PLAYING WITH PROTONS GOES DIGITAL

RECOMMENDATIONS HANDBOOK FOR SCHOOL LEADERS, POLICY MAKERS & STAKEHOLDERS

Co-funded by the Erasmus+ Programme of the European Union

PLAYING WITH PROTONS GOES DIGITAL is a project funded by the Erasmus+ Programme of the European Union (REF: 2020-1-IT02-KA226-SCH-095525). The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Document Control Page	
WP/Task	Tasks T1-T6
Title	PLAYING WITH PROTONS GOES DIGITAL Recommendations Handbook for School Leaders, Policy Makers & Stakeholders
Due date	30/05/2023 Extension of the project to 30/11/2023
Submission date	30/11/2023
Abstract	The Playing with Protons Goes Digital Recommendations Handbook for School Leaders, Policy Makers and Stakeholders is a set of concrete recommendations and guidelines addressing innovative teachers (teachers as agents of change), school leaders, educational policy makers and external stakeholders offering an array of instructions, school development plans and profiling tools, and connections with O1,O2, O3 and O4 that aim at facilitating open schooling through synergies between schools and the local and wider community. This Output also aims to address matters related to both school change and science education and STEAM policy using innovative methodologies and the project's own activities. The Recommendations are based on research, expert opinion from the institutions involved (especially Ellinogermaniki Agogi school, INFN and Città della Scienza) and concrete evidence collected during the project's implementation, including, of course, feedback from participating teachers and schools.
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Dissemination level	☐ internal ☒ public ☐ confidential

Document Control Page			
Version	Date	Modified by	Comments
0.1	30.09.23	I. Ntovolou	Table of Contents – First Draft
0.2	15.11.23	S. Sotiriou	Final Draft - Comments and Improvements
FINAL	30.11.23	S. Sotiriou	Final Version

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EXECUTIVE SUMMARY

Playing With Protons Goes Digital project is based on the development of a conceptual and methodological framework that builds on the essential features of creative Science Education that can facilitate Deeper Learning in STEM combined with Arts. The Playing with Protons Goes Digital framework supports creativity as a generic element in the processual and communicative aspects of the pedagogy by integrating arts (virtual arts, performing arts, design, music). Based on project-based and inquiry approaches teachers will be asked to create their own AR and VR projects to introduce their students in a variety of abstract and invisible concepts of microcosmos. The approach Is based on the Deeper Learning Competence Framework that was used to capture learners' progress and understanding during such creative activities and populate their Deeper Learning profiles. The proposed framework guided teachers during the project interventions towards better realizing their emerging role as coaches of learning and provided the reference for the development of the assessment approaches and the enabling technologies that the project has developed.

Playing with Protons goes Digital Recommendations Handbook for School Leaders, Policy Makers & Stakeholders (IO5), is a comprehensive guide targeting innovative teachers, school leaders, policymakers, and stakeholders. It provides concrete recommendations, guidelines, and tools to facilitate open schooling by fostering synergies between schools and the local community. The handbook addresses school change, science education, and STEAM policy through innovative methodologies and project activities. Recommendations are grounded in research, expert opinions from the project partners, and concrete evidence gathered during the project's implementation, including valuable feedback from participating teachers and schools.

IO5 also provides guidance on creating an educational environment designed to captivate the imaginations of young minds, fostering enthusiasm for scientific research, discoveries, and future careers in science. Regarding science careers, the document explores aspects of Responsible Research and Innovation outlined in key European documents. This includes a focus on gender equity and strategies to support girls in choosing scientific careers.

In addition, IO5 addresses the implementation of Playing with Protons Goes Digital activities (such as workshops and outreach events) and outline strategies for defending and prevailing the lack of trust in science and contribute to what can be termed as 'Science Democracy.' This objective achieved through innovative activities facilitating the transfer of knowledge from INFN-related research and ideas. School students played a pivotal role as science ambassadors and defenders, utilizing relevant digital tools to contribute to a more informed and trusting public perception of science.

IO5 is organized in four chapters:

Chapter 1 describes the overall project approach and emphasizes the transformative role of teachers as agents of change and envisions a pathway towards more engaging science classrooms. By integrating innovative STEAM activities into teaching practices and implementing a Playing with Protons Goes Digital-inspired continuous professional development (CPD) strategy, we aim to inspire science education. It addresses policy makers, advocating for the enrichment of national curricula with resources validated by prestigious research centers such as INFN, CERN, and Città della Scienza. Finally it explores potential alignment with national policies on STEAM and teachers' skills, incorporating insights from EU guidelines and documents.

Chapter 2 presents the key findings drawn from all phases of the Playing with Protons goes Digital project. They relate to teachers' digital competences, schools' infrastructure and support, the availability of digital tools and resources provided, and the related educational outcomes for the participating students. In each section we describe in detail the project related work focusing on the key project contributions.

Chapter 3 presents a series of recommendations for each finding of our project. The recommendations are organised in three categories focusing on teachers, school leaders and educational stakeholders.

Chapter 4 concludes the deliverable.

1

INTRODUCTION

1 INTRODUCTION

Playing with Protons Goes Digital was conceived as a project to a) present frontier physics research topics, as a catalyst for the **effective interaction between Art and STEAM disciplines towards promoting learners' Deeper Learning**, b) present a new vision for teaching outlining strategies for **how Educators' roles and conditions can support and enable deeper learning for learners** and c) to support and **facilitate the aforementioned approaches with meaningful digital technologies**, such as Augmented/Virtual reality applications. Playing with Protons Deeper Learning Paradigm incorporates the idea that a range of competences and their orchestrated skillful application leads to STEAM mastery.

The project's core educational method (i.e., inquiry based and project-based learning) is based on the six pedagogical principles that elaborately represent deeper learning abilities that are mentioned in common definitions. Inquiry based learning is a method that evolves Engaging Learners; Exploring Contextual Issues; Explaining Scientific Concepts and Inquiry Abilities; Elaborating Knowledge and Abilities in New Contexts; Evaluating Learners' Knowledge and Abilities. This framework builds on a four-strand model developed to capture what it means to learn science in school settings by adding two additional main strands incorporated for informal science learning, reflecting a special commitment to interest, personal growth, and sustained engagement that is the hallmark of informal settings. These principles will guide the overall project and that are at the core of the deeper learning paradigm (see Table 1-1).

