected data on students' perceptions of their motivation and learning related to the gameplay activities. Subsequently, the teacher trainees evaluated the outcomes of these implementations in preparation for the final workshop session, where they engaged in collaborative sharing and discussion. Finally, each participating teacher produced an individual written reflection on the overall training experience, guided by a structured guide.

The assessment of trainees was based on a set of guiding principles that included mandatory attendance of two-thirds of the face-to-face training hours. The assessment criteria were aligned with the training provider's guidelines and focused on commitment and participation in face-to-face sessions, as well as a group portfolio that included a group reflection, the developed game and REDs, and an analysis of the results from implementation with students. Additionally, trainees were assessed on their individual written reflection on the training experience. The final grade was assigned on a scale from 1 to 10, in accordance with Order 4595/2015 of 6 May.

2.2 Study participants

Seventeen out of 26 teachers attending the workshop gave informed consent to participate in this study, being 10 females and 7 males. All participating teachers were experienced professionals from 10 schools located in the central region of Portugal. Teachers belonged to seven different teaching groups: five teachers were from the 1st Cycle of Basic Education, four teachers belonged to the Special Education group, two teachers were from the Physics and Chemistry group, two taught Computer Science, two taught Visual Arts, one belonged to the Portuguese and English group, and one taught Catholic Moral and Religious Education.

3 RESULTS

This section is organized according to the sections of the data analysis, explained above.

3.1 Quality of the games created

Five educational games were developed during the workshop, each targeting different school levels and freely available via the EduCITY app. Aligned with the workshop's objectives, the games integrated multiple-choice questions on sustainability and at least one AR resource, such as an ARBook or augmented marker, which can integrate 3D models [15].

The resulting educational games were: a) *Nutrifit: Food and Movement Challenge,* b) *SatS – Science at Frei Gil School,* c) *Flamingo Goes to School,* d) *On the Trails of the Arboretum,* and e) *Discovering Urban Art – Aveiro*. The games were implemented with students across various educational levels, from primary to secondary education. Notably, in the development of games c) and e), students actively participated in the co-creation process, contributing to the content of the game. Each game comprised between 7 and 17 questions, and incorporated between 2 and 5 AR resources. The games focused on sustainability, highlighting key pedagogical, technological and interdisciplinary features considered essential for high-quality learning experiences. It is noteworthy that four of the games were designed to be played in out-of-school settings, thereby extending the learning experience beyond the traditional classroom environment. One game was specifically developed for implementation within the school playground.

Table 1 presents the evaluation of the games according to the top performance descriptors. For each descriptor an illustrative example from the game content is presented. The value N indicates the number of games that achieved a full score (total) in each category.

Table 1. Descriptors of Top Performance in Educational Games produced under the Workshop.

Top Performance Descriptors and Weighting (Total of 10 Points)	***Example of citation***	***N***
Informative initial and final game messages (providing information on learning objectives, context, etc.) - 0.5	"Welcome to the 'NutriFit: Food and Movement Challenge'! This game starts at the entrance to the School A. Nowadays, sustainable food is essential, so become young explorers in search of magical ingredients. Join me and discover how to be sustainable and make the world a better place!"	5
Clear and adequate instructions for all points of interest – 0.5	"Now you will learn more about a protected tree in Portugal that gives its name to the place where the School B is located. Turn left and head towards the Fountain. At the marker with the Flamingo, explore Augmented Reality. Fix the image by activating the pin"	5
At least two creative questions per group member - 2.0	"Eucalyptus was introduced to Portugal at the beginning of the 19th century as an exotic species used to beautify parks and gardens. Its wood began to be used to produce paper pulp in the mid-20th century. In which country were eucalyptus trees (*E. globulus*) used for the first time in the world to produce pulp? Answer options: 1 – Australia: 2 - United States; *3 – Portugal; 4 - South Africa"	2
Constructive and explanatory feedback for all questions, differentiating between correct and incorrect answers - 2.0	"Feedback of correct answer: Did you know that, in addition to paper, eucalyptus trees can be used to produce more sustainable and environmentally friendly materials, such as cellulose pulp, newspaper products, bioproducts, biofuels, among others? Feedback of incorrect answer: Portugal was a pioneering country in using eucalyptus (*E. globulus*) for paper production.	4

