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BIOS4YOU AR 2.0

BIO-INSPIRED STEM TOPICS FOR ENGAGING YOUNG GENERATIONS
THANKS TO THE USE OF AUGMENTED REALITY

WP2 Activity 1 - part2

Identification of AR technology most suitable to be used in the school sector for providing gamification content in the STEM subject

Project Number: KA220-BW-23-30-126516

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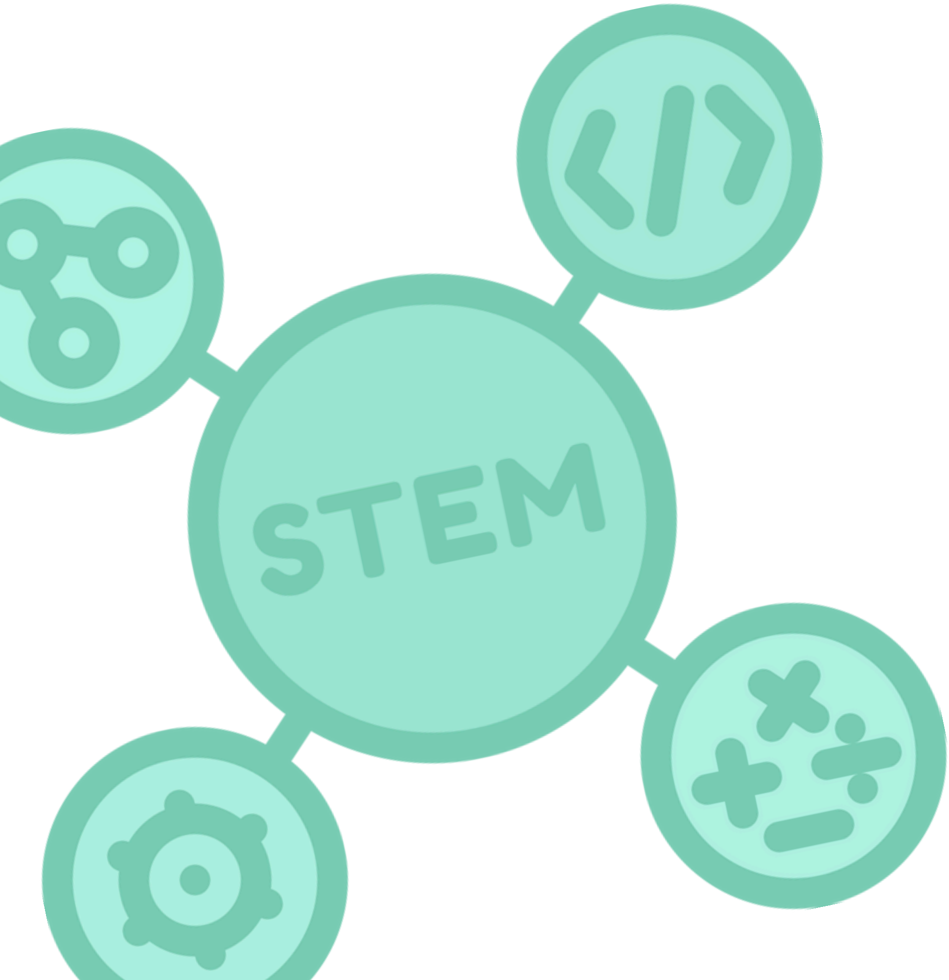
What is STEM education?

STEM education stands as an acronym and refers to an interdisciplinary approach to teaching and learning that integrates concepts and skills from four core disciplines: Science, Technology, Engineering, and Mathematics. Responses to the question "What is STEM?" can vary significantly depending on the source consulted. From a policy angle, such as views from organizations like the NSF and legislative bodies, to an educational perspective, typical of K-12 agencies and school districts, STEM is often seen as a traditional set of disciplinary subjects encompassing science, mathematics, technology, and engineering, without much integration. Hence, the prevailing modern understanding of STEM education highlights integration–meaning the purposeful fusion of various disciplines to tackle real-world problems (Sanders, 2009). STEM education's aim is to prepare students with the knowledge, skills, and competencies needed to thrive in today's rapidly evolving technological and scientific field by solving real world problems. STEM is an educational approach that is designed to introduce into the teaching of Mathematics and Science, which are essential for understanding basic phenomena for life, the science of Technology and Engineering, as they are the means for humans to interact with the natural world. By that means, STEM, as an interdisciplinary approach, focuses on understanding and solving real-world problems. Interdisciplinarity entails exploring various subjects and linking scientific fields together, enabling students to understand not just specific knowledge but also how sciences intersect and influence different aspects of everyday life (Matsangouras, 2012).



What is STEM education?

The idea of interdisciplinarity in education is a theory that was developed and supported since the 20th century by pioneering educators such as John Dewey, who advocated learning using strategies and activities inspired by students' real-life experiences (Dewey, 1934). Later, both Piaget and Papert built on and developed the ideas of Dewey, as well as constructivist theory, according to which learning is an active process rather than a mere transmission of knowledge to students. Knowledge is constructed and based on children's personal experiences of everyday life, while at the same time depending on each individual's prior knowledge (Piaget, 1974). In this perspective educators and teachers took on a guiding and supportive role while the centre of the learning process got placed exclusively in the hands of the learner.

In the 1990s, the National Science Foundation of the United States established the linking of the fields of Science, Mathematics, Engineering, and Technology. Initially the term "SMET" was used, but in 2001 Dr. Judith Ramaley, assistant director of the Education and Human Resources Division, at NSF in 2001 established the term "STEM" worldwide (Chute, 2009).

In fact, she defined STEM as an educational inquiry in which learning was situated in a context in which students solve real-world problems and create opportunities, therefore pursuing innovation. The National Science Foundation of the United States wanted to give particular attention to each of the four components above with two main objectives. Firstly, at the national level, it sought to promote essential technological and engineering advancements to maintain competitiveness globally. Secondly, it aimed to equip every student with a solid understanding of the fundamental principles of STEM subjects and their interconnections, thereby fostering literacy and ensuring viable employment opportunities in adulthood (Chesky & Wolfmeyer, 2015).

At the start of the 21st century, there was an increased urgency for an interdisciplinary approach to Mathematics, Science, Technology, and other related fields. In the United States, there was a general concern about students' low achievement in mathematics and, particularly, in science, coupled with a lack of interest in pursuing studies in these disciplines (Kuenzi, 2008). Researchers and educators concluded that the best way to revive students' interest in science and technology was to redefine the relationship between these two fields.

Sanders (2009) characterized integrated STEM education as approaches that explore teaching and learning between or among two or more STEM subject areas, or between a STEM subject and other school subjects. Sanders suggests that deliberate outcomes for learning at least one additional STEM subject should be incorporated into a course, such as a math or science learning outcome in a technology or engineering class. Moore et al. (2014), on the other hand, defined integrated STEM education as an endeavor to merge some or all of the four disciplines of science, technology, engineering, and mathematics into a single class, unit, or lesson, emphasizing connections between these subjects and real-world problems.

In 2009, STEM education took off thanks to the President of the United States, Barack Obama, who boosted STEM education and increased the number of teachers in the field. The President launched the Educate to Innovate initiative to move American students from the middle to the top of the pack in science and math achievement over the next decade. In fact, he argued that "science is more essential for our prosperity, our security, our health, our environment, and our quality of life than it has ever been before." (Obama, 2009). Later In 2012, the United States National Research Council proposed the STEM (Science, Technology, Engineering and Mathematics) as a new method of teaching, seeking to promote the integration of Science, Technology, Engineering and Mathematics (STEM), into the curriculum, while fostering collaborative learning among students (Pellegrino and Hilton, 2012; Siekmann and Siekmann, 2012; Korbel, 2016-Miller et al., 2017).

What is STEM education?

In 2013, President of the United States, Barack Obama, argued "One of the things that I've been focused on as President is how we create an all-hands-on-deck approach to science, technology, engineering, and math... We need to make this a priority to train an army of new teachers in these subject areas, and to make sure that all of us as a country are lifting up these subjects for the respect that they deserve." (Obama, 2013).
Although the STEM educational approach originated in the United States to address its own educational needs, it quickly gained international adoption. Stemming from America, with its core objectives of enhancing competitiveness in STEM fields and fostering student engagement in science, mathematics, engineering, and technology activities, the principles and practices of STEM are now prevalent in all American universities and many secondary schools, including specialized STEM institutions. Moore et al. (2014) described integrated STEM education as the integration of science, technology, engineering, and mathematics into a unified class, unit, or lesson. This integration is based on establishing connections between these disciplines and real-world problems. While integrated STEM curriculum models may focus primarily on learning objectives from one STEM subject, they incorporate contexts from other STEM fields. Integrated STEM education is characterized by teaching content from multiple STEM domains within authentic contexts, emphasizing STEM practices to enhance student learning. Europe is also moving in a similar direction.

The European Union is funding projects that promote STEM in education, with the aim of training more students in STEM fields to meet its needs in the upcoming years due to lack of science professionals. Back in 2015, the European Schoolnet ran a STEM in Education survey report (Kearney, 2015), providing national measures from 30 countries. According to the European Schoolnet, 80% of the 30 countries (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Greece, Hungary, Ireland, Israel, Italy, Lithuania, Poland, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Switzerland and the United Kingdom) participating in the STEM in Education survey report that STEM education is a priority for their teacher. Although, in 2013, the European Union has produced research showing both weak student performance in science and mathematics and a lack of a trained workforce in STEM fields. In EU policy-making, the need to integrate new technologies into education and workforce training has been included as a matter to be addressed as a matter of immediate priority (Commission, 2015). However, the STEM educational approach is not only seen as necessary for students who will in the future pursue careers around STEM subjects. The main purpose of this innovative educational approach is to prepare all students and equip them with 21st century skills and competences to successfully keep up with modern societies through the problem-solving process, which will focus on real problems of the modern world (Moore & Smith, 2014). The European Schoolnet aims to inspire and aid members of education ministries, schools, teachers, and other relevant stakeholders across Europe in reshaping educational practices to suit the digitalized societies of the 21st century. The European Schoolnet achieves this by identifying and experimenting with promising innovative methods, sharing evidence of their impact, and facilitating the adoption of teaching and learning approaches that align with contemporary standards for inclusive education. According to Marc Durando, Executive Director of European Schoolnet "Through our activities, we support teachers and school heads in their transformation processes. Technology alone does not transform teaching practices. Any transformation process has to be the result of a strategy and a vision where the heads of school will assert their key role alongside the teaching community as the driving force for change."
Fostering STEM talent in young individuals to shape them into the much-needed STEM professionals of tomorrow remains a primary focus for European Schoolnet. Additionally, there is a persistent issue of teaching STEM subjects in isolation.

What is STEM education?

Therefore, efforts to promote interdisciplinary teaching, aligned with real-world challenges like sustainability or research, as well as fostering collaboration and implementing comprehensive STEM education approaches across all levels of schooling, will remain central priorities in the coming years. Since 2010, Scientix, overseen by European Schoolnet, has been at the forefront of sharing knowledge and experiences in STEM Education. Through its portal, publications, campaigns, professional development activities, and networking events, Scientix has played a pivotal role in this domain. Initially supported by the European Union's FP7 and Horizon 2020 research and innovation programs from 2010 to 2022, Scientix transitioned to being solely managed by European Schoolnet in April 2023.

The formation of the Scientix STEM Alliance was a response to a critical shortage of STEM skills in Europe. Factors such as diminishing interest in STEM careers, declining performance in traditional STEM education, and a gap in digital literacy are leading to a decrease in STEM graduates. This trend not only stifles innovation but also limits our ability to address pressing global issues like climate change, mobility, and energy. This initiative acted as the central project for all collaborations pertaining to STEM education with industry partners.