Table 1-1 The main Pedagogic Principles and the Educational Objectives for the design and implementation of the Deeper Learning Paradigm in the framework of Playing with Protons Goes Digital project.

Strands – Pedagogic Principles	Educational Objectives
Sparking Interest and Excitement	Experiencing excitement, interest, and motivation to learn about phenomena in the natural and physical world.
Understanding Scientific Content and Knowledge	Generating, understanding, remembering, and using concepts, explanations, arguments, models, and facts related to science.
Engaging in Scientific Reasoning	Manipulating, testing, exploring, predicting, questioning, observing, analysing, and making sense of the natural and physical world.
Reflecting on Science	Reflecting on science as a way of knowing, including the processes, concepts, and institutions of science. It also involves reflection on the learner's own process of understanding natural phenomena and the scientific explanations for them.
Using the Tools and Language of Science	Participation in scientific activities and learning practices with others, using scientific language and tools.
Identifying with the Scientific Enterprise	Coming to think of oneself as a science learner and developing an identity as someone who knows about, uses, and sometimes contributes to science.

The six pedagogical principles of deeper learning in connection to STEAM education can be translated into six crucial intellectual and motivational abilities.

While (1) understanding scientific content and knowledge, (2) engaging in scientific reasoning, as well as (3) reflecting on science represent intellectual abilities (4) using the tools and language of science (collaborative problem solving), (5) sparking interest and excitement, and (6) identifying with the scientific enterprise rather represent motivational abilities. However, our research will be the first to fully implement and empirically test the deeper learning paradigm. Regarding the interrelations among the various intellectual and motivational abilities, we will explore them in an evidence-based manner without previously analytically derived hypotheses. For that matter, we need to assess our pupils' abilities before, after, and especially throughout the intervention.

Our approach emphasizes the transformative role of teachers as agents of change and envisions a pathway towards more engaging science classrooms. By integrating innovative STEAM activities into teaching practices and implementing a Playing with Protons Goes Digital-inspired continuous professional development (CPD) strategy, we aim to inspire science education. Additionally, the handbook addresses the interaction between schools and the local community, proposing a school opening-up process through events and projects that utilize the methodologies and activities of Playing with Protons Goes Digital.

Furthermore, this handbook extends its reach beyond the confines of individual schools. It addresses policy makers, advocating for the enrichment of national curricula with resources validated by prestigious research centers such as INFN, CERN, and Città della Scienza. The document explores potential alignment with national policies on STEAM and teachers' skills, incorporating insights from EU guidelines and documents.

This handbook sheds light on how these stakeholders can effectively engage with schools and teachers through Playing with Protons Goes Digital strategies, particularly during challenging times such as the current pandemic. In essence, this introduction sets the stage for a comprehensive exploration of the recommendations and guidelines that follow, grounded in a commitment to advancing education, science, and innovation through collaborative and innovative approaches.

In this framework Playing with Protons Goes Digital has set as key aim to a) demonstrate the key role of advanced technological applications in the development of highly motivating learning experiences for learners, b) demonstrate how science works, c) implement a series of innovative scenarios for school practice that offering access to unique scientific resources to teachers and students organized under a systematic pedagogical framework and d) provide a model for the coordination of educational and outreach activities of major research infrastructures.

1.1 DEVELOPING MORE CONDUCTIVE, HIGHLY MOTIVATING AND FLEXIBLE LEARNING ENVIRONMENTS

The aim of the project was to build on a successful initiative from CERN -Playing With Protons[1] - and to go a step further, by proposing ways that (through the effective use of advanced tools – i.e. an AR authoring and Delivery Platform) **could scale them up to involve more students and teachers across Europe**.

Inspired by the vision to enhance the educational footprint of large research infrastructures like CERN, Playing with Protons, was developed in the framework of the recently completed CREATIONS project2 and was piloted in 91 schools in Greece and the UK with the active involvement of 183 teachers and more than 5,000 students. As described in the paper, the diversity and breadth of inquiry- and creativity-based learning activities led by the teachers who took part in the training courses at CERN was immense. According to the evaluation results presented in the paper, 'Playing with Protons' not only increased teachers' interest in physics, but also boosted "their creative confidence to introduce primary students to various scientific processes and discovery endeavors into the microcosmic world of particles as well as the macrocosmic universe". In addition, the course helped

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[1] https://cms.cern/news/playing-protons-two-years-and-counting

[2] https://creations-project.eu/

create teacher online communities of interest in Greece and the UK, through which learning resources developed by teachers, such as lesson plans and educational scenarios, are freely available to anyone interested in primary physics.

By utilizing the use of existing technological solutions, the project brought into the classroom activities that are based on real-world problems and will involve students in finding their own answers and solutions, testing their ideas, receiving feedback, and working collaboratively with other students and researchers beyond the school classroom. For example, **a series of virtual collaboration activities,** were designed and implemented, **promoting inquiry based and problem-solving processes in an immersive environment**. In this case students performed the assigned tasks from their schools, allowing for more schools to be involved in the process. Collaboration in the framework of the project has demonstrated that the current communication channels and the related AR tools could easily meet the computational demands of such on-line collaborative learning processes, that can enable the exploitation by teachers and students with limited ICT resources (e.g., school communities in remote or disadvantaged areas) to the advanced Playing With Proton Goes Digital applications that enable innovative ways for teaching and learning. To this end, the Digital AR Platform (IO3, https://playingwithprotons.infn.it/ar-platform/) offered innovative, interactive, collaborative and context-aware functionalities, which are student-centered, focusing on contextualized and adaptable learning experiences.