Integration of the different pillars of Sustainability (environmental, social, and economic) - 1.0	"Immerse yourselves in the mysteries of this city through the different artistic manifestations present in some outdoor spaces, exploring the environmental, social and economic aspects."	2
Evidence of an interdisciplinary or multidisciplinary approach within the game and/or its questions - 1.0	"Water can freeze into structures that resemble diamonds. In diamond, each carbon atom is bonded to four other atoms in such a way that the geometry is tetrahedral, leaving no free electrons for conduction. Therefore, diamond does not conduct electricity. The structure of diamond corresponds to a(n) ... Answer options: 1 - irregular solid made up of 4 faces, 4 vertices and 7 edges; 2 - irregular polyhedron made up of 4 faces, 4 vertices and 6 edges; 3 - Platonic solid made up of 4 faces, 4 vertices and 8 edges; *4 - regular polyhedron made up of 4 faces, 4 vertices and 6 edges"	4
Inclusion of original and group-edited resources - 1.5	https://youtube.com/shorts/XocGPCBYAQ0?feature=share	5
Augmented reality elements that are creative, engaging and educationally appropriate - 1.5	"Point the camera at the information board and click on the AR button. Read the information carefully."	5

The data reveal that all games included a clear and informative introduction and conclusion, effectively situating learners within the game narrative and providing relevant context and objectives. Similarly, the instructions associated with each point of interest were consistently explicit and accessible, enabling smooth navigation and student engagement with the activities.

In relation to the use of creative questioning, the games varied in performance. While two provided at least two original and thematically relevant questions per group member, the remaining 3 offered fewer questions or demonstrated less originality in their formulation. Feedback on participants' responses also varied; however, in the majority of games (4), detailed and constructive explanations were provided, clearly distinguishing between correct and incorrect answers and thereby reinforcing learning outcomes.

Sustainability was approached holistically in two games, with a conscious integration of its environmental, social, and economic dimensions. Although full integration was not universal, partial inclusion of all three pillars was observed in the remaining cases, indicating an awareness of the theme's multidimensional nature. The interdisciplinary scope of the games was also evident in four games, with questions and content drawing from multiple domains such as environmental science, mathematics, and cultural studies. Only one game reflected a more limited disciplinary range.

All games incorporated original resources that had been developed or refined collaboratively by the groups, reflecting both creativity and shared authorship. Additionally, the AR elements employed across all games were consistently engaging, pedagogically appropriate, and creatively integrated into the narrative, further enhancing the immersive experience.

Overall, the results highlight a strong commitment to innovative and pedagogically sound game-based learning, with particular strengths in narrative framing, instructional clarity, creative resource development, and technological integration.

3.2 Teachers' perspective of their own learning

Teachers' reflections on the learning outcomes obtained through the training course are summarized in Table 2. The sub-themes are exemplified through illustrative quotations drawn from participants' responses. The most frequently cited outcome was Professional Teacher Development (N = 62), which encompassed the following sub-themes:

a) Professional Competencies Development (N = 21), highlighting the acquisition of new knowledge, skills, and strategies to implement active and innovative methodologies;

b) Development of Educational Games (N = 17), emphasizing the pedagogical considerations involved in designing interactive games using the EduCITY platform;

c) Reflection on Pedagogical Practice (N = 14), underlining the continuous refinement of teaching strategies and game design, informed by participants' experiences implementing the games with students; and

d) Collaborative and Interdisciplinary Work (N = 10), reflecting enhanced collaboration across subject areas and engagement in community-based projects.

A second major theme identified was Integrating Technologies into Teaching and Learning (N = 35), which included:

a) Using Mobile Devices (N = 16), involving the appropriation of mobile technologies and interactive tools to enrich real-world learning experiences;

b) Exploring AR (N = 10), which contributed to a deeper understanding of AR's educational potential; and

c) Learning New Digital Tools (N = 9), such as Padlet, EduCITY, and multimedia editors, fostering broader integration of digital technologies into classroom practice.

Table 2. Learnings outcomes from the training course.

Theme	Sub-theme	Descriptors	Examples	N
Professional Teacher Development (N=62)	Professional Competencies Development	Acquisition of new knowledge, skills and strategies for teaching practice to implement active and innovative methodologies	'… learn how to use new tools and also to empower students to exploit them, ….'	21
	Development of Educational Games	Building educational games aligned with the EduCITY game logic	'I learnt how to create a game from scratch, reflecting on its implementation, evaluating and reformulating its construction.'	17
	Reflection on Pedagogical Practice	Critically analysing the effectiveness of the games and resources developed	'…, it is always important to reflect on its pedagogical meaning and how it will contribute to the students' learning.'	14
	Collaborative and Interdisciplinary Work	Exchanging experiences and knowledge between teachers from different areas	'The collaborative work between teachers from different groups promoted the exchange of experiences.'	10
Integrating Technologies into Teaching and Learning (N=35)	Using mobile devices	Using mobile devices to promote student engagement and learning	'… I was able to see the potential of mobile devices as promoters of student involvement and active participation, …'	16
	Exploring AR	Learning about the concept, creation, and functionalities of AR	'I learnt how to create Augmented Reality resources such as ARBooks and Augmented Markers.'	10
	Learning New Digital Tools	Knowledge and use of platforms such as Padlet, EduCITY, app.leonardo.ai	'Learning to use new tools, mainly Artificial Intelligence'	9