Introduction of STEAM in Secondary School

STEAM education is an interdisciplinary approach that emphasizes the connections between science, technology, engineering, art and math disciplines, fostering critical thinking, problem-solving skills, creativity, and innovation (Bertrand & Namukasa, 2022). This part of the guideline provides an overview of the rationale behind STEAM education, its benefits, challenges, and strategies for successful implementation in secondary school.

In recent years, there has been a growing emphasis on integrating STEAM education into secondary school curricula worldwide. This initiative aims to prepare students for the demands of the 21st century by equipping them with essential skills and knowledge across multiple disciplines. By incorporating elements of science, technology, engineering, arts, and mathematics into educational practices, STEAM education seeks to nurture holistic development and cultivate a workforce capable of addressing complex global challenges . Global researchers have proposed the idea that teachers should endorse the utilization of STEAM as an educational instrument that enhances the learning journey (Matsuura & Nakamura, 2021). Numerous studies have underscored the manifold advantages of integrating STEAM education into secondary school curricula. According to the article published in the Journal of STEM Education Research, students exposed to STEAM pedagogy exhibit notable enhancements in their academic performance, particularly excelling in mathematics and science disciplines (Smith et al., 2020). This empirical evidence reinforces the efficacy of STEAM methodologies in bolstering student achievement.

The incorporation of STEAM education into secondary school settings is supported by a wealth of compelling rationales, primarily rooted in the acknowledgment of the interconnectedness of various disciplines. This interconnectedness mirrors the real-world scenario where problems often transcend disciplinary boundaries (National Research Council, 2014). By embracing a holistic approach that integrates these disciplines, STEAM education offers students a platform to explore diverse perspectives and develop a comprehensive understanding of complex phenomena.

Introduction of STEAM in Secondary School

In essence, STEAM education recognizes that many challenges facing society today, such as climate change or global health crises, cannot be adequately addressed through the lens of a single discipline. Rather, they require a multifaceted understanding that draws upon insights from science, technology, engineering, arts, and mathematics. This interdisciplinary approach not only enriches students' learning experiences but also prepares them to tackle real-world problems more effectively. Moreover, STEAM education in secondary school fosters creativity and innovation by providing students with hands-on, project-based learning experiences. Research has shown that engaging in such activities stimulates students' curiosity and encourages them to experiment and explore new ideas (Quigley, Herro, & Jamil, 2019). By working on STEAM projects, students learn to think critically and creatively, developing essential skills that are highly valued in today's workforce. STEAM activities in the classroom fosters collaboration and teamwork, skills paramount for navigating the collaborative environments prevalent in modern workplaces. Collaborative projects not only enhance students' interpersonal skills but also mirror the collaborative nature of professional settings, preparing them for seamless integration into diverse teams (Smith et al., 2020). Furthermore, STEAM education promotes the development of critical thinking and problem-solving skills, which are vital for success in the 21st century. Through inquiry-based learning and problem-solving activities, students learn to analyze information, evaluate evidence, and generate innovative solutions to complex problems (Stohlmann, Moore, & Roehrig, 2012). These skills not only benefit students academically but also empower them to become active and informed citizens capable of addressing the challenges facing their communities and the world at large. In essence, the integration of STEAM education in secondary schools equips students with a multifaceted skill set, preparing them to thrive in an ever-evolving world (Smith et al., 2020).

Introduction of STEAM in Secondary School

In secondary education, the implementation of STEAM education encounters several challenges. A fundamental obstacle is the integration of diverse subjects into the curriculum, as emphasized by Matsuura and Nakamura (2021). They stress the importance of aligning STEAM initiatives with existing educational frameworks while ensuring coherence and relevance across disciplines. However, achieving this integration within the conventional structure of secondary education systems remains complex (National Research Council, 2014). Teacher readiness is another significant concern highlighted by Stohlmann, Moore, and Roehrig (2012). Their research indicates that many teachers lack the necessary pedagogical strategies and content knowledge for effective STEAM integration. Professional development programs tailored to STEAM pedagogy and interdisciplinary approaches are essential to address this gap (Bertrand & Namukasa, 2022). Furthermore, the availability of resources poses a substantial challenge. Quigley, Herro, and Jamil (2019) discuss how access to materials, equipment, and facilities is crucial for hands-on, experiential learning inherent in STEAM education. Assessment methods present yet another hurdle. Traditional assessment frameworks may not adequately capture the interdisciplinary skills fostered by STEAM education. Smith, Johnson, and Williams (2020) emphasize the need for innovative assessment strategies that assess students' ability to apply knowledge across multiple disciplines. However, developing and implementing such assessments require significant time, expertise, and institutional support. Addressing these challenges is essential for realizing the full potential of STEAM education in secondary schools. Collaboration among teachers, adequate training and resources, and the development of effective assessment methods are crucial aspects to consider.

The integration of STEAM education in secondary school within modern educational frameworks presents both challenges and opportunities. While it has found its place in educational agendas, there is still a notable disparity in the quality and quantity of initiatives, according to research by Kim and Kim (2016) and Perignat and Katz-Buonincontro's (2019) literature review. These studies emphasize the need for more tangible learning outcomes, particularly in areas like creativity, problem-solving, and arts education. Kim and Kim's (2016) proposed criteria for effective STEAM learning - situational context, creative design, and emotional engagement - serve as guiding principles in creating meaningful learning experiences. Various initiatives, including museum visits, hands-on experiments, and digital simulations, as highlighted by Li and Wong (2020), offer diverse pathways to STEAM integration, catering to students' diverse learning preferences and interests. Noteworthy projects such as the Global Science Opera and UK CREATIONS initiatives exemplify collaborative efforts that bridge the gap between arts and sciences, enriching students' understanding through interdisciplinary exploration and creative expression (Tesconi & de Aymerich, 2020). Similarly, initiatives like GetWet demonstrate STEAM's potential in addressing socio-environmental issues and fostering community engagement (Colucci-Gray et al., 2019). These experiences highlight the multifaceted nature of STEAM education, encompassing innovative pedagogical approaches, interdisciplinary collaborations, and real-world applications, all aimed at nurturing holistic learning experiences for students.

Conclusion

In conclusion, the introduction of STEAM education in secondary schools represents a pivotal step towards preparing students for the challenges and opportunities of the 21st century. The interdisciplinary nature of STEAM fosters critical thinking, problem-solving skills, creativity, and innovation, aligning with the demands of a rapidly evolving world. While the integration of STEAM into educational frameworks offers immense potential, it also presents significant challenges. Addressing these challenges requires collaborative efforts among teachers, policymakers, and stakeholders to ensure coherent integration, teacher readiness, resource availability, and appropriate assessment methods. Despite these challenges, the diverse initiatives and projects showcased in the literature underscore the transformative impact of STEAM education in enriching students' learning experiences, fostering interdisciplinary understanding, and empowering them to become active contributors to their communities and the world at large. Moving forward, continued investment in STEAM education and concerted efforts to overcome existing challenges will be essential for realizing its full potential and equipping students with the skills and competencies needed to thrive in an increasingly complex and interconnected global landscape.

STEM pedagogical approach and Augmented Reality

Inquiry-Based Learning, Project-Based Learning (PBL), Problem-Based Learning (PrBL)

In the evolving landscape of Science, Technology, Engineering, and Mathematics (STEM) education, innovative pedagogical approaches are continuously sought to foster deeper understanding, engagement, and critical thinking among students. Augmented Reality (AR) emerges as a potent tool that not only captivates students but also amplifies learning experiences.
This document is organized as follows: Section 1 is focused on STEM Education and how it could be enhanced through Augmented Reality (AR), Section 2 introduces Active Learning discussing three prominent pedagogical approaches: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), and Problem-Based Learning (PrBL); a subsection delves into the fusion of AR technology with the three pedagogical approaches. Through this integration, educators can create immersive, interactive, and dynamic learning environments that empower students to explore, create, and solve real-world challenges within STEM disciplines. Finally, Section 3 reports about the STEM pedagogical approach currently implemented in the BioS4You AR 2.0 Consortium countries (Germany, Italy, Estonia, Greece, Lithuania)

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning, Project-Based Learning (PBL), Problem-Based Learning (PrBL)

STEM EDUCATION AND AUGMENTED REALITY

Augmented reality (AR) is a 3D technology that enhances the user's sensory perception of the real world with a contextual layer of information [1]. AR has become a popular topic in educational research in last decades as a way to enrich teaching and learning processes [2]. AR's media characteristics, namely sensory immersion, navigation and manipulation, seem to work as promoters of positive emotions while learning, and create more efficient and better learning outcomes [3]. By visualizing complex concepts as three-dimensional objects, AR enables interactive and real-time reality. Existing literature has identified the multiple benefits of including AR in education. These qualitative reviews have concluded that the inclusion of AR applications in education is relevant because they improve students' learning achievements and their motivation to learn.

Table 1 presents some of the most cited qualitative reviews of AR in education (from ref.[3]).

Table 1
Qualitative reviews of AR applications in education

Study	Studied variables	Main findings
Radu (2012)	Learning effects; advantages; disadvantages	AR increases content understanding. AR favors long-term knowledge retention. AR increases learning motivation.
Wu, Lee, Chang, and Liang (2013)	Leaming effects; technological issues; pedagogical issues; learning issues. Advantages and disadvantages; field of 'education, level of education	AR enables: ubiquitous, collaborative and situated learning; visualizing the invisible; and bridging formal and informal learning.
Baca, Baldiris, Fabregat, Graf, and Kinshuk (2014)	Benefits of AR in education	The main advantages of AR in education are learning gains and motivation. 'The main difficulty is maintaining superimposed information.
Diegmann, Schmidt-Kraepelin, Eynden, and Basten (2015) *Akeayir and Akcayir (2017)*	Advantages and disadvantages; field of 'education, level of education	The main advantage of AR in education is learning gains. The most reported challenge is the difficulty for students to use it.

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning, Project-Based Learning (PBL), Problem-Based Learning (PrBL)

Some researchers have pointed out that AR has potential educational affordances which are especially useful in the science, technology, engineering, and mathematics (STEM) fields, including spatial ability, practical skills, conceptual understanding, and scientific inquiry learning [4-7]. Indeed, the integration of Augmented Reality (AR) in STEM education has opened new frontiers in teaching and learning, transforming the educational landscape for students. AR technology offers immersive experiences that enhance understanding and engagement in STEM subjects. For example, in physics, there are expensive or insufficient laboratory systems, system faults, and difficulty simulating other experimental circumstances; in technology, many schools do not have enough computers; in engineering, there are only a few instructors who are knowledgeable in computer-aided design (CAD); and in mathematics, few teachers incorporate technology into their lessons often because they believe it is still better to teach through the traditional methods. Another great application of Augmented Reality in science is an AR-based simulation scheme for a cooperative investigation-based teaching activity in a science course and which discovered that AR-based simulation could involve learners more deeply in the investigatory project activity than traditional simulations could.