1.2 DEMONSTRATING HOW SCIENCE WORKS

The project activities simulated the work of real scientists who have access to facilities and resources regardless their location. In this way our approach focused on the presentation of new working methods and models, based on the shared use of resources across different disciplines between researchers in virtual research communities in all *eScience* fields. The Playing With Protons Goes Digital approach demonstrated a series of educational activities in which **students were engaged in "border crossings" from their own everyday world culture into the subculture of science**. The subculture of science (collective set of norms, practices, language, and tools) is in part distinct from other cultural activities and in part a reflection of the cultural backgrounds of scientists themselves. By developing and supporting experiences that engage learners in a broad range of science practices, we can increase the ways in which students identify with and make meaning from their science learning experiences. For this purpose, the educational context of Playing With Protons Goes Digital was not transmitted in a theoretical way but rather in a biomatic way in the form of a real life experience. The project team provided ICT tools (based on the Digital AR Platform) and scaffolds that enhance learning, support thinking and problem solving, model activities and guide practice, and that allow for representation of data in different ways. In the framework of the Playing With Protons Goes Digital activities (included in Handbook of Resources, IO2)[3] students were able to personalize a set of resources for reference and problem solving. A great variety of learning activities were supported: browsing and querying AR resources from different research centers, laboratories and other sources; 3-D visual objects and representations (e.g., elementary particles, fields, planets); animations of quite complex phenomena and experiments and visualization of complex physical phenomena or mathematical problems (e.g., performing geometrical calculations in 3D environments). A rich collection of technical tools, appropriately orchestrated in the Digital AR Platform were available to teachers and their students. During these activities students' initial predictions were compared with data from the different experiments and they had the chance to

[3] https://playingwithprotons.infn.it/educational-scenarios/

realize. The consortium has demonstrated that the implemented approach has advanced everyday teaching for several reasons:

- **Increasing motivation:** Students are more likely to feel a sense of personal investment in a scientific investigation as they will actively participate in the research procedure and add their own aesthetic touches to the different tools they are using for experimentation. Such an approach could help to make science “fashionable” among students. It must be noted also that inquiry-based pedagogy (supported by the use of ICT tools) address a variety of learning styles and strengthen higher order thinking skills essential for success in mathematics, science, engineering, and technology related courses.

- **Extending the experimentation possibilities:** The use of advanced tools and animations and the access to data from frontier experiments (like ATLAS and CMS) can serve as spurs to the imagination, promoting the interest of the students to be involved in scientific investigation. They were personally experienced the procedures involved in an authentic research project and thereby gain a far better understanding of science and engineering. The process freed from the pressing time limitation of the teaching hour. In this way their classroom was transformed into a scientific laboratory. The partnership believes that students can come to view the experimentation or the data analysis procedures as a craft that rewards dedication and precision but simultaneously encourages a spirit of creativity, exuberance, humour, stylishness and personal expression.

- **Developing critical capacity:** Too often students accept the readings of scientific instruments without question. When students got involved in the project activities for example by performing their own experiments and observations, they developed a healthy skepticism about the readings and a more subtle understanding of the nature of the scientific information and knowledge.

- **Making connections to underlying concepts:** Our working hypothesis was that amending the traditional scientific methodology for experimentation with visualization applications and model building tools has helped students and learners in general to articulate their mental models, make better predictions, and reflect more effectively. Additionally, working to reconcile the gaps and inconsistencies within their mental models, system models, predictions and results, has provided the learners with a powerful, explicit representation of their misconceptions and a means to repair them.

- **Understanding the relationship between science and technology:** Students gained firsthand experience in the ways that technological design (and mainly e-Infrastructures) can both serve and inspire scientific investigation. The overall Playing With Protons Goes Digital learning experience offered the option of teaching students as individuals, in small groups and in large groups while it provided links to other schools and research facilities in their country and abroad. The versatility of the tools that were integrated was one of the most compelling factors of the project.

Overall, a sustained school-research experience provides an ideal opportunity for students to become familiar with the process and culture of science and even to become engaged participants in the scientific enterprise. In the framework of the project short-term or one-time such informal science education experiences were more challenged to acquaint students with the culture of science in the fullest sense. Through participation in such activities, students can develop a greater appreciation of how scientists work together and the specialized language and tools they have developed. In turn, students also can refine their own mastery of the language and tools of science. For example, students participating in the "hunt of Higgs Boson" mission come together as a community to solve a particular problem. Using the tools of science to analyse data and to select the best candidates, students become more familiar with how scientists work on their research problems. The repertoire of the proposed resources has facilitated various patterns of group working. Flexibility is the key, because whatever visions of education we design our systems around, we can be sure that they will need to perform in a very different way in a few years' time. The Playing With Protons Goes Digital Digital AR Platform, along with the Handbook of Resources allows students to work through material at their own pace, with different levels of support according to their own preferences. Inevitably, different students embrace technology to greater or lesser extents and in different ways through the complementary interfaces the system offers.

By engaging in scientific activities, students also develop greater facility with the language of scientists; terms like *hypothesis*, *experiment*, and *control* begin to appear naturally in their discussion of what they are learning. In these ways, students begin to gain entry into the culture of the scientific community and start to change the way they think about themselves and their relationship to science. They think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science. When a transformation such as this one takes place, young people may begin to think seriously about a career in a research laboratory.

3

FINDINGS

2 FINDINGS

3.1 INTRODUCTION

In this chapter, we present the findings drawn from all phases of the Playing with Protons goes Digital project. The main findings relate to teachers' digital competences, schools' infrastructure and support, the availability of digital tools and resources provided, and the related educational outcomes for the participating students. In each section we describe in detail the project related work.

3.2 FINDING 1 - LACK OF DIGITAL COMPETENCES AND LIMITED USE OF ADVANCED TECHNOLOGIES IN SCHOOL CLASSROOMS

70% of respondents were familiar with Augmented Reality (AR) or Virtual Reality (VR) technologies and 64% are interest in learning about advanced technologies. However, only 18% of them utilized these technologies as teaching support.

Playing with Protons goes Digital project Contribution

The project focused **on enhancing teachers' digital competences.** We aimed to empower teachers and educators **by offering them an integrated online platform**, that would enable them to collaboratively design online innovative Science, Technology, Engineering, Arts, and Mathematics (STEAM) resources. This platform was enriched with interactive Augmented Reality artifacts aiming to personalize the learning experience of students. This approach proved to be efficient in encouraging students to actively participate, working independently and evolving into co-creators of AR-enhanced STEAM models.