The reflections collected from the teachers highlight the substantial impact of the EduCITY workshop on their professional growth and integration of technology. The workshop's multifaceted approach, which combined digital tools, game-based learning, and AR, facilitated significant advances in both the teachers' technical and pedagogical capabilities. It enabled them to embrace innovative methodologies and adopt strategies that promote active student engagement, real-world learning, and interdisciplinary collaboration. These outcomes suggest that the EduCITY workshop effectively supported teachers in becoming more reflective, collaborative, and adaptable in their teaching practices, ultimately fostering a more engaging and future-oriented learning environment.

3.3 Future teaching practices

The teachers expressed a strong intention to apply, adapt, and expand the knowledge gained during the EduCITY workshop, as presented in Table 3. The most frequently cited outcome was Strategic Objectives (N = 25), which encompassed the following sub-themes:

a) Continuous Improvement and Pedagogical Innovation (N = 15), with participants planned to refine the games developed during the training and create new ones tailored to diverse contents and themes;

b) Integration in School Projects and Initiatives (N=4), illustrating the potential for embedding EduCITY in institutional projects;

c) Expansion and Scalability in trainee own practices (N=3), by teachers intended to adapt the methodology to create new games for other educational contexts they are involved in; and

d) Dissemination and Sharing of Resources to others (N=3) also surfaced, with some teachers mentioning they will introduce EduCITY tools to, for example, other teachers and educational stakeholders.

A second theme identified was Pedagogical Approaches Anticipated (N=6), which included:

a) Promoting Active and Collaborative Learning (N=5), particularly by integrating EduCITY into classroom projects and encouraging students to participate in game content creation; and

b) Adaptation and personalisation (N=1), in the context of special education, where the teacher aimed to design playful, inclusive content suited to individual learning profiles.

Table 3. Applicability of the lessons learnt during the workshop to future teaching practice.

Theme	*Sub-theme*	*Descriptors*	*Examples*	*N*
Strategic Objectives (N=25)	Continuous Improvement and Pedagogical Innovation	Improve or create new games and resources to address different contents and themes	'I intend to integrate the methodologies explored into my teaching, developing educational games …'	15
	Integration in School Projects and Initiatives	Involve students in creating digital projects in the ICT Workshop	'I organise the ICT Workshop in my school, I could even involve students in creating their own digital projects.'	4
	Expansion and Scalability in trainee own practices	Create new educational games based on the experience gained	'I intend to use the EduCITY methodology, which could be adapted to other educational contexts, …'	3
	Dissemination and Sharing of Resources to others	Introducing the EduCITY game to other educational stakeholders	'With this learning project I intend to i) (…) presenting the game to Maths and Experimental Science teachers and ii) guide my Chemistry students in adapting the project as an EduCITY game in partnership with the City Council and the team from the University of Aveiro.'	3
Pedagogical Approaches Anticipated (N=6)	Promoting Active and Collaborative Learning	Involve students in creating their own game content	'Involve students in creating their own digital projects.'	5
	Adaptation and Personalisation	Creating educational games for special education students	'As a special education teacher, I am driven to create and adapt content and materials to the profiles of each of my students.'	1

In sum, teachers expressed strong intentions to apply, adapt, and expand the EduCITY workshop knowledge through diverse strategic objectives (like innovation, technology integration, and practices expansion and sharing) and pedagogical approaches (including active learning and personalization). The finding in the 'Results' section directly inform the 'Conclusions' discussed below.

4 CONCLUSIONS

The EduCITY workshop, which centred on the integration of educational games, AR, and innovative digital tools into teaching practices, proved to be an effective professional development experience for the participating teachers. Through the creation and implementation of high-quality AR-based educational games, the workshop successfully facilitated the development of pedagogical skills, technological proficiency, and a collaborative mindset. The teachers reported significant gains in their ability to design interactive learning experiences that engage students actively and meaningfully, while simultaneously fostering interdisciplinary learning and reflection on teaching practices. These findings are consistent with previous research on the impact of AR on student engagement and motivation [1]–[3].