From Ref. [8]

AR-Based Framework for STEM Education derived from the review as a bisis for school administration and policy makers

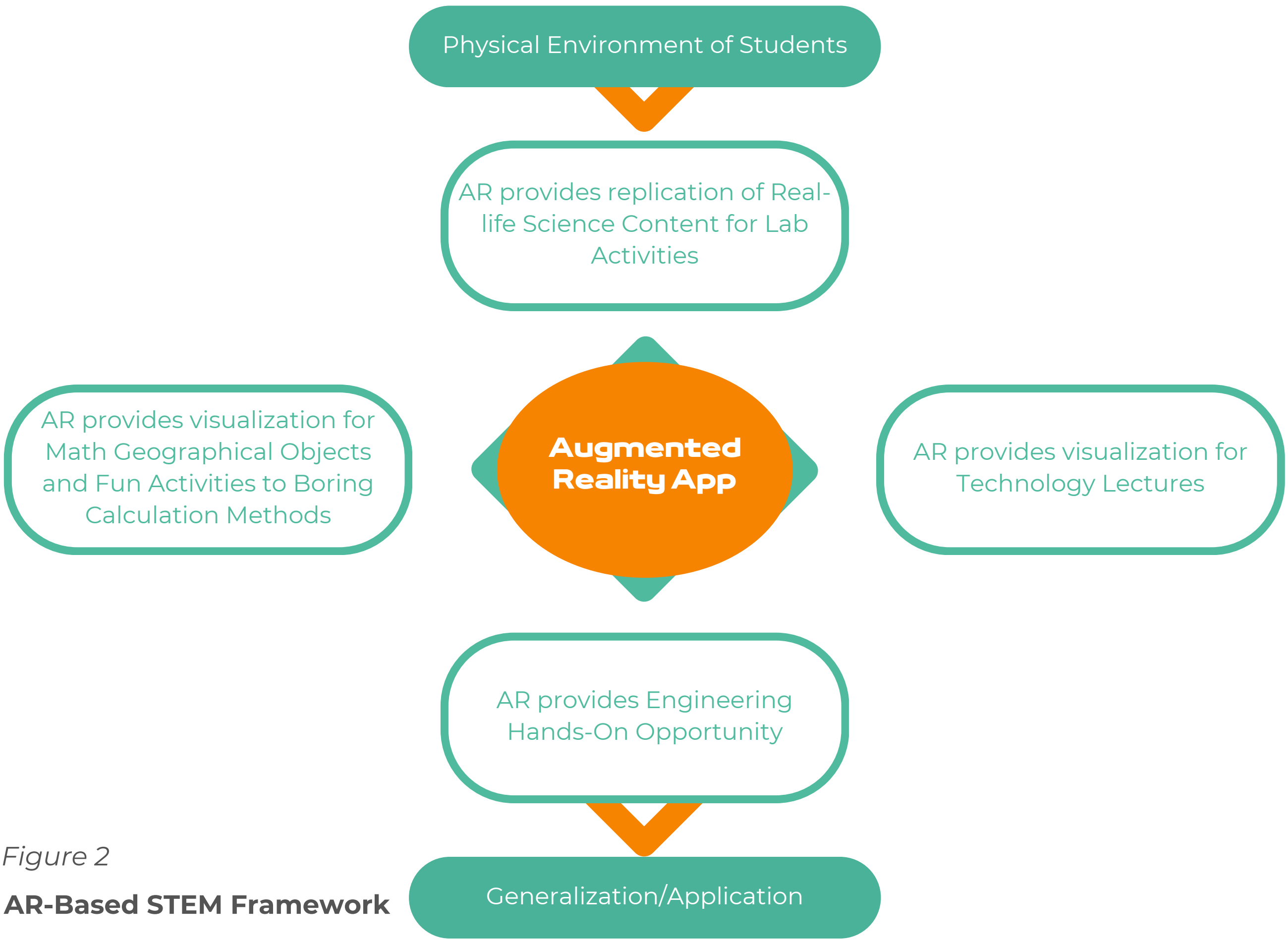


Figure 2

AR-Based STEM Framework

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

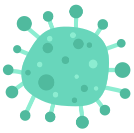
The technologies that are being gradually introduced in educational contexts enable students to diversify the ways for knowledge building. However, the exploitation of new technologies in the classroom is always a challenge for all interveners in the educational process. The arrival of a new technology, as is the case of augmented reality devices, captures the teachers' attention. It creates the expectation that its uses may provide students with new ways to interact, new possibilities of collaboration between students and between students and teachers and potentially an increase in the motivation for learning. But the referred expectations and the most suitable strategies for its use need to be validated and new ones to be explored. The prototypes range from simple technological integrations to more complex ones with the introduction of an augmented reality system [9].

Augmented Reality enriches STEM education by overlaying digital content onto the physical world, thereby bridging the gap between abstract concepts and tangible experiences. By leveraging AR, educators can transform traditional lessons into captivating adventures where students interact with virtual models, simulations, and data visualizations in real-time. This interactive engagement not only enhances comprehension but also fosters curiosity, creativity, and collaboration among learners.

Although there has been some research on the use of AR in education to inform the development of specific educational applications, there has been limited research on the development of a pedagogical framework and the provision of resources for teachers to implement it effectively [10-11]. In this context, our project aims to identify and explore the pedagogical strategies by evaluating them in real teaching and learning scenarios, particularly in terms of competences developed and student motivation levels, as well as on the ways of integrating different devices for augmented reality.

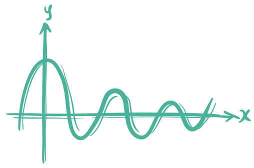
STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

Examples of AR Applications in STEM Education [12-15]



Biology

AR brings biological concepts to life by overlaying digital information onto real-world specimens. Students can examine detailed 3D models of cells, organs, or organisms, fostering a deeper understanding of biological structures and functions.



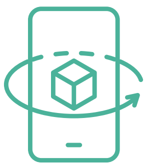
Physics

AR simulations in physics allow students to conduct experiments in virtual environments. They can visualize complex concepts like motion, forces, and electricity, making abstract theories tangible through interactive simulations.

Chemistry

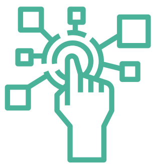
AR applications in chemistry enable students to explore molecular structures and chemical reactions. They can manipulate 3D molecular models and witness reactions in real-time, enhancing comprehension of chemical principles.

Advantages of AR in STEM Learning [12-15]



Enhanced Visualisation

AR facilitates visualisation of abstract concepts, making complex theories more accessible and comprehensible for students.



Interactive Learning

AR promotes active learning by engaging students in interactive experiences, fostering curiosity and deeper engagement with STEM subjects.

Experiential Education

AR simulations offer experiential learning opportunities, allowing students to conduct virtual experiments or explore phenomena not feasible in traditional classroom settings.

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

ACTIVE LEARNING

There is no single definition of learning that is universally accepted by theorists, researchers, and practitioners. However, a broadly accepted statement indicates that learning implies a change in human behavior, knowledge, skills, beliefs, and attitudes [16]. Theoretical traditions have set four major learning theories: Behaviorism, Cognitivism, Humanism, and Constructivism [16]. Nonetheless, Constructivism is the most popular learning theory in educational technology. Constructivism is an approach to learning that states that people actively construct knowledge and that reality is determined by the learner's experience. There are several principles related to constructivism as a theory for teaching and learning. In this sense, we highlight four principles that are key to understanding the importance of constructivism in educational technology. First, the central idea of constructivism is that knowledge is not transmitted from the teacher to the student but is an active process of construction [16]. This implies that students construct new knowledge on top of their prior knowledge and that prior knowledge influences the new knowledge that a learner will construct from new learning experiences. Second, another important notion of constructivism is that learning is an active rather than a passive process. A passive view of teaching sees the learner as an empty vessel that must be filled with knowledge, while constructivism holds that learners construct meaning through active engagement with the environment. Third, learning is a social activity. The social world of a learner includes the people that influence the learner's life, such as family, friends, teachers, policymakers, and others. This social environment plays a central role in the construction of meaning by the learner, and thus, learning can be described as a collaborative process. Fourth, although learning is described as a social activity, all knowledge is personal, that is, each individual learner has a distinctive point of view, based on existing knowledge and previous experiences [17]. This means that same activities, teaching methods, and lessons may result in different learning by each student, because their interpretations of things and ideas may differ.

There is a significant number of approaches to learning that derive from the principles of constructivism; however, the most common pedagogical approaches in AR interventions are Inquiry-based learning, Project-based learning, and Project-based learning. All these approaches implement similar strategies in educational interventions, such as considering students as the protagonists of the learning process, using scaffolding, including various learning scenarios, considering high thinking skills, and focusing on real problems. Nonetheless, each approach has unique characteristics that give it its place in the pool of learning approaches. The subsequent sub-sections present brief definitions of each of these pedagogical approaches and list their main characteristics.

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

Inquiry-based learning (IBL)

Also known as Discovery learning, this is an active pedagogical approach that requires the student to search a problem, pose questions, and then search for possible solutions to those questions. In this approach, the teacher is a facilitator of knowledge and the student is the protagonist of the learning process. Inquiry-Based Learning (IBL) stands as a beacon of innovation in modern education, championing a pedagogical approach that places curiosity, exploration, and discovery at its core. Unlike traditional didactic methods, IBL empowers learners to actively engage in the learning process, fostering critical thinking, problem-solving skills, and a lifelong thirst for knowledge. At its essence, Inquiry-Based Learning is a student-centered approach that prompts learners to pose questions, investigate phenomena, and construct their understanding of concepts through exploration and reflection. Rooted in the principles of constructivism and cognitive psychology, IBL shifts the focus from the dissemination of information by teachers to the active engagement of learners in meaningful inquiry processes. By nurturing curiosity and autonomy, IBL not only deepens conceptual understanding but also cultivates essential skills such as critical thinking, problem-solving, and communication. This approach uses different strategies such as small group discussion and guided learning. Instead of memorizing facts and material, students learn by doing, which allows them to construct knowledge by exploration, experience, and discussion. Adapted from the work by Lazonder and Harmsen [18], next we describe some of the most important advantages of IBL in educational settings.

1. **It increases learning experiences for students by allowing them to explore topics themselves.**
2. **It teaches skills needed for all learning areas because as they explore a topic, students construct critical thinking and communication skills.**
3. **It encourages curiosity in students, as it allows them to share their ideas on a topic.**
4. **It deepens students' understanding of topics because rather than simply memorizing facts, students make their connections about what they are learning.**
5. **It increases commitment with the material by allowing students to explore topics, make their own connections, and ask questions, which encourages them to fully engage in the learning process.**

Perhaps one of the most notorious advantages of IBL in educational processes, is that it increases the motivation for learning. When students engage with the material in their own way, they not only gain a deeper understanding of the topics but develop a passion for exploring and learning.

STEM Inquiry-Based Learning is a powerful method to engage students and cultivate a deeper understanding of scientific concepts. By placing inquiry at the forefront of learning, STEM IBL empowers students to ask questions, investigate phenomena, and construct knowledge collaboratively, thus preparing them for the complexities of the modern world. STEM IBL is a pedagogical approach that emphasizes exploration, experimentation, and discovery. Rather than simply delivering information to students, educators facilitate learning experiences that encourage active inquiry. Through open-ended questions, hands-on experiments, and authentic investigations, students embark on a journey of discovery, driving their own learning process. Whether exploring the principles of physics through building contraptions or conducting biological field studies, STEM IBL encourages students to think critically, solve problems creatively, and develop a deeper appreciation for the scientific method.

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

Implementing Inquiry-Based Learning requires thoughtful planning, scaffolding, and facilitation to create rich, inquiry-driven learning experiences. Successful implementation of STEM IBL relies on the following key phases:

1. **Active Engagement: Spark curiosity by presenting students with thought-provoking questions, real-world problems, or intriguing phenomena that serve as the catalyst for inquiry.**
2. **Inquiry: Empower students to take ownership of their learning by allowing them to formulate their own questions, design experiments, and drive the investigation process. Scaffold learners' inquiry processes through guided exploration, providing resources, frameworks, and support as needed.**
3. **Collaboration: Foster collaboration and communication skills by encouraging students to work together in teams, share ideas, and engage in scientific discourse.**
4. **Exploration: Incorporate hands-on experiments, simulations, and real-world experiences that allow students to interact with phenomena directly within authentic contexts that connect to students' interests, experiences, and the world around them, making the inquiry process relevant and meaningful.**
5. **Reflection: Provide opportunities for students to reflect on their learning experiences, evaluate their methods and results, and make connections between their findings and broader scientific principles.**

STEM IBL offers numerous benefits for both students and educators. IBL begins with sparking curiosity, inviting learners to question the world around them and embark on intellectual journeys driven by genuine inquiry. By placing students at the center of the learning process, STEM IBL promotes active engagement and deepens understanding of STEM concepts. Then, learners engage in authentic, real-world problems or scenarios that prompt them to apply disciplinary knowledge and skills to explore solutions collaboratively, taking on active roles as investigators, researchers, and creators, assuming ownership of their learning process and fostering a sense of agency. Educators provide scaffolding and guidance to scaffold learners' inquiry processes, facilitating deeper exploration, and metacognitive reflection. Moreover, IBL encourages creativity and innovation as students design experiments, propose solutions to real-world problems, and explore novel ideas. Through inquiry, students develop critical thinking skills as they analyze data, draw conclusions, and evaluate the validity of their findings. The benefits of Inquiry-Based Learning are manifold, transcending mere acquisition of knowledge to encompass holistic development and lifelong learning readiness. IBL cultivates critical thinking skills as students analyze evidence, evaluate arguments, and propose solutions to complex problems. The intrinsic motivation fueled by curiosity sustains learners' engagement and drives their pursuit of knowledge beyond the classroom. By nurturing curiosity and self-directed inquiry, STEM IBL instills a passion for learning that extends beyond the classroom and into students' lives. Finally, IBL fosters collaboration and communication skills as students engage in dialogue, debate ideas, and co-construct knowledge with peers. IBL promotes equity by providing all students, regardless of background or ability, with opportunities to participate actively in the learning process and contribute meaningfully to scientific inquiry.