To enhance teachers' digital competences and provide educational opportunities for educators in using the AR Digital Platform and learning 3D model creation, so they can harness the capabilities of Augmented Reality in their teaching processes and deliver greater educational value in their lessons, we have organized numerous **training events**.

These events served also as vision building activities, designed to introduce teachers to the project's approach. During the practical sessions of the workshops, examples provided by the consortium were collaboratively tested with teachers to demonstrate the tool's potential and possible implementations.

Teachers were supported in creating their own AR models and concepts using the project-provided tools. The consortium ensured continuous support and guidance throughout the pilot phases by providing online training guidance on using the AR Digital Platform to facilitate teachers' work.

3.3 FINDING 2 - POOR SCHOOLS' INFRASTRUCTURE AND LACK OF SUPPORT

Significant investment to upgrade schools' infrastructure in AR/VR activities is necessary. 66% of the teachers involved in the Needs Analysis and in the project implementation perceive their school's digital equipment as poor.

Despite the positive reception of technology by both students and teachers, who found it helpful, some teachers expressed concerns about the challenges their schools may face in providing technological support due to the lack of equipment such as tablets, projectors, or even internet connection.

The online platform developed (https://playingwithprotons.infn.it/)is a sustainable online environment that offers all the necessary tools and resources for teachers and educators to become active practitioners and have access to high quality and structured resources, as well as support in designing their own innovative content, lessons and activities. This online environment functions as a resources repository where participants enjoy full access to innovative scenarios, ready for classroom use as well as to numerous supporting materials for teachers and students. All resources are available once delivered and updates and adaptations are regularly made and even beyond the funding period. The platform also includes support materials for educators, templates, and the methodology for the creation of their own material. All educators can reach out to project partners through our platform and receive **full support and guidance for setting up and running their own Playing with Protons Goes Digital classrooms and activities. Guides, and the materials** offered accelerate impact and reach beyond the countries and school involved and beyond the duration of the project. It also allows other initiatives and projects to use and adapt Playing with Protons Goes Digital ideas and resources.

The Playing with Protons Goes Digital online environment is the main vehicle ensuring the sustainability of the project and the continuation of activities beyond the funding period. Through the online platform the project team supports teachers remotely and offer them a variety of learning options, as well as support for students working on STEAM projects outside their classrooms, responding therefore to a lockdown or temporary school closures. Importantly, the students' co-design artifacts or use artifacts that were be developed by teachers in the framework of their involvement in the proposed activities.

The main tool for achieving this goal is the AR Digital platform (Playing with Protons Goes Digital AR Platform) which was build for this purpose. This is a platform that allows users to create their own augmented reality artefacts (e.g. these could be models of detectors, particles collisions) **without any prior technical knowledge**. It is an educational oriented, adopted, and interactive tool that visualizes the students' creations while they develop their own digital projects on the platform. The platform enables teachers to take abstract concepts and bring them to life in a way that is both visually stimulating and engaging for students. By creating interactive and immersive experiences, the platform allows learners to explore and interact with complex scientific ideas in a way that was never before possible.

3.4 FINDING 3 - LIMITED ACCESS TO RESOURCES

64% of respondents needed a freely available digital toolkit with scenarios, guides and all the necessary AR digital tools. After receiving the Handbook of Resources, over 70% of teachers were satisfied with scenario topics, curricula integration, methodology, and tools. The majority of teachers (71%) expressed strong interest in the scenario topics, considering them both interesting (71%) and easily integrable into the curriculum (76%).

The Playing with Protons Goes Digital project proposed an innovative science teaching approach for students aged 10 to 15. The project aimed to empower teachers and students to become confident digital content designers despite the lack of the equipment provided by their schools and become science ambassadors, inspiring students about the wonders of science and potential careers in the field.

For this reason, the project's Handbook of Resources (IO2) produced (https://playingwithprotons.infn.it/outputs/), which includes a set of activities with basic AR/VR applications, a guide for teachers to design their own STEAM activities, and instructions on implementing the project in schools. The Handbook of Resources facilitates the smooth implementation of activities, while it is offering numerous scenarios for remote learning.

The project provided training to science teachers, and the Handbook guides them on fully incorporating activities into the curriculum, focusing on increasing students interest and motivation. The activities were designed for schools in various settings, including rural and remote areas, and involve collaboration with research institutes and science centers. The handbook also offers guidance for teachers to create their own activities based on the project's methodology.

Additionally, the project includes classroom activities to engage other stakeholders, fostering knowledge transfer and diffusion of CERN and INFN related research.

3.5 FINDING 4- ENHANCING STUDENTS' SCIENTIFIC PERSPECTIVES

The inquiry approach positively impacted students' attitudes towards learning science. Agreement on statements like 'Learning science is interesting' increased from 53% to 70%, while similar positive effects were observed in other relevant aspects, demonstrating the interest in the proposed activities with augmented reality tools (58%) and increased motivation in science (from 50% to 62%).

The findings from our implemented activities align closely with the comprehensive methodology, AR platform utilization, and the resources provided in the Handbook. The positive shifts observed in students' responses to questions regarding their perception of science and engagement can be attributed to the strategic approach employed. Specifically in each part of our approach, we could make the following observations.

Methodology

The inquiry-based methodology, rooted in six pedagogical principles, has evidently contributed to the positive outcomes. The principles focus on engaging learners, exploring contextual issues, explaining scientific concepts, elaborating knowledge in new contexts, and evaluating learners' knowledge and abilities. The transformative role of teachers as agents of change, coupled with continuous professional development, aligns with the observed increase in students' interest and positive responses.

AR Platform Utilization

The use of the Digital AR Platform played a pivotal role in creating innovative, interactive, and collaborative learning experiences. The platform provided context-aware functionalities, fostering student-centered and adaptable learning experiences. Through virtual collaboration activities and real-world problem-solving, students engaged in inquiry-based and problem-solving processes. The platform facilitated the sharing of resources, promoting collaboration beyond the school classroom. The incorporation of advanced tools and animations enhanced experimentation possibilities, contributing to increased motivation and critical capacity among students.