The main findings indicate that teachers successfully created high-quality Augmented Reality (AR) games integrating various aspects of sustainability's pillars (environmental, social, economic) through an interdisciplinary approach relevant to school curricula. Alongside the AR games, educators developed other high-quality digital resources, utilizing online platforms like Canva for videos and images, Generative AI for topic-related visuals, and incorporating 3D models to improve the attractiveness of in-game questions and feedback. Thus, results demonstrate teachers' ability to produce educational games that effectively blend sustainability concepts with AR-enhanced interactivity.

The depth and breadth of the content covered highlight the teachers' significant engagement with the theme. This suggests the workshop successfully enabled educators to adopt innovative methodologies, effectively integrate digital tools into their practices, and engage students in real-world, context-based learning. These outcomes align with previous studies demonstrating AR's utility in facilitating the visualization of abstract concepts and promoting interdisciplinary learning [8], [10].

Regarding teachers learning, they valued the workshop for improving their proficiency with digital classroom tools, particularly mobile devices and AR, acknowledging mobile AR games as valuable new methods for enhancing student engagement and enthusiasm. They expressed a strong sense of professional growth, demonstrated by their ability to use the EduCITY platform for game development, explore novel pedagogical strategies, and critically reflect on their teaching. Furthermore, the workshop's collaborative environment fostered a community for exchanging ideas and developing cross-disciplinary projects, facilitating a holistic approach to education. This focus on collaboration and interdisciplinary teaching aligns with the EduCITY project's broader goal [7] of promoting education for sustainability through a Smart Learning City Environment.

This new learning is said by the teachers as having high applicability into their future practices, as many have plans to integrate the knowledge and skills acquired during the training to continue using the developed game, the EduCITY app, and the EduCITY web platform in their teaching practices, e.g., to extend the game implementation to other classes of the same school or from the school cluster or even developing new games within running school projects. Many expressed a commitment to enhancing and expanding the games they had created, adapting them to different subjects, and using them as a tool for active and collaborative learning. Other tools introduced in the workshop, as Canva, were said that they will be continued using as well. Furthermore, several teachers expressed an interest in continuing to use AR in their classrooms, demonstrating an increased confidence in using emerging technologies to engage students and promote deeper learning experiences. Moreover, teachers plan to use what they learned about interdisciplinarity in the workshop in the development of new games for teaching. Hence, the feedback collected from the teachers emphasised the value of the workshop in terms of practical application. These outcomes were in line with the workshop's design, which encouraged teachers to reflect on their learning experiences and apply their newly acquired skills to their teaching practices, which is in line with literature recommendations [4].

While the EduCITY workshop yielded significant positive outcomes for teachers in terms of professional development, game-based learning, and technology integration, there were certain limitations that should be considered for future implementations. One such limitation was the varying levels of technological access and proficiency among teachers. Although the workshop provided valuable insights into integrating digital tools such as AR and mobile-based games, some teachers from schools with limited access to technology or robust internet connectivity faced challenges in fully implementing them. This finding echoes the concerns raised by Alalwan et al. [5], highlighting the need for institutional support in overcoming barriers to technology adoption. For future workshops, a more tailored approach might be required to support educators in these contexts, providing specific guidance on how to adapt the tools for schools with limited resources.

Additionally, while the interdisciplinary and collaborative nature of the workshop was widely appreciated, the practical implementation of innovative teaching methods could be constrained by teachers' demanding curricula and associated time limitations, potentially restricting opportunities for experimentation of new methodologies. Moving forward, it would be beneficial to consider how to integrate these practices more seamlessly into existing teaching schedules or to offer continued support through follow-up sessions. This would help reinforce the strategies learned and encourage their consistent use in everyday teaching practices. This idea is consistent with suggestions in the literature that advocate for sustained professional development and ongoing support for teachers [8].

Future work could explore integrating emerging technologies, such as virtual reality and artificial intelligence, into the workshop. These tools could further enhance the learning experience and address specific educational needs, such as for special education or diverse learning requirements. Additionally, expanding the project to include collaboration across schools or districts could promote a broader exchange of ideas and enhance its impact.

Another area for future development is the continuous evaluation and improvement of the workshop itself. Gathering ongoing feedback from teachers' post-workshop could help identify any gaps in the training and offer insights into how the games and tools have been implemented in real classrooms after the training. This reflective process would allow for continuous iteration of the workshop format, ensuring its relevance and effectiveness in the long term. This is in line with the case study approach used in the

research, where qualitative data and feedback were critical for understanding the impact and areas for improvement [16].