Despite its numerous benefits, implementing STEM IBL can present challenges, including the need for adequate resources, time for exploration, and support for educators transitioning to a facilitative role. Additionally, ensuring equitable access to inquiry-based experiences for all students requires careful consideration of diverse learning needs and backgrounds. Educators must also provide scaffolding and guidance to help students navigate the inquiry process effectively, especially for those who may struggle with independent exploration.

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

Project-based learning (PBL)

This is a student-centered approach to learning, in which students gain knowledge and skills by working for an extended period to investigate and answer to a complex question, problem, or challenge. Unlike conventional instruction, where students passively absorb information, PBL empowers learners to actively explore real-world challenges through hands-on projects. This approach not only fosters deep understanding of STEM concepts but also cultivates critical thinking, collaboration, and problem-solving skills essential for success in today's rapidly evolving world. Within this approach, learners tend to have more autonomy over what they learn, maintaining interest and motivating them to assume greater responsibility for their learning. In addition, PBL poses that it is important that learners not only solve problems in real-world contexts but also to allow them to witness the practitioners solving similar problems. Adapted from the work of Vallera [19], PBL includes following key elements for educational technology:

1. **teach significant content through knowledge and skills,**
2. **require critical thinking, problem-solving, collaboration, and various forms of communication,**
3. **engage rigorous investigation,**
4. **create a need to know essential content and skills,**
5. **provide continuous feedback**
6. **have students present their final projects to a public audience.**

At its core, STEM PBL integrates science, technology, engineering, and mathematics into interdisciplinary projects that mirror authentic tasks encountered in professional settings. Whether designing sustainable energy solutions, constructing model bridges, or coding interactive applications, students tackle complex problems that require creative thinking and application of STEM principles. By immersing themselves in these projects, learners develop a deeper appreciation for the interconnectedness of STEM disciplines and gain practical skills applicable across diverse fields. Successful implementation of STEM PBL hinges on several key elements:

1. **Authentic Context: Projects should be grounded in real-world scenarios, enabling students to see the relevance of their learning and its impact on society.**
2. **Inquiry-Based Learning: Encourage curiosity and exploration by posing open-ended questions that prompt investigation and experimentation.**
3. **Collaboration: Foster teamwork and communication skills by assigning group projects that require students to brainstorm ideas, delegate tasks, and share responsibilities.**
4. **Problem-Solving: Emphasize the process of problem-solving, encouraging students to identify challenges, brainstorm solutions, and iterate on their designs through trial and error.**
5. **Reflection: Provide opportunities for students to reflect on their learning experiences, identify areas for improvement, and celebrate successes.**

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

PBL offers numerous benefits for both students and educators. Projects pique students' interest and motivation, leading to deeper engagement and retention of STEM concepts. Projects serve as authentic assessments of students' understanding and skills, providing insights into their ability to apply knowledge in real-world contexts. Beyond STEM competencies, PBL fosters the development of essential skills such as critical thinking, communication, collaboration, and perseverance. Moreover, by simulating professional challenges, PBL prepares students for future careers in STEM fields, where problem-solving and innovation are paramount. Finally, PBL promotes equity by providing all students, regardless of background or ability, with opportunities to excel and contribute meaningfully to collaborative projects.

While STEM PBL offers numerous benefits, its implementation may present challenges, including resource constraints, time limitations, and the need for professional development. Additionally, ensuring equitable access to PBL experiences for all students requires careful consideration of diverse learning needs and backgrounds. Educators must also balance the freedom of inquiry inherent in PBL with the need for scaffolded support to prevent students from feeling overwhelmed or directionless. STEM Project-Based Learning holds immense promise for transforming STEM education by engaging students in authentic, hands-on experiences that foster critical thinking, collaboration, and problem-solving skills. By embracing the principles of inquiry, authenticity, and collaboration, educators can empower learners to become lifelong problem solvers and innovators capable of addressing the complex challenges of our interconnected world.

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

Problem-Based Learning

Problem-Based Learning (PBL) shifts the traditional paradigm of instruction by placing real-world problems at the center of the learning experience. Through active exploration, collaboration, and critical thinking, students engage in solving complex problems, thereby gaining a deeper understanding of STEM concepts and honing essential skills vital for success in the modern world.

At its core, PBL challenges students to confront authentic, ill-structured problems that mirror those encountered in professional contexts. Rather than passively receiving information, learners embark on a journey of discovery, guided by their innate curiosity and fueled by the desire to find solutions. In STEM education, this approach takes on a multidisciplinary nature, integrating principles from various fields to address multifaceted challenges. Whether designing sustainable cities, investigating environmental issues, or developing innovative technologies, students immerse themselves in meaningful, hands-on experiences that bridge theory and practice.

Successful implementation of PrBL in STEM education hinges on several key elements:

1. **Authentic Problems: Present students with real-world problems that are relevant, engaging, and aligned with their interests and experiences.**
2. **Inquiry and Exploration: Encourage students to ask questions, conduct research, and explore potential solutions through experimentation and analysis.**
3. **Collaboration: Foster collaboration and teamwork skills by organizing students into groups, where they can share ideas, leverage diverse perspectives, and collaborate effectively.**
4. **Reflection and Iteration: Provide opportunities for students to reflect on their problem-solving process, evaluate their strategies and outcomes, and iterate on their solutions based on feedback and new insights.**
5. **Application and Transfer: Emphasize the application of STEM concepts and skills in practical contexts, enabling students to transfer their learning to new situations and challenges.**

Problem-Based Learning offers numerous benefits for both students and educators in STEM education:

1. **Deep Understanding: By engaging in authentic problem-solving experiences, students develop a deeper understanding of STEM concepts and principles, as they apply theoretical knowledge to real-world contexts.**
2. **Critical Thinking: PrBL cultivates critical thinking skills as students analyze problems, evaluate evidence, and develop logical arguments to support their solutions.**
3. **Collaboration and Communication: Through collaborative problem-solving, students enhance their communication skills, learn to work effectively in teams, and appreciate the value of diverse perspectives.**
4. **Innovation and Creativity: PrBL sparks creativity and innovation as students explore alternative solutions, experiment with new ideas, and develop novel approaches to solving problems.**
5. **Motivation and Engagement: By tackling meaningful problems that resonate with their interests and passions, students are motivated to invest time and effort in their learning, leading to greater engagement and persistence.**

STEM pedagogical approach and Augmented Reality: Inquiry-Based Learning (IBL), Project-Based Learning (PBL), Problem-Based Learning (PrBL)

Integration of Augmented Reality

Inquiry-Based Learning (IBL) with Augmented Reality

Inquiry-Based Learning revolves around students exploring questions, problems, or scenarios to construct their understanding of concepts. Augmented Reality amplifies IBL by providing students with immersive environments where they can pose hypotheses, conduct experiments, and analyze data in dynamic simulations. For instance, in a physics class, students can use AR to visualize gravitational forces or electromagnetic fields, allowing them to experiment and observe phenomena that would otherwise be inaccessible.

Project-Based Learning (PBL) with Augmented Reality

Project-Based Learning immerses students in real-world projects that require them to apply interdisciplinary knowledge and skills to solve authentic problems. Augmented Reality enhances PBL by enabling students to design and prototype solutions in virtual environments before implementing them in the real world. For example, students tasked with designing sustainable architecture can use AR to simulate building structures, assess environmental impacts, and iterate designs collaboratively, fostering innovation and practical problem-solving skills.

Problem-Based Learning (PrBL) with Augmented Reality

Problem-Based Learning presents students with complex, ill-structured problems that require critical thinking, analysis, and synthesis of information. Augmented Reality complements PrBL by providing students with contextualized scenarios where they can explore multifaceted problems from various perspectives. For instance, in a biology class, students can use AR to investigate ecological challenges such as habitat loss or species extinction, prompting them to propose solutions grounded in scientific principles and ethical considerations.

Incorporating Augmented Reality into STEM education unlocks a myriad of possibilities for enriching pedagogical practices and empowering students as active participants in their learning journey. By synergizing AR technology with Inquiry-Based Learning, Project-Based Learning, and Problem-Based Learning approaches, educators can cultivate a generation of STEM enthusiasts equipped with the knowledge, skills, and mindset to tackle the complexities of the future with confidence and ingenuity.

How do pedagogical approaches affect the impact of augmented reality on education?

Many studies have identified the trends, advantages, opportunities, challenges, and impact of AR technology on education. However, most of the previous studies failed to analyze the pedagogical approaches, somehow ignoring that the success of an intervention depends not only on the technical characteristics of the technology but also on the pedagogical strategies to implement them. A recent study identified, in the light of the learning theories, how pedagogical approaches affect the impact of AR on education. Analyzing the students' learning outcomes in AR interventions, the highest impact was obtained when interventions employed the collaborative pedagogical approach. Pedagogical approach refers to the method that teachers use to deliver the knowledge so that students engage in the learning process. The lack of formal pedagogical approaches when applying AR to learning activities tends to confuse and frustrate students.

The STEM pedagogical approach currently implemented in the consortium countries

The STEM pedagogical approach currently implemented in Germany

Germany has a well-developed STEM education mechanism, the most representative of which is the STEM education chain (STEM Bildungskette), the core of STEM education in Germany. It is an educational ecosystem in which students, teachers, schools and society can effectively participate and achieve a virtuous circle (Boshan, 2019). Germany has long been renowned for its well-developed professional teaching system, with the training of STEM personnel being its main objective, and it is therefore important to focus on its approach to STEM teaching. STEM teaching in Germany is referred to as MINT (Mathematics, Informatics, Natural Sciences and Technology). Germany has implemented a number of policy initiatives to ensure the success of MINT teaching. It has also made bold changes in talent development by incorporating off-campus and on-campus experimental projects into the curriculum and evaluating and assessing them in a way that is comparable (Li, 2022).
The primary STEM pedagogical approach in Germany initially focused on traditional teaching methods, emphasizing theoretical knowledge over practical application. Over time, there was a shift towards more interactive and student-centered methods, integrating real-world problems to enhance engagement and understanding. Currently, inquiry-based learning is at the forefront, promoting hands-on experiments and collaborative problem-solving. This approach aims to equip students with
critical thinking and innovative skills necessary for the future. To delve deeper into the STEM pedagogical approach in Germany, focusing on inquiry-based learning as outlined by Siemens Stiftung, it's pivotal to understand its core principles and methodologies. This approach prioritizes active student engagement through experimentation, encouraging learners to investigate real-world problems and seek solutions through a scientific lens. Emphasis is placed on integrating students' prior knowledge and experiences, making learning personally relevant and deeply impactful. Furthermore, collaboration between educators and students is crucial, promoting a co-constructive learning environment where ideas can be freely explored and evaluated. This pedagogical strategy not only enhances understanding of STEM fields but also fosters critical thinking, creativity, and the ability to apply knowledge in practical contexts, preparing students for future challenges in a rapidly evolving world. For a comprehensive understanding and examples of implementation, visiting the Siemens Stiftung website provides valuable insights (Siemens Stiftung).