Handbook of Resources

The Handbook of Resources extended the impact beyond individual schools, addressing policy makers and advocating for curriculum enrichment. It provided a model for the coordination of educational and outreach activities involving major research infrastructures. The resources offered through the Handbook, including AR scenarios, 3D visual objects, and collaborative problem-solving activities, empowered teachers and students. The emphasis on personalization of resources for reference and problem-solving further supported a variety of learning activities.

Overall Project Vision

The project's aim to demonstrate the key role of advanced technological applications, present new visions for teaching, and support educators with meaningful digital technologies has been realized. The emphasis on promoting deeper learning, incorporating innovative STEAM activities, and inspiring science education has resulted in positive student outcomes. The alignment with national policies on STEAM and teachers' skills, as well as the focus on the interaction between schools and the local community, has further enriched the project's impact.

Beyond the findings related to the methodology and project structure, we cannot overlook the implementation process in school. This could be defined in several sections regarding students' background and attitude and teachers' implementation.

Supporting Teacher's work

- Teachers actively familiarize themselves with the technology, especially the scenarios, result on a smoother integration of digital tools into their classrooms. This initial step was crucial in creating an effective learning environment.
- Teachers well-informed about the subject, lead to more effective implementation of scientific concepts and inquiry-based learning

methods. This knowledge transfer positively impacted the quality of education delivered through the project.

- Teachers who clearly defined goals for each scenario implemented more effective teaching strategies. Specific objectives allowed educators to tailor training to meet the developmental needs and expected achievements of their students.

- The educators' enthusiasm and effective guidance in incorporating augmented reality can play a crucial role in influencing students' excitement about the learning process.

- Careful planning before classroom sessions, including objective definition and material adaptation, maximized the impact of the methodology and AR scenarios. This approach ensured a well-organized and impactful implementation.

- Encouraging learners to work autonomously during AR sessions, with teachers assuming the role of external observers, facilitated a positive learning environment. This autonomy supported student interaction with the system and promoted self-paced learning.

- Facilitating post-session discussions based on students' experiences and session goals promoted reflection and reinforced learning objectives. This practice contributed to a deeper understanding of explored scientific concepts.

Impact on Students

- Students had not at all or little experience with digital AR tools or innovative activities in the school environment, so the use of rich digital material generated significant interest. Moreover, the use of technology, especially augmented reality, tends to motivate students who may find traditional teaching methods less engaging. The interactive and dynamic nature of AR scenarios often sparks greater motivation.

- Augmented reality provides a highly interactive and immersive learning experience, allowing students to actively engage with educational content.

- The visual and multi-sensory nature of augmented reality enhances the learning environment, making abstract concepts more tangible and easier to comprehend. Moreover, augmented reality often allows students to make connections between theoretical concepts and real-world applications, fostering a deeper understanding of the subject matter. The increased understanding of science subjects leads to increased students' confidence of self-efficacy in science. Augmented reality scenarios often require students to apply critical thinking, problem-solving, and decision-making skills, contributing to a sense of achievement and accomplishment, too.

- Collaborative activities within augmented reality scenarios promote teamwork, discussion, and shared problem-solving, making the learning experience more dynamic. Moreover, augmented reality can be tailored to individual learning styles, allowing students to explore content at their own pace and providing a personalized learning experience and experience a positive learning experience.

- The positive association of augmented reality with enjoyable and interactive activities creates a more favorable and exciting learning environment for students.

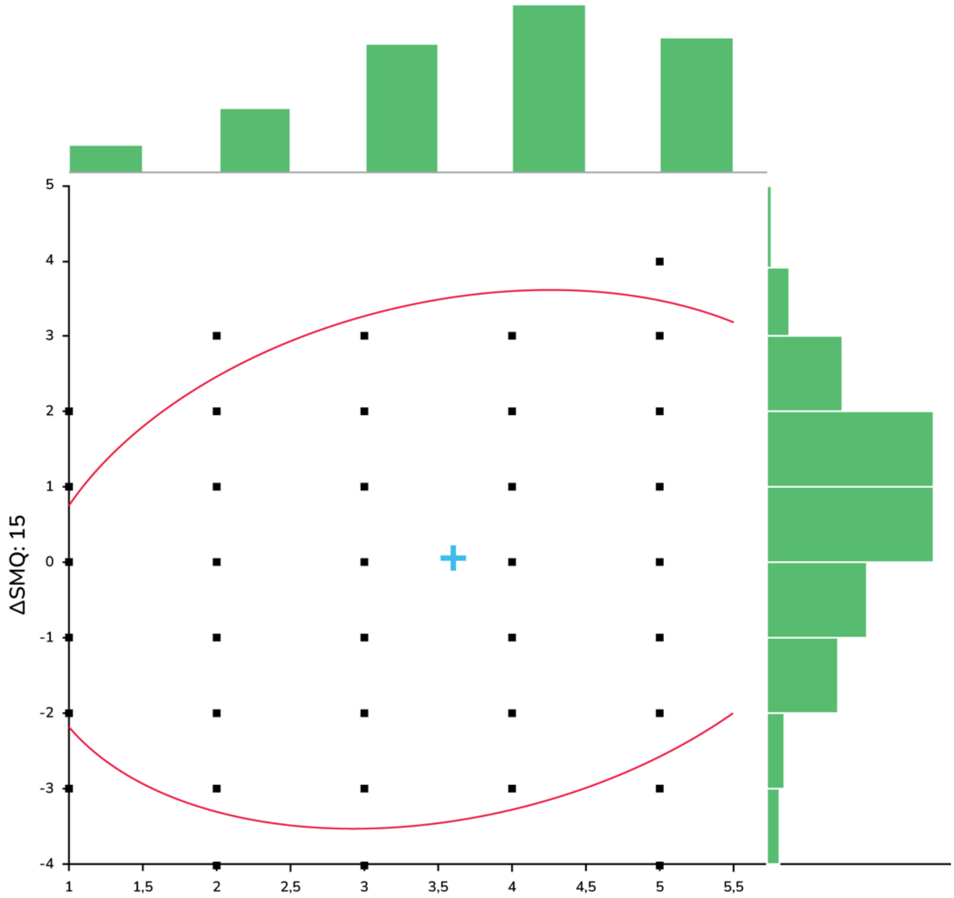
In summary, the findings reflect the success of the Playing with Protons Goes Digital project in achieving its goals. The integration of advanced technological tools, the emphasis on inquiry-based learning, and the collaborative approach have collectively contributed to a positive shift in students' perceptions and engagement with science. The methodology, AR platform, and Handbook of Resources have synergistically worked together to create a transformative learning experience for both students and teachers.