In conclusion, the EduCITY workshop has proven to be a valuable tool for enhancing teachers' professional development, fostering innovation in pedagogy, and promoting the integration of digital tools into teaching practices. By enabling teachers to create educational games that incorporate sustainability, interdisciplinary learning, and AR, the workshop has laid a strong foundation for future educational practices. With continued support, further refinement of the workshop's content, and a focus on scalability, there is significant potential to extend the benefits of the EduCITY project to a broader educational community, as noted by previous research on the successful integration of AR in education [8].

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REFERENCES

[1] F. Arici, R. M. Yilmaz, and M. Yilmaz, "Affordances of augmented reality technology for science education: Views of secondary school students and science teachers," *Hum. Behav. Emerg. Technol.*, vol. 3, no. 5, pp. 1153–1171, Dec. 2021, doi: 10.1002/hbe2.310.

[2] C. Y. Chang and G. J. Hwang, "Trends in digital game-based learning in the mobile era: a systematic review of journal publications from 2007 to 2016," *Int. J. Mob. Learn. Organ.*, vol. 13, no. 1, p. 68, 2019, doi: 10.1504/IJMLO.2019.096468.

[3] S. Mystakidis, A. Christopoulos, and N. Pellas, "A systematic mapping review of augmented reality applications to support STEM learning in higher education," *Educ. Inf. Technol.*, vol. 27, no. 2, pp. 1883–1927, Mar. 2022, doi: 10.1007/s10639-021-10682-1.

[4] S. Tzima, G. Styliaras, and A. Bassounas, "Augmented Reality Applications in Education: Teachers Point of View," *Educ. Sci.*, vol. 9, no. 2, p. 99, May 2019, doi: 10.3390/educsci9020099.

[5] N. Alalwan, L. Cheng, H. Al-Samarraie, R. Yousef, A. Ibrahim Alzahrani, and S. M. Sarsam, "Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective," *Stud. Educ. Eval.*, vol. 66, p. 100876, Sep. 2020, doi: 10.1016/j.stueduc.2020.100876.

[6] J. Barroso-Osuna, J. J. Gutiérrez-Castillo, M. C. Llorente-Cejudo, and R. V. Ortiz, "Difficulties in the Incorporation of Augmented Reality in University Education: Visions from the Experts," *J. New Approaches Educ. Res.*, vol. 8, no. 2, pp. 126–141, Jul. 2019, doi: 10.7821/naer.2019.7.409.

[7] M. Marques and L. Pombo, "Teacher training on mobile and game-based learning: literature review and training program proposal," Jul. 2023, pp. 707–715, doi: 10.21125/edulearn.2023.0278.

[8] L. Pombo and M. M. Marques, "Guidelines for Teacher Training in Mobile Augmented Reality Games: Hearing the Teachers' Voices," *Educ. Sci.*, vol. 11, no. 10, p. 597, Sep. 2021, doi: 10.3390/educsci11100597.

[9] M. M. Marques and L. Pombo, "The Impact of Teacher Training Using Mobile Augmented Reality Games on Their Professional Development," *Educ. Sci.*, vol. 11, no. 8, p. 404, Aug. 2021, doi: 10.3390/educsci11080404.

[10] L. Pombo, "Exploring the role of mobile game-based apps towards a smart learning city environment – the innovation of EduCITY," *Educ. + Train.*, vol. 65, no. 2, pp. 253–264, Feb. 2023, doi: 10.1108/ET-06-2022-0238.

[11] R. Rodrigues, J. Ferreira-Santos, J. Draghi, M. M. Marques, and L. Pombo, "Educity, a Project for a Sustainable Smart Learning City Environment – Preliminary Results," in *International Conferences e-Society 2024 and Mobile Learning 2024*, 2024, vol. 2, pp. 255–262.

[12] L. Pombo and M. M. Marques, “Learning with the Augmented Reality EduPARK Game-Like App: Its Usability and Educational Value for Primary Education,” 2019, pp. 113–125.

[13] V. Braun and V. Clarke, “Using thematic analysis in psychology,” *Qual. Res. Psychol.*, vol. 3, no. 2, pp. 77–101, 2003, doi: 10.1191/1478088706qp063oa.

[14] “MAXQDA.” Verbim software, 2024, [Online]. Available: www.maxqda.com.

[15] R. Rodrigues and L. Pombo, “Mobile Augmented Reality app with 3D models: The EduCITY app,” Mar. 2024, pp. 3824–3830, doi: 10.21125/inted.2024.0994.

[16] R. K. Yin, *Case Study Research Design and Methods*, 5th ed. Thousand Oaks, CA: SAGE Publications, Inc., 2015.