The stages of learning, © Siemens Stiftung

The STEM pedagogical approach currently implemented in Germany

Italy is making significant strides in modern education, particularly in the realms of Science, Technology, Engineering, and Mathematics (STEM). Embracing innovative pedagogical approaches, Italian educators are reshaping the landscape of STEM education to equip students with the skills and knowledge necessary for success in the 21st century. We here present and discuss the current STEM pedagogical approach implemented in Italy, highlighting key initiatives, strategies, and outcomes shaping the educational landscape.
STEM education in Italy is characterized by a holistic approach that integrates scientific principles, technological advancements, engineering practices, and mathematical reasoning. While the traditional Italian education system has long emphasized theoretical knowledge, recent reforms prioritize hands-on learning experiences, problem-solving skills, and interdisciplinary collaboration. The overarching goal is to nurture a generation of critical thinkers, innovators, and problem solvers capable of addressing complex challenges in an increasingly globalized world.
The STEM pedagogical approach in Italy encompasses several key elements:
1. Interdisciplinarity: STEM subjects are interconnected, and the curriculum emphasizes the integration of disciplinary knowledge to solve real-world problems. This interdisciplinary approach fosters a holistic understanding of STEM concepts and their applications in various contexts.
2. Active Learning: Project-based learning is a cornerstone of STEM education in Italy, where students engage in hands-on projects that require critical thinking, collaboration, and creativity. By tackling authentic problems, students develop practical skills and gain a deeper understanding of STEM principles; Inquiry-based learning encourages students to ask questions, explore phenomena, and construct knowledge through investigation and experimentation. In Italy, IBL is integrated into STEM curriculum to foster curiosity, problem-solving skills, and a scientific mindset.
3. Technology Integration: Technology plays a central role in STEM education, enabling students to access vast resources, simulate experiments, and engage in virtual learning experiences. From coding and robotics to data analysis and digital modeling, technology integration enhances STEM learning opportunities in Italy.
4. Teacher Professional Development: Continuous professional development is essential for educators to effectively implement the STEM pedagogical approach. In Italy, teacher training programs focus on pedagogical strategies, curriculum design, and the use of educational technologies to support STEM instruction.

In recent years, Italy has launched several initiatives and collaborations to promote STEM education and innovation. For instance, partnerships between schools, universities, and industry stakeholders provide students with opportunities for hands-on experiences, mentorship, and internships. Additionally, STEM competitions, workshops, and extracurricular activities engage students in STEM-related fields and encourage them to pursue careers in STEM disciplines. Challenges such as resource constraints, curriculum alignment, and equitable access to STEM education persist. Addressing these challenges requires sustained efforts from policymakers, educators, and stakeholders to ensure that all students have access to high-quality STEM learning experiences.

In conclusion, Italy is at the forefront of STEM education innovation, leveraging a pedagogical approach that emphasizes interdisciplinary integration, project-based learning, inquiry-based learning, technology integration, and teacher professional development. By nurturing a generation of critical thinkers, problem solvers, and innovators, Italy's STEM education initiatives are poised to shape the future of education and empower students to thrive in an increasingly complex and interconnected world.

The STEM pedagogical approach currently implemented in the consortium countries

The STEM pedagogical approach currently implemented in Greece

Currently, there is not a specific STEM pedagogical approach implemented in Greece, however, there exists such a direction throughout the independent educational STEM programs that are being implemented in primary and secondary education. Therefore, from 2010 to 2015, the Greek Ministry of Education, Religious Affairs and Sports launched a comprehensive national initiative called "Digital School" aimed at modernizing school education in Greece. This initiative comprised various actions categorized into five key areas: Infrastructure enhancement, development of digital educational content, training programs for teachers, implementation of electronic education management systems, and additional support measures. "Digital School" constituted a significant component of the broader framework program known as "New School," which was introduced in 2010. Within the "New School" Framework Programme, STEM education was identified as a primary focus area. The "Digital School Platform, Interactive Books, and Learning Object Repository" (2010-2015) represents a central project within the Digital School initiative aimed at providing digital educational content for schools. Managed by CTI, the SCIENTIX National Contact Point (NCP) in Greece, this initiative has led to the creation of expanded materials that emphasize coding, problem-solving techniques, and logical reasoning. Additionally, thousands of digital interactive learning resources and learning scenarios have been developed for various subjects including Physics, Mathematics, Chemistry, Biology, Geography, Environmental Education, Technology, and Informatics, as part of the Digital School National initiative (dschool.edu.gr). These resources are freely accessible through the "Photodentro" National Learning Object Repository and the National Aggregator of Educational Content which has been established to facilitate cross-curricular and interdisciplinary searching of digital resources using thematic taxonomies and learning approaches. Most of these resources advocate for inquiry-based learning, problem-based learning, constructionism, and experiential learning. Moreover, an online platform named ΑΙΣΩΠΟΣ (aesop.iep.edu.gr) has been created to aid in the development and authoring of innovative scenarios utilizing digital resources and web-based materials. For science subjects, an inquiry-based model is utilized in the authoring process, which includes organizing objectives, adopting didactical approaches, and structuring scenarios into implementation phases, all based on a specific developmental approach.

In Greece, as part of the professional development program for teachers, the ongoing "B-Level ICT Teacher Training" program concentrates on instructing educators in designing educational activities utilizing digital media and resources. This training is specifically tailored for in-service teachers specializing in STEM fields and primary education. Emphasizing inquiry and problem-based teaching and learning methods, the curriculum of this program places significant importance on digital labs in STEM domains. The course receives significant support from Photodentro learning resources, including learning objects, scenarios, educational software, and open educational practices, along with interactive textbooks. Learning scenarios created by teachers and trainers during the B-Level course are accessible through the IFIGENEIA portal. Currently, approximately more than 25% of in-service teachers have participated in the course. The program consists of 96 hours of theory and practice delivered in 3-hour sessions, as well as a 3-hour exam where teachers are required to develop their own scenario on a specified topic. The management of the program falls under the responsibility of the Computer Technology Institute and Press (CTI) 'Diophantus'.

The STEM pedagogical approach currently implemented in the consortium countries

As an official proposal from the state regarding STEM education, in 2018 the Ministry of Education and Religious Affairs of Greece selected a number of schools of all levels from all over the country to be oriented towards this new education. In addition, the Institute of Educational Policy (IEP) of the Ministry of Education and Culture set up a special unit. The Institute of Science, Technology, Mathematics, Technology and the Arts (STEM/STEAM), which gives opinions on all matters relating to its fields of knowledge for primary and secondary education.

In 2020 by decision of the Minister of Education and Religious Affairs, an action entitled "Skills Workshops" got introduced on a pilot basis in Primary and Secondary Education, which consists in the trial addition of new thematic cycles in Kindergarten and in the compulsory timetable of Primary and Secondary School in order to strengthen the cultivation of soft skills, life skills and technology and science skills in students. A similar decision shall determine the duration of the pilot action, the number, duration and content of the new thematic cycles and of the individual thematic units of each of them, the number and geographical distribution of the school units in which the pilot action is introduced, the timetable of lessons to be applied in these units, the specialisations of the teachers assigned to teach the new thematic cycles and units, the way in which pupils are assessed and any other matter relating to the implementation of the pilot action shall be regulated. The “Skills Workshops” are separated into four skill cycles, with one of them called “Creating and Innovating - Creative Thinking and Initiative” including STEM/ Educational Robotics, Entrepreneurship- Career Education- Getting to know professions, hands-on workshops. The targeting of the programmes has been defined on the basis of the so-called 21st century skills: life skills, soft skills and technology and science skills. Examples of modern skills include critical thinking, creativity, cooperation, collaboration, communication, flexibility and adaptability, initiative, organisational capacity, empathy and social skills, problem-solving, digital and technological literacy. "Skills Workshops" were awarded for their contribution to global citizenship education by the Education Network, GENE: Global Education Network in Europe and received a "Certificate of National Recognition for Quality in Global Education" as an outstanding innovation.

Furthermore through the years, many different educational organisations have the approval by the Ministry of Education, Religious Affairs and Sports to implement STEM related educational programmes both in primary and secondary education. An example is the “FIRST® LEGO® League”, a program that is being approved by the Ministry of Education, Religious Affairs and Sports (F15/133790/D2) since 2014, which introduces STEM to children aged 4-16 through fun, exciting, hands-on learning. Participants gain real-world problem-solving experience through a guided, global robotics project based learning program, helping today's students and educators build a better future together. This educational program inspires young people to experiment and develop their critical thinking, coding, and design skills through hands-on STEM and robotics learning. It is a partnership between the non-profit organization FIRST® (For Inspiration and Recognition of Science and Technology) and the LEGO® education division and has been held annually since 1998 in more than 110 countries worldwide. In Greece it is being implemented by the educational organisation Eduact. After its successful pilot implementation in the skills labs in 2020 - 2021, the generalization of the Robotics & STEAM FLL Program to the schools of the territory from the school year 2021-2022 onwards was approved. Another example is “F1 in Schools” competition that is supported by large scale European Initiatives like the INSPIRING SCIENCE EDUCATION policy support action (www.inspiringscience.eu).

This initiative (http://www.f1inschools.gr/) is offering a way to learn
STEM related subjects in such an exciting way, achieving great results and increasing the intake of students into Engineering careers. The contest has been organised since 2011.
A more recently approved program was "VR educational workshop" which is addressed to students of Primary and Secondary Education, for all school units of the country was approved for the first time for the school year 2022-2023 and got extended for the school year 2023-2024 as well.

The STEM pedagogical approach currently implemented in Lithuania

In Lithuania, the STEM approach being implemented is primarily project-based learning (PBL). Project-based learning (PBL) is a student-centered approach to education that emphasizes the development of critical thinking, problem-solving, and collaboration skills through the completion of complex, real-world projects. In this analysis, we will explore the implementation of PBL in Lithuania's educational system, focusing on its unique aspects and benefits.

PBL is a teaching method that involves students in the process of gaining knowledge and skills by working on projects that are designed to simulate real-world scenarios. These projects are typically complex, challenging, and require students to work collaboratively to find solutions to problems. PBL is not just about completing a project; it is a process that fosters critical thinking, problem-solving, and collaboration skills.

Project-based learning (PBL) is implemented in Lithuania through a combination of traditional project activities and continuous projects. In traditional project activities, students choose a topic, formulate the idea, and work in a team to develop a project that is supervised by lecturers. The project is marked by teachers from different disciplines, and students are assessed by their peers. The project is designed to last for three months, with students integrating knowledge and skills from different subjects, working in a team, and gaining practice.

In continuous projects, students carry out the same project in different phases throughout the academic year. Each phase is related to the learning subjects that the project complements. For example, in the e-Business study program, students have the opportunity to develop a project that becomes a functioning business after they graduate.

The implementation of PBL in Lithuania is supported by the European Commission, which aims to combine digital teaching-learning with project-based learning, applied in an international context. This initiative focuses on problem-solving and solution seeking, providing students with a rich learning path that integrates transdisciplinary approaches and innovative active pedagogies.