3.6 FINDING 5 - ENHANCING STUDENTS' DIGITAL SKILLS

The assessment of the Playing With Protons Goes Digital project implementation revealed a positive correlation between the increase of students' interest and the development of the students' competences in using the AR tools and resources (see Figure 1).

This highlights the project's positive impact on increasing students' skills in using advanced tools to describe complex phenomena.

The project's emphasis on making students co-designers of AR models significantly contributed to their increased digital skills. Actively involving students in the creation process exposed them to advanced tools, fostering a hands-on learning experience. This approach not only enhanced their technological proficiency but also fostered a sense of ownership and engagement. By becoming co-designers, students were immersed in the process of understanding, experimenting, and applying digital tools. This hands-on involvement allowed them to explore the intricacies of creating AR models, developing problem-solving skills along the way. The collaborative nature of this approach promoted teamwork and shared problem-solving, further enriching the learning experience. Overall, the project's strategy of making students co-designers successfully combined theoretical knowledge with practical application, empowering them with valuable digital skills.



CORRELATION **N 421**

	POST IMI: 7. After working at this activity for a while, I felt competent.	ΔSMQ: 15
For a while, I felt competent		0,221 Pearson's r 0,181 Spearman's rs 0,145 Kendall's tau
ΔSMQ: 15	0,221 0,181 0,145	

Figure 2-1 Correlation Matrix and values between Interest (SMQ values) and Competence in the use of AR (IMI)

4

RECOMMENDATIONS

4 RECOMMENDATIONS

In this chapter we are presenting a series of recommendations for each finding of our project. The recommendations are organized in three categories focusing on teachers, school leaders and educational stakeholders.

4.1 RECOMMENDATION 1 - DEVELOPMENT OF DIGITAL COMPETENCES

For Teachers

Take part on training activities to reinforce digital competences.

To optimize educational outcomes in the realm of STEAM (Science, Technology, Engineering, Arts, and Mathematics), teachers are encouraged to:

- **Explore and Utilize Digital Tools and Resources**: Actively seek out and employ various tools and resources available to enhance digital competencies. This proactive approach will aid in creating captivating and effective STEAM content for students.
- **Collaborate in AR Model Creation**: Engage in teamwork with colleagues and students to co-develop augmented reality (AR)-enhanced models. This collaboration will foster a dynamic and interactive learning environment, making educational experiences more immersive and effective.
- **Pursue Continuous Professional Development**: Remain dedicated to ongoing professional growth by seeking out opportunities for learning and development. Keeping abreast of the latest educational technologies and teaching methodologies is crucial for staying relevant and effective in the ever-evolving educational landscape.
- **Develop Personalized AR Artifacts**: Empower teachers to create their own augmented reality artifacts. This capability enables educators to bring abstract concepts to life, offering students visually stimulating and

engaging lessons. Exploring the unique potential of AR in education can transform the learning experience, making complex ideas more accessible and interesting.

These strategies not only enhance the learning experience for students but also contribute to the professional enrichment of educators, aligning with modern educational needs and technological advancements.

For School Leaders

Provide opportunities for training, organize workshops and seminars.

To foster a more effective and engaging STEAM (Science, Technology, Engineering, Arts, and Mathematics) education environment, School Leaders should consider the following strategies:

- **Promote Digital Platform Adoption**: Actively encourage and facilitate the use of digital platforms within the school setting. It's important to recognize and emphasize their potential at various levels, particularly in enhancing digital competencies among teachers and boosting student engagement in STEAM subjects.
- **Support AR-Enhanced STEAM Teaching**: Provide necessary support for teachers to incorporate Augmented Reality (AR)-enhanced STEAM models into their teaching practices. This involves fostering a culture of collaboration and innovation within the school community, enabling educators to explore and implement cutting-edge teaching methods.
- **Invest in AR Training Sessions**: Allocate resources specifically for training sessions that focus on the effective use of AR in educational materials. Ensuring that teachers have access to continuous professional development opportunities is crucial for maximizing the benefits of the initiative and keeping them abreast of the latest educational technology trends.
- **Evaluate Initiative Impact Regularly:** Conduct regular assessments of the impact of these initiatives on student learning outcomes. This process

should include collecting feedback from both teachers and students. Such evaluations are essential for making informed decisions regarding the continuation and enhancement of the initiatives, ensuring they remain effective and relevant.

Implementing these strategies can lead to a more enriched, future-ready education system that leverages the latest technological advancements to enhance learning outcomes.

For Educational Stakeholders

Integrate of digital competencies and AR technologies in educational policies by creating a digital database with guidelines that fosters teachers' training on digital skills to enhance the quality of education.

For a comprehensive approach to integrating technology in education, the following strategies should be considered at policy level:

- **Advocate for Policy Integration of Digital Skills and AR**: Strongly support the inclusion of digital competencies and Augmented Reality (AR) technologies in educational policies. It's crucial to recognize their significance in preparing students for the digital era. This involves understanding the transformative impact of these technologies on learning and advocating for their incorporation at the policy level.
- **Resource Allocation for Technology Adoption**: Ensure that sufficient resources are allocated for the widespread adoption of advanced technologies in schools, such as AR tools. This includes funding for professional development of educators, necessary infrastructure upgrades, and ongoing technical support. Adequate financial support is key to the successful implementation and sustainability of these technologies in educational settings.
- **Foster Collaborative Efforts**: Encourage collaboration among educational institutions, policymakers, and industry partners. Such collaborations are instrumental in promoting the development and effective implementation of innovative educational technologies.

Through these partnerships, schools can gain access to cutting-edge resources and expertise, enhancing the educational experience.

- **Curricula Integration of Advanced Tools and STEAM Projects**: Explore the potential for integrating advanced digital tools and collaborative STEAM (Science, Technology, Engineering, Arts, and Mathematics) projects into official curricula. Aligning educational policies with the objectives of enhancing digital literacy and fostering creativity in students is crucial. This alignment ensures that the curriculum remains relevant and effective in equipping students with necessary 21st-century skills.

Implementing these strategies can lead to a more enriched, future-ready education system that leverages the latest technological advancements to enhance learning outcomes.

4.2 RECOMMENDATION 2 – UPGRADE AND EFFECTIVE USE OF SCHOOLS' INFRASTRUCTURE

For Teachers

Teachers should pursue professional development through workshops or online courses to enhance their digital skills with existing school equipment. Additionally, they should advocate for improved digital infrastructure to enhance education quality and student engagement in AR/VR activities.

- Teachers should seek professional development opportunities to enhance their digital skills in using the existing school equipment (tablets, laptops, etc) correctly and effectively for their lesson needs. Workshops, training sessions, or online courses can help them become more proficient in using digital technologies for educational purposes.
- Teachers should actively communicate with school administrators and advocate for improved digital infrastructure. They can highlight the impact of inadequate resources on the quality of education and student engagement in AR/VR activities.

For School Leaders

School leaders must allocate resources for upgrading digital infrastructure, providing hardware, software, and support for advanced digital tools and platforms using augmented reality. Encourage continuous professional development for teachers to ensure effective integration of digital technologies into teaching practices.

- School leaders should prioritize and allocate resources to upgrade the digital infrastructure of the school. This includes providing necessary hardware, software, and technical support to ensure a conducive environment for AR/VR activities.
- Encourage and facilitate ongoing professional development for teachers to ensure they are equipped with the necessary skills to effectively integrate digital technologies into their teaching practices.

For Educational Stakeholders

Advocate for increased educational funding, including grants and government support, to enhance digital infrastructure in schools. Integrate digital literacy into the curriculum to address challenges of limited hardware, ensuring equitable access to essential skills.

To effectively integrate technology into educational systems and address infrastructure challenges, the following approaches can be considered:

- **Advocate for Increased Educational Funding**: Plans and Actions for enhanced funding in educational budgets, specifically targeting the improvement of digital infrastructure in schools. This advocacy could involve seeking grant funding and government support to augment the technological capabilities of educational institutions. Increased funding is crucial for equipping schools with the necessary digital tools and infrastructure to provide a modern education.

- **Incorporate Digital Literacy into Curriculum**: Integrate digital literacy as a strategic component of the curriculum to address the challenges posed by inadequate school infrastructure. Even in settings where hardware and software resources are limited, teaching digital literacy ensures that students develop the essential skills to effectively use whatever technology is available. This inclusion can help bridge the gap caused by varying levels of technology access across different schools.

- **Address Equity Issues through Digital Literacy**: Including digital literacy in the curriculum is also a vital step towards addressing equity issues. Students from schools with limited infrastructure might not have sufficient exposure to digital technologies outside the classroom. By ensuring that digital literacy is a fundamental part of the curriculum, there is a concerted effort to guarantee that all students, regardless of the quality of their school's infrastructure, acquire a baseline understanding of critical digital skills. This approach helps in leveling the playing field and ensuring that all students are prepared for a technology-driven world.

These strategies collectively aim to enhance the educational landscape, ensuring that students are not only equipped with necessary digital skills but also have equitable access to the benefits of technology in their learning journey.

4.3 RECOMMENDATION 3 - DIGITAL HANDBOOK OF RESOURCES

For Teachers

Teachers should take advantage of the freely available AR-STEAM resources and engage actively in chances for valuable training, and foster collaboration to share experiences from their implementations.

- Actively implement AR STEAM scenarios in the classroom and actively participate in evaluation processes. Communicate any challenges related to the curriculum, timetables, schools' infrastructure, and specific needs for implementation.
- Creatively adapt the inquiry-based AR STEAM methodology to suit the educational context and address students' developmental needs. Consider their identified needs and expected achievements when planning and implementing scenarios.
- Engage in careful planning before implementing AR scenarios. This includes addressing aspects such as curriculum alignment, scheduling within timetables, and ensuring compatibility with schools' infrastructure.
- During AR sessions, guide students in the effective use of AR equipment, such as mobile phones and tablets. Ensure they are comfortable and proficient in using these tools to enhance their learning experience.

For School Leaders

Effectively integrate AR STEAM scenarios into the educational framework by defining clear goals aligned with the school's mission, organizing a strategic curriculum plan, providing comprehensive guidelines to teachers, communicating educational objectives, leading seamless incorporation, and supporting professional development for effective implementation.

- Clearly define goals aligning with the school's mission and vision for integrating AR STEAM scenarios into the educational framework.
- Organize a strategic plan for integrating AR STEAM activities into the curriculum, identifying points that enhance learning experiences and complement existing subjects.
- Provide comprehensive guidelines to teachers, including detailed instructions on conducting sessions, utilizing AR equipment, and aligning activities with educational goals.
- Communicate educational objectives, ensuring teachers understand pedagogical goals, learning outcomes, and the broader impact on students' experiences.
- Lead the seamless incorporation of AR STEAM activities into the curriculum, identifying opportunities to enhance existing subjects and align with academic standards.
- Support professional development related to AR technologies through training sessions, equipping teachers with skills for effective implementation.

For Educational Stakeholders

Develop policies for the creation and accessibility of digital toolkits with innovative STEAM and augmented activities, address digital infrastructure gaps through strategic investments, and integrate inquiry-based methodologies connected with Big Ideas into educational policies to prepare students for the digital age with engaging and hands-on learning experiences.

- Develop policies that facilitate the creation and widespread availability of digital toolkits with innovative STEAM and augmented activities. Ensure that such resources are accessible to teachers across various educational settings.
- Formulate policies to address the digital infrastructure gaps highlighted in the evaluation results. Prioritize investments in technology to create an environment conducive to the successful implementation of digital tools in education.
- Encourage the integration of innovative teaching approaches, such as inquire based approach into educational policies. Emphasize the importance of preparing students for the digital age through engaging and hands-on learning experiences.