The STEM pedagogical approach currently implemented in Estonia

In Tallinna Kesklinna Vene Gümnaasium (TKVG), there is a burgeoning emphasis on integrating STEAM pedagogy into the educational framework, although Estonia lacks a specific STEAM pedagogical approach at the national level. Instead, there is a notable trend towards implementing independent educational STEAM programs in both primary and secondary education institutions across the country. Tallinn Technical University (TTÜ) and Tallinn University (TLU) stands out as the primary provider of courses tailored specifically for teachers seeking to integrate the STEAM approach into their pedagogy. Through these courses, educators gain valuable insights into designing interdisciplinary curriculum, fostering hands-on learning experiences, and leveraging technology to enhance teaching across STEM and arts disciplines. TTÜ's and TLU’s commitment to equipping teachers with the necessary tools and strategies underscores the importance of STEAM education in preparing students for future success in diverse fields. As such, TTÜ plays a pivotal role in shaping the educational landscape and advancing STEAM pedagogy in Estonia.

In TKVG, project-based learning (PBL) holds a central position in primary and secondary school (1-4 Grade), fostering a dynamic and engaging learning environment for students. PBL is characterized by its emphasis on hands-on, inquiry-driven projects that enable students to explore real-world problems and develop critical thinking, collaboration, and problem-solving skills. At TKVG, PBL is integrated into the curriculum across various subjects, allowing students to delve deeply into topics of interest while addressing curriculum standards. In TKVG primary and secondary school, PBL initiatives are carefully designed to align with the school's educational objectives and the interests of the students. Teachers play a crucial role in guiding and facilitating the PBL process, providing support and scaffolding as students work through the project stages. PBL projects often begin with an open-ended question or problem statement, sparking students' curiosity and inquiry. Throughout the project, students engage in research, experimentation, and collaboration, applying knowledge and skills from different subject areas to solve authentic problems. For example, a PBL project on environmental sustainability might involve researching local ecosystems, conducting experiments to measure pollution levels, and designing solutions to reduce waste.

One of the key strengths of PBL at TKVG is its ability to promote interdisciplinary learning. By integrating multiple subject areas into a single project, students gain a holistic understanding of complex topics and develop connections between different areas of knowledge. For instance, a PBL project on ancient civilizations might incorporate elements of history, geography, art, and literature, allowing students to explore the cultural and historical context of ancient societies.

At TKVG, PBL also emphasizes the development of essential skills such as communication, collaboration, and problem-solving. Students work in teams to plan and execute their projects, learning to communicate effectively, delegate tasks, and resolve conflicts. Through hands-on exploration and experimentation, students develop confidence in their abilities and a deeper understanding of the subject matter.

In TKVG we are dedicated to innovative approaches to education, including the integration of robotics and mathematics, which we refer to as "robomathematics." Robomathematics is a dynamic educational framework that combines the principles of robotics with mathematical concepts, providing students with a unique and hands-on learning experience. Through robomathematics, students engage in interactive activities that blend theoretical mathematical concepts with practical applications in robotics. This integration allows students to deepen their understanding of mathematical principles while simultaneously developing their problem-solving, critical thinking, and technical skills.

The STEM pedagogical approach currently implemented in the consortium countries

At TKVG, we believe that robomathematics not only enhances students' mathematical proficiency but also fosters creativity, collaboration, and innovation. By exploring the intersection of robotics and mathematics, students are equipped with the skills and knowledge necessary to succeed in an increasingly technology-driven world. Through our robomathematics program, we aim to inspire curiosity, cultivate a passion for learning, and empower students to become confident and proficient in both mathematics and robotics.
Desmos and GeoGebra are widely used as digital tools that significantly enrich the STEAM education experience in secondary school in Estonia. Both platforms offer interactive opportunities to explore mathematical concepts, and their utility extends beyond mathematics to incorporate elements of technology, engineering, and art.

Lithuania is implementing a project to establish 10 STEAM centers, which aims to gain students' interest with their developed sciences, improve their practical skills, creativity, initiative, raise entrepreneurship and leadership competencies required for their successful professional careers. STEAM centers will encourage students to take a more specific interest in nature and exact sciences and to choose to study in these fields. STEAM centers will invite teachers to become actively involved as well, where they will be able to improve their qualifications. According to the principle of open access, in cooperation with researchers, teachers will be able to design the adaptation of science infrastructure to the educational process. The first 7 regional centers are already open, and three methodological ones will open in near future.

In Lithuania, PBL is primarily implemented in higher education institutions, such as Vilnius Business College. Here, PBL is used to teach business management and marketing, among other subjects. The projects are designed to be long-term, with students working in teams to develop business ideas, attracting real-world businesses as clients, and learning how to work in a team and experience change management in business. The projects are supervised by lecturers, who provide guidance and support throughout the process. Furthermore, Kaunas University of Technology also implements PBL in a number of modules. For instance, in the Physics module, students do 4 projects in a semester, each taking 1 month to complete. Each week of the month is dedicated to a specific project task, such as: analyzing the task, clarifying the idea and distributing the work, conducting the experiment, developing the calculations, preparing the report and presentation. The projects are overseen by lecturers and professors as well, who offer guidance and assistance throughout the entire process.

PBL offers several benefits, including the development of critical thinking, problem-solving, and collaboration skills, as well as the opportunity for students to experience real-world business scenarios. However, it also presents challenges, such as managing the uncertainty and complexity of projects, as well as the need for teachers to adapt to a more facilitative role.

In conclusion, PBL is a valuable approach to education that is being effectively implemented in Lithuania's educational system, particularly in higher education institutions. It offers students the opportunity to develop critical thinking, problem-solving, and collaboration skills while experiencing real-world business scenarios. Despite the challenges, PBL is a rewarding experience for students, as it prepares them for the world beyond the classroom.

The STEM pedagogical approach currently implemented in the consortium countries

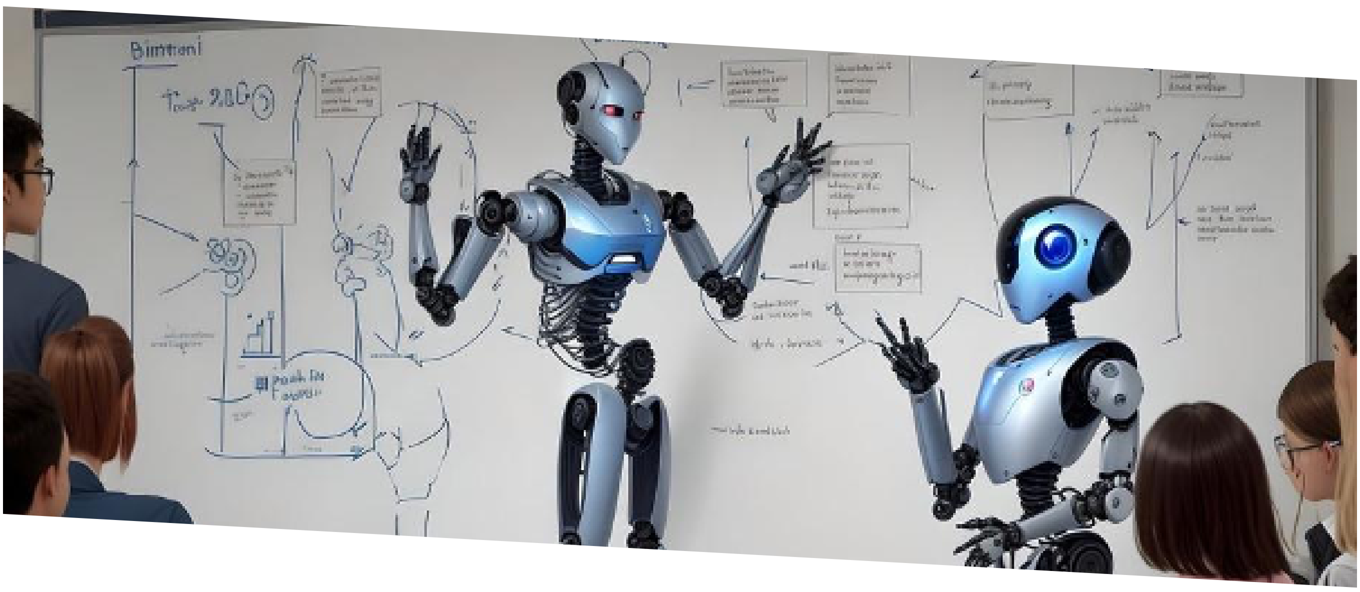
In TKVG, Desmos is used as mathematics visualization that allows students to visualize and interact with mathematical concepts, from basic algebra to complex calculus. This interactive approach helps demystify abstract concepts and makes math more accessible and engaging. In science classes, Desmos is used to plot data from experiments, model scientific phenomena, or simulate equations related to physics or chemistry, making the mathematical aspects of science tangible. In technology classesDesmos requires students to think algorithmically as they create graphs and animations, laying foundational skills for future programming learning.

GeoGebra is also important to education and is used for educational purposes in TKVG. GeoGebra excels in offering dynamic geometry tools, allowing students to construct and manipulate geometric figures. This hands-on approach is invaluable for understanding geometric principles and theorems in a more intuitive and engaging way. GeoGebra is used for a wide range of STEM applications, from exploring calculus and algebra to physics simulations. Its versatility makes it an excellent tool for integrating different STEM fields. GeoGebra is a useful tool for collaborative projects that foster teamwork and communication skills among students as they work on joint projects.

Introduction

The focus on student learning during the 21st century education needs to be capable of producing future citizens with skills in Science, Technology, Engineering, and Mathematics (STEM) and who can deal with challenging complex life practices, which is best to be developed throughout the education, starting from primary schools (Prinsley & Johnston, 2015). The concept of an ecosystem of social networks of peers, educators, friends, and families to support in school and out of school contexts of learning offers promise in developing this for schoolteachers and students and finding appropriate societal contexts for connecting to educational practices (NRC, 2015). An early focus with appropriate experiences connecting to real- world settings and the concept of ecosystem can influence and foster innovation in STEM. Interdisciplinary, integrated, and connected to the real-world approaches of the school experience are a way to focus on STEM education and provide insight into innovation for new life practices for everyone. Schools and future teachers need to prepare young people for contemporary life practices and future workplaces with a new vision of this planet. A thorough overhaul of STEM education and teacher preparation is necessary in primary, secondary, and post-compulsory education. STEM education and research is not only the slogan, but it should also have a clear purpose to connect curricula, capable of generations in workplaces producing innovations that could develop new paths for the world (NGSS, 2013). Future STEM education programmes and research need this focus to be able to have the capacity to develop innovative new pathways towards lifestyle changes that lead to sustainability.

In a world with greater population, global interconnection, technological advancement, and large-scale problems than ever before in human history, complex problems require sophisticated problem-solving skills and innovative, complicated solutions. In the United States, colleges train scientists in a manner similar to the way they were trained decades ago, while these new challenges place different demands on science. Traditional science training provides a solid foundation of facts and basic science technique, but rarely examines how to foster scient creative, cross-disciplinary problem identification and solving skills.



What is interdisciplinary learning?

In the 1960s, interdisciplinary teaming was an instructional innovation for school improvement aimed to reduce teacher isolation, foster interdependence, and promote collegiality and collaboration. Since then, team teaching has been a strategy used across the USA for various purposes, including to gain control of large groups of students and to interject variety into the single-subject, single-teacher classrooms (Murata, 2002).

Definitions of interdisciplinarity generally contain the feature of integrating two or more academic disciplines together. In interdisciplinary teaching, it commonly involves teachers focusing on making connections between subject areas obvious for students to see (Sdunekv & Waitz, 2017). Instead of curricula being fragmented, these connections make learning more natural and foster deep conceptual understanding (Capraro & Jones, 2013). Interdisciplinary teaching emphasizes application and synthesis of content and skills, and the interdisciplinary content promotes meaningful inquiry by demonstrating logical connections and using problem-based learning (Sdunekv & Waitz, 2017).

There are two broad types of interdisciplinary learning which, in practice, often overlap.

- Learning planned to develop awareness and understanding of the connections and differences across subject areas and disciplines. This can be through the knowledge and skill content, the ways of working, thinking and arguing or the particular perspective of a subject or discipline.
- Using learning from different subjects and disciplines to explore a theme or an issue, meet a challenge, solve a problem or complete a final project. This can be achieved by providing a context that is real and relevant, to the learners, the school and its community.

In an interdisciplinary team, teachers need to develop teamwork, communication skills, and positive attitudes toward interdisciplinary teaching (Al Salami et al., 2015), because most teachers feel they lose autonomy while investing time in decision- making and potentially have conflicts among each other on the team (Shapiro & Dempsey, 2008). Teacher choice, curriculum-driven design, and administrative support are necessary for interdisciplinary teams to be effective (Margot & Kettler, 2019).

Several challenges hinder STEM interdisciplinary instruction. First, secondary teachers rarely had experiences in using interdisciplinary STEM instruction in their preservice teaching experiences. The isolating teaching experience of preservice teachers sets up barriers to forming interdisciplinary collaboration when they become in-service teachers (Asghar et al., 2012). Second, teachers feel their content knowledge outside of their disciplinary expertise is insufficient for them to implement interdisciplinary STEM instruction (Graves et al., 2016). Third, teachers are challenged when aligning what they need to teach with other subjects through the lens of interdisciplinary collaboration (Frykholm & Glasson, 2005). Fourth, practicing teachers often experience “siloing” of the different disciplines, in- flexible class schedules, and stringent timelines for implementing curricula, which can discourage the interdisciplinary nature of integrated STEM lessons (Lesseig et al., 2017). Finally, the lack of a common planning time, such as a professional learning community (PLC), hinders collaborative planning. It is highly recommended that teachers collaboratively discuss interdisciplinary lessons and instruction to make interdisciplinary team-teaching work (Capraro & Jones, 2013).

In fact, interdisciplinary science is the collaborative process of integrating knowledge/expertise from trained individuals of two or more disciplines leveraging various perspectives, approaches, and research methods/methodologies to provide advancement beyond the scope of one discipline’s ability.

Why is interdisciplinary learning important and what are the benefits it brings to students?

When students graduate, they should be able to evaluate complex information to come up with their own ideas and perspectives, and critical thinking. Interdisciplinary learning supports critical thinking by helping students:

- Understand multiple viewpoints
- Evaluate conflicting perspectives
- Build structural knowledge

Interdisciplinary study helps students learn by connecting ideas and concepts across different disciplines. Students can apply the knowledge gained in one domain to a different one as a way to deepen their learning experience.

The most effective approach to interdisciplinary study enables students to build their pathway by choosing courses that make sense to them. For example, finding a theme that crosses disciplinary boundaries in literature, art and history, or science and mathematics is not difficult. Studying topics thematically is one way to bring ideas together, resulting in more meaningful learning. By allowing students to choose their preferred subjects, their understanding is deepened when they reflect on the connections between what they are learning in different disciplines.

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Interdisciplinary study allows for the synthesis of ideas from many disciplines

Interdisciplinary study addresses students' differences and helps develop important, transferable skills. These skills, such as critical thinking, communication and analysis are essential and develop continually at all stages of life. Educational systems serve students best if they enable and encourage students to build their interdisciplinary pathways. This approach can foster a love of learning, ignite a spark of enthusiasm and address learning differences for students.

The idea of interdisciplinary studies reflects a growing belief that standard curricula have become too siloed along disciplinary lines and that in an increasingly complex world, students need help understanding the connections between diverse forms of knowledge and inquiry

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Why is interdisciplinary learning important and what are the benefits it brings to students?

In general, the importance and benefits of interdisciplinary learning in today's education system are as follows:

Embracing real-world complexity: The world outside the classroom is built with distinctive layers of interconnected ideas, systems, and challenges. Interdisciplinary learning acknowledges this complexity and provides students with the tools to navigate it. Students gain a broader perspective and better understand real-world issues by integrating knowledge from various fields. They learn to analyze problems from multiple angles and develop innovative solutions.

Fostering critical thinking: Interdisciplinary learning fosters critical thinking skills by encouraging students to analyze, synthesize, and evaluate information from various disciplines. It challenges them to ask unconventional questions, consider different perspectives, and make connections between diverse concepts. This process develops their ability to think critically, make informed decisions, and solve complex problems—a vital skill set for the challenges they will face in their future careers.

Encouraging collaboration: In the professional world, collaboration is key. Interdisciplinary learning promotes collaboration among students, fostering teamwork and communication skills. As they work together to solve multidisciplinary problems, students learn to appreciate different viewpoints, respect diverse opinions, and collaborate effectively to achieve shared goals. These skills are essential for success in an increasingly interconnected and globalized society.

Enhancing creativity and innovation: Interdisciplinary learning encourages students to think outside the box and explore unconventional approaches. Combining knowledge and techniques from different disciplines can create innovative solutions to complex problems. The blending of ideas from diverse fields often leads to breakthrough innovations. By embracing interdisciplinary learning, students develop their creative thinking abilities, becoming more adaptable and prepared to tackle future challenges.

Addressing complex global issues: Many of the pressing challenges we face today, require multidimensional solutions. Interdisciplinary learning equips students with the skills and mindset necessary to address these complex issues. By understanding the affiliation of various factors, students can develop comprehensive strategies that encompass social, economic, and environmental perspectives. This prepares them to become active global citizens who can contribute to positive change **(click here).**

Interdisciplinary and integration STEM

Due to the possibility of seamless integration of materials from different domains, interdisciplinary and integrated STEM (I-STEM) could strongly link to real-world experience in STEM fields. This integration has the potential to promote and improve the learning of each discipline involved (Toma & Greca, 2018). In order to effectively integrate different STEM disciplines, it is necessary to bring together ideas and principles from disparate disciplines (Blustein et al., 2013) PBL (problem-based and/or project-based learning) (Krauss & Boss, 2013), and interdisciplinary scientific inquiry (Moore, 2014) are some of the pedagogical approaches that have been used to support I-STEM education. I-STEM success relies heavily on the PBL process, which is generally recognized as a key component of I-STEM (Stohlmann et al., 2012). The real process of scientific inquiry cannot always be compartmentalized in such a tidy manner, and for achieving a solution, several disciplines necessarily need to link together. The goals of I-STEM include, but are not limited to, improving the students' STEM literacy, 21st century skills, STEM job preparation, STEM interest and engagement, and the capacity to draw connections across STEM disciplines (Ayres, 2016) Interdisciplinary and integrated approaches to teaching and learning, and teacher preparation that translates to classroom practices are key aspects to be focused on to produce a responsible generation that is capable of using the STEM knowledgebase for changes in practices (Kurup et al, 2019). The interdisciplinary integrated ap- proach of STEM education needs to ensure that democratic civic-informed decision making aligns with the Next Generation Science Standards (NGSS, 2013) and National Research Council (NRC, 2015). This approach could generate a knowledgebase for problem solving and could lead to democratic civic practices for attaining capacity for informed decisions.

Effective use of interdisciplinary and integrated STEM involves different ways of thinking, solving problems, and communicating, and these approaches need consideration in building teachers' capacity for innovation in classroom practices. Students not only used these approaches to learn a range of technological activities to plan, analyze, evaluate, and present their work, but also learn the valuable reasoning and thinking skills to find alternatives in socio- scientific issues and problems when they are used in classroom projects. These aspects are essential for functioning both within and outside the school environment and are about creativity, design principles, and processes involved. These are essentially required in interdisciplinary and integrated STEM knowledgebases.
Teachers are expected to teach students how to solve problems that they will face in their careers as scientists and engineers. However, real-world problems in a human- built world are often interdisciplinary in nature and occur in complex systems (Dym et al., 2005). These problems, usually interdependent of the system, require sophisticated problem-solving skills, innovative and complicated solutions, and involvement of multiple components (Levy, 1992; Richardson & all, 2001). For example, when solving a real-world food deficit problem using hydroponics to increase vegetable production and overcome technical difficulties (e.g., lighting, and water and nutrition supply), environmental and social impacts should also be taken into consideration when designing the system.

Interdisciplinary and integration STEM

Teaching systems thinking when solving problems aligns with developing twenty-first century career skills, and helps students learn how to cope with complexity, and make scientifically and mathematically sound decisions to solve a real-world problem in a complex designed system (Dym et al., 2005). Yet, teachers are typically not prepared to teach students how to solve problems using systems and interdisciplinary thinking.

Professional societies, such as the American Society for Engineering Education (ASEE), National Academy of Engineering (NAE), and the National Research Council (NRC), call for new educational approaches that focus on hands-on, interdisciplinary, and socially relevant aspects of science, technology, engineering, and mathematics (STEM) to improve K-12 STEM education. In addition, the Next Generation Science Standards (NRC, 2013) and the Framework for K-12 Science Education (NRC, 2012) enumerated core disciplinary ideas, crosscutting concepts, and science and engineering practices for grades K-12. This current educational reform movement provides a new vision of STEM education to help students make sense of the fragmented and departmentalized knowledge that is typically taught in disciplinary silos. As defined by the National Research Council, STEM integration is “working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines” (NAE, 2014). Consequently, integrated STEM teaching approaches should attempt to mirror solving a real-world problem in a complex designed system, where students use knowledge and skills from multiple disciplines that relate to their everyday lives (Wang & Knobloch, 2018).
Although STEM integration encourages interdisciplinary collaboration, teachers are traditionally trained to teach domain-specific knowledge. There is a growing concern regarding how teachers trained in one of the STEM domains are not equipped to incorporate less familiar practices into their teaching. In addition, high schools are structured in ways that continue to encourage teachers to stay in their teaching disciplinary silos (Boyd, 2017). Regardless of the core discipline(s), most scholarship in interdisciplinary integrated STEM is focused on elementary and middle school level instruction. Various challenges have been reported to hinder STEM interdisciplinary instruction in previous research studies (Lesseig et al., 2017). As a result, more research studies are needed to investigate the importance of using interdisciplinary STEM as teaching approaches in high school settings.
Teacher’s beliefs refer to beliefs related to teaching including knowledge, students, and instruction (Buehl & Beck, 2014). Beliefs shape who teachers are as individuals and are influential in teachers’ decision-making, thinking, and practice in classrooms practices (Caudle & Moran, 2012). One of the underlying assumptions to understand teachers’ thought processes, especially beliefs, is that it would lead to understanding what guides their classroom behaviors. Although beliefs are a difficult construct for empirical investigation because they tend to be philosophical or spiritual, beliefs are stronger predictors of behaviors than knowledge because they are centric to one’s identity and more difficult to change. However, the relationships between teachers’ actions and their effects are not always considered as linear. For example, teachers teach topics that they believe are interesting, but their students may find the topics dreary (Farrell & Ives, 2015). Teachers may believe in learner-centered teaching, but their practices may be didactic in nature. Many factors, internal and external shape teachers’ beliefs and influence their practices. These factors include disciplinary subculture (Fang, 1996), knowledge, skills, and abilities (Buehl & Beck, 2014); teacher preparation programs (Rice & Kitchel, 2017); time and resources, curriculum and standards (Buehl & Beck, 2014); years of teaching experiences (Lumpe et al., 2000); school and classroom environments; and education-related policies (Buehl & Beck, 2014). In short, teachers’ beliefs and practices are not context-free, but situational.

Interdisciplinary and integration STEM

As for teachers' beliefs and practices of STEM integration, many teachers consider STEM integration as the use of all four disciplines, but they have no clear understanding of the enactment of integration (Breiner et al., 2012). Research has shown that teachers see connections between STEM disciplines (Wang & Knobloch, 2018) and believe that integration helps students connect school learning with real-world problems. Furthermore, integrated STEM instruction can increase student engagement and problem-solving abilities. However, teachers also report challenges in integrating other STEM subjects, because they lack the content and pedagogical knowledge for effective integration (Kurup et al., 2019).

Teachers also tend to focus on disciplinary content rather than cross-disciplinary ideas, perhaps because they have difficulty facilitating discipline- based learning while also giving a central role to real-life problems and global issues. Teachers face barriers to integrating technology and engineering due to their students and their lack of knowledge and skills in these areas (Bybee, 2013). Therefore, teachers often focus on science and math with little integration of technology or engineering. In regard to interdisciplinary STEM education, Weinberg and McMeeking (2017) studied science and mathematics, and identified barriers that hindered interdisciplinary collaboration. These barriers included standards, level of control, assessment fit, teacher knowledge, skills and abilities, and collaboration. Their results echoed Buehl and Beck's (2014) findings that teachers' experience and knowledge, as well as classroom, school, and district factors all have influence on their beliefs and practices.

Augmented reality in classrooms: requirements and strategies

Essential Guidelines for Managing and Utilizing AR to Foster Active Learning and Collaboration in Education

In education, the philosophy guiding the incorporation of augmented reality (AR) technology is deeply rooted in the belief that technology, when used purposefully, has the potential to enrich the learning experience by providing engaging and engaging opportunities. This philosophy is driven by several fundamental requirements:

Certainly, active engagement is one of the fundamental requirements for recreating a classroom in which students are not passive recipients of information, but active participants in their learning journey. AR technology encourages and helps this active engagement, pushing students to explore their studies with curiosity and enthusiasm.

AR technology has the unique ability to bring learning to life by placing it in authentic contexts so that theoretical knowledge is learnt in practical applications. For this reason, it is important to prepare with a practical project and present it together with the theoretical explanation. This ensures that the gap between theoretical knowledge and real-world applications is bridged, allowing students to see the practical relevance of what they are learning. For example, students could use AR overlays to visualise molecular structures in chemistry, gaining a clearer understanding of molecular interactions.

Furthermore, being able to use all the channels that technology offers allows for different styles and manners of representation, especially for visual, auditory and kinesthetic learners. By offering multi-sensory experiences, AR ensures that each learner can engage with the material in a way that resonates with them personally.

An additional requirement for the teacher is knowing how to use platforms that allow their students to work in pairs or groups. Indeed, AR fosters collaboration and creativity among students, who work together on AR projects, design interactive experiences and reimagine learning materials in innovative ways. This collaborative approach encourages students to think creatively and solve problems collectively.

Finally, the integration of AR technology aims to improve the digital literacy not only of students but especially of teachers. Having knowledge and mastery of a technology allows a teacher to guide students in navigating AR applications and using the technology effectively. For instance, students could acquire skills in using AR authoring tools to create their own interactive AR projects, thus developing digital skills essential for the world of work.

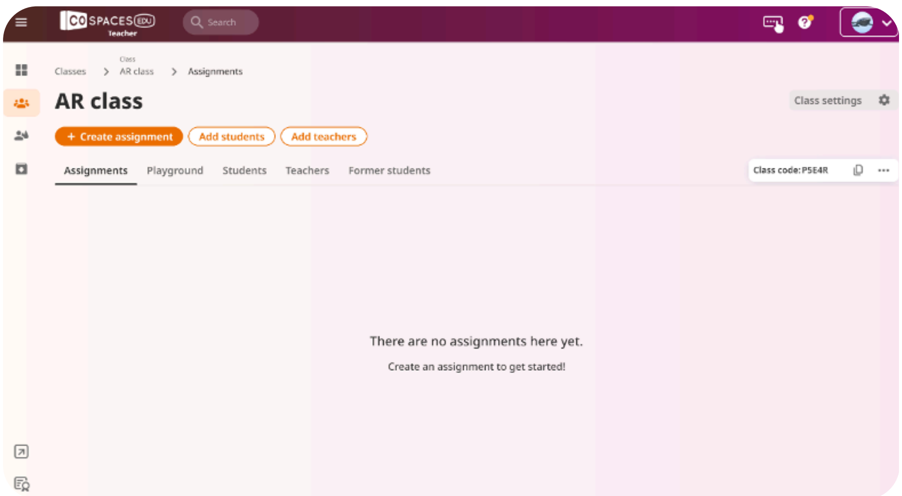
“In augmented reality educational activities, the teacher must take on the role of a facilitator”

Instructional Strategies

The integration of augmented reality (AR) in education presents a unique opportunity to enhance student engagement and foster collaboration. To maximize the potential of AR in the classroom, teachers must implement thoughtful strategies that promote active learning and teamwork. By incorporating interactive lessons, encouraging experiential learning, and leveraging AR for both individual and group activities, educators can create dynamic and immersive learning environments.
But teachers do not need expensive or hard-to-find tools and technologies to use virtual and augmented reality. In fact, anyone can start with simple methods and techniques, using creative approaches with existing technologies like interactive whiteboards, PCs, tablets, and smartphones.
In augmented reality activities, the teacher acts as a facilitator, so it is important to have a detailed understanding of the experiences they will present to the class.
For this reason, we recommend taking a gradual approach, allowing both teachers and students time to learn and adapt to new practices and behaviours.

To effectively use augmented reality (AR) in the classroom, teachers should adopt a variety of strategies aimed at promoting active learning and collaboration. Here are some key approaches:

Designing interactive lessons:

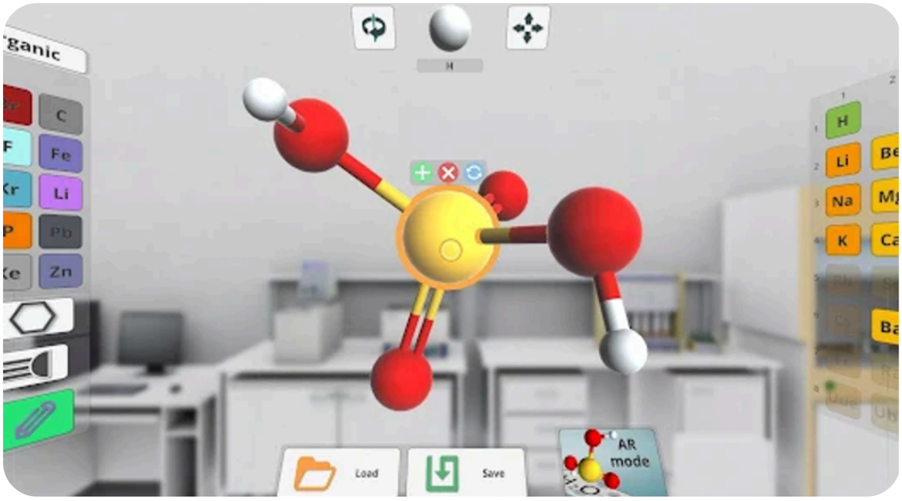


Teachers should integrate AR into lessons to engage students in practical and immersive activities. This can include using AR apps or platforms that allow students to explore visual and interactive content, such as 3D models or simulations.

Figure 1 - CoSPACE platform

Augmented reality in classrooms: requirements and strategies

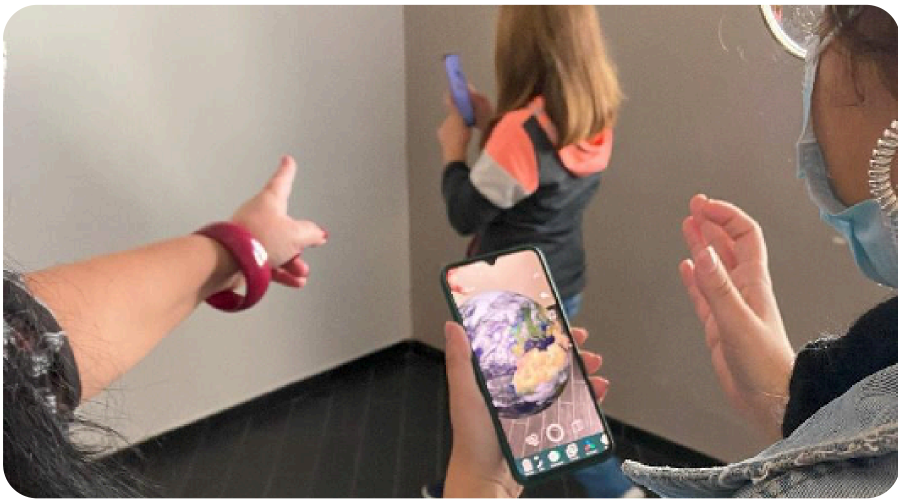
Encouraging experiential learning:



AR offers the opportunity to connect theory with practice. Teachers can design activities that allow students to apply abstract concepts to real-world situations, such as using AR to explore molecular structures in chemistry or visualize physical phenomena.

Figure 2 – (Molecules AR) AR App for creating molecules

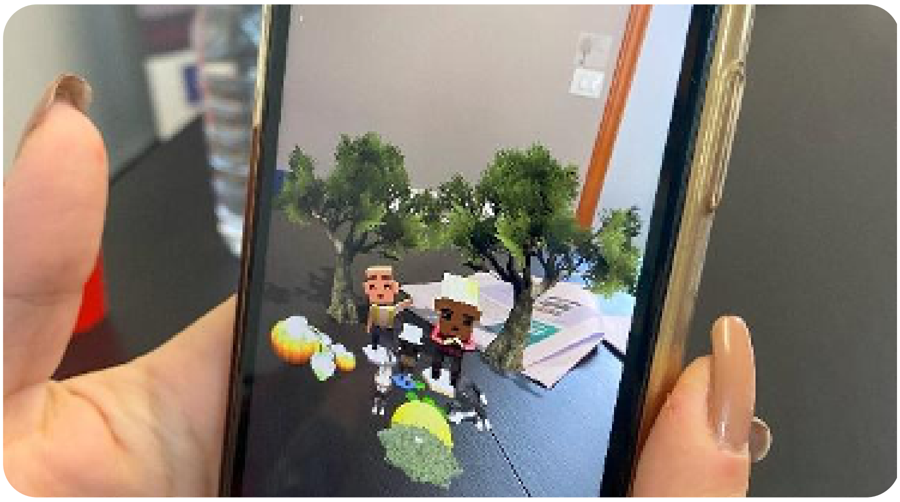
Promoting collaboration:



Teachers should encourage group work where students collaborate on AR projects. These activities help develop key skills such as communication, problem-solving, and critical thinking, while students explore new digital content.

Figure 3 - (Brave New Words project) AR activity

Personalizing learning

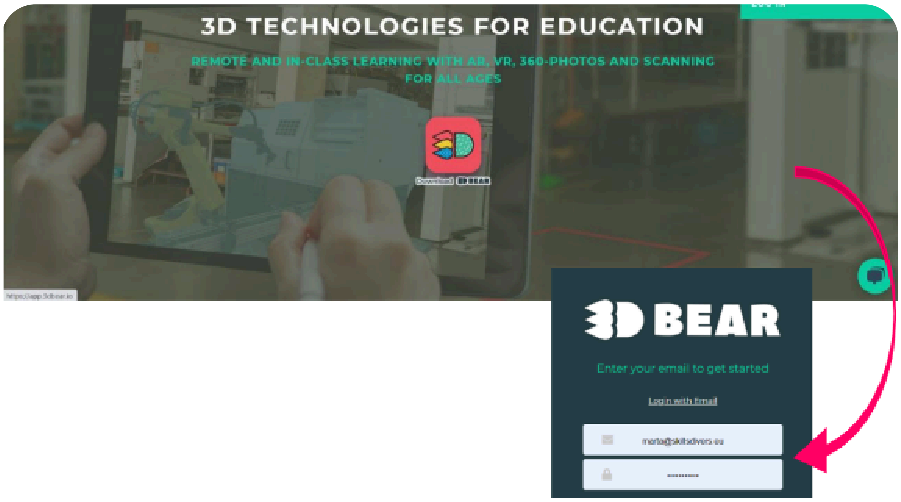


AR can be used to create differentiated learning experiences that cater to various learning styles. Teachers can use AR to provide visual, auditory, and kinesthetic resources that meet the individual needs of each student.

Figure 4- (Brave New Words project) AR activity

Augmented reality in classrooms: requirements and strategies