4.4 RECOMMENDATION 4 - ENHANCING STUDENTS' SCIENTIFIC PERSPECTIVES

For Teachers

Embrace inquiry-based learning, integrate digital tools seamlessly, and encourage autonomous exploration. Foster collaborative, immersive experiences, ensuring careful planning. After implementation, facilitate discussions for reflective, engaging science education.

- Ensure careful planning before conducting classroom sessions. This includes defining objectives, adapting materials, and organizing the implementation of the methodology to maximize their impact and meet the developmental needs and expected achievements of the students.
- Ensure a smooth integration of digital tools into the classroom setting.
- Continue integrating and expanding the use of inquiry-based and project-based learning methodologies in science education.
- Encourage student engagement through activities that promote exploration, explanation, and evaluation of scientific concepts.
- Using advanced digital tools for creating interactive and collaborative learning experiences. Integrate advanced tools to enhance experimentation possibilities, fostering a dynamic and immersive environment for students to explore scientific phenomena.
- Encourage learners to work autonomously and at their own pace. Teachers should assume the role of external observers, intervening only when necessary, such as in the case of arguments or when further explanations are needed.
- After implementation, facilitate class discussions based on students' experiences and the goals of the session. This promotes reflection and reinforces learning objectives, fostering a deeper understanding of the scientific concepts explored.

For School Leaders

Empower teachers through continuous professional development, fostering collaboration within schools. Allocate resources for technology and training, promoting autonomy and clear goal-setting for impactful integration of digital tools in education

- Provide resources and support for continuous professional development opportunities for teachers, ensuring they stay updated on innovative teaching methods and digital tools.
- Encourage collaboration among teachers within the school. Create platforms for sharing experiences and insights from implementing inquiry based methodology, advanced AR tools, and scenarios.
- Allocate necessary resources, including technology and training, to support the effective integration of digital tools and scenarios into the curriculum.
- Encourage autonomy in the classroom by supporting teachers in fostering self-paced learning experiences for students during classes.
- Reinforce the importance of defining clear goals for each scenario to maximize the impact of teaching strategies and ensure alignment with the school's educational objectives.

For Educational Stakeholders

Promote integration of innovative methodologies and advanced digital technologies like AR in education. Align policies, emphasize personalization in resources, and advocate for technological support to enhance STEAM education and community collaboration.

- Advocate for the integration of innovative methodologies, such as inquiry-based learning and advanced digital tools, into the curriculum to enhance the overall quality of education.
- Align policies with the use of advanced technological applications in education, emphasizing the importance of new visions for teaching and supporting educators with meaningful digital technologies.
- Promote outreach activities involving major research infrastructures, creating models for coordination that involve collaboration between schools and the local community.
- Emphasize the importance of personalization in learning resources, supporting a variety of learning activities and catering to diverse learning styles and interests.
- Ensure alignment with national policies on STEAM education and teachers' skills, emphasizing the significance of interaction between schools and the local community.
- Advocate for technological support in schools, addressing issues related to the availability of equipment and the development of skills and knowledge required for effective use of augmented reality and other digital tools.

4.5 RECOMMENDATION 5 - ENHANCING STUDENTS' DIGITAL SKILLS

For Teachers

Teachers should actively engaging students as co-designers in the learning process.

- Teachers should actively involve students in the learning process. Such an approach not only enhances students' technological proficiency but also fosters a sense of ownership and engagement. Teachers should guide students in understanding, experimenting, and applying digital tools within the curriculum.

For School Leaders

School Leaders should prioritize the availability of tools and resources in their schools and encourage and facilitate professional development of the school staff.

- Prioritize and allocate resources to upgrade the digital infrastructure of the school. This includes providing necessary hardware, software, and technical support to ensure a conducive environment for activities involving digital platforms and advanced digital tools.
- Encourage and facilitate ongoing professional development for teachers to ensure they are equipped with the necessary skills to effectively integrate digital technologies into their teaching practices. This support is crucial for maintaining a high standard of education aligned with technological advancements.

For Educational Stakeholders

Education stakeholders should increase the funding for digital infrastructure and teachers' professional development. They need to emphasize digital literacy in the curriculum for equitable access to essential technology skills. Their decisions have to made based on evidence from educational practice.

- Education stakeholders should advocate for increased funding in educational budgets specifically designated for improving digital infrastructure in schools. This advocacy may involve seeking grant funding and governmental support to enhance technological capabilities in educational institutions.
- Emphasize the importance of incorporating digital literacy into the curriculum. Even in schools with limited hardware and software resources, teaching digital literacy ensures that students develop essential skills for using available technologies effectively. This promotes equity in education by providing a baseline understanding of digital skills for all students.
- They have to make their decisions based on evidence from the educational practice. The funding has to be allocated to tools and applications that have proven their capacity to qualitative upgrade the learning process.

5

CONCLUSIONS

5 CONCLUSIONS

The Playing with Protons Goes Digital initiative tackles fundamental challenges in education by offering solutions for integrating advanced digital tools such as Augmented Reality (AR) and Virtual Reality (VR) into educational settings. This integration has shown a positive influence on students' scientific understanding and digital proficiency. The use of innovative AR tools, combined with inquiry-based teaching methods, has led to a transformative educational experience, enhancing both student and teacher engagement and interest in science.

Remarkably, teachers and students were able to create and utilize their own AR projects without needing previous experience or knowledge in digital technologies. This approach has demonstrated a favourable impact on students' interest in science and their digital abilities.

The project's recommendations emphasize the need for teachers to improve their digital skills, incorporate AR-STEAM (Science, Technology, Engineering, Arts, and Mathematics) resources, and involve students in the design process. School leaders are advised to enhance infrastructure, offer training and guidelines, and align educational objectives. Educational stakeholders are encouraged to integrate digital competencies into curriculums, support funding for AR initiatives, and foster collaborative efforts.

Overall, the project highlights the importance of accessible tools, inquiry-based learning methods, and collaborative endeavors in improving digital skills and science education. This initiative is viewed as a preliminary step towards establishing a robust and enduring approach to science and STEAM education, as well as building a strong community of educators across Greece, Italy, Spain, and Great Britain. It is believed that this project could significantly impact the countries of the participating organizations and the broader educational community.

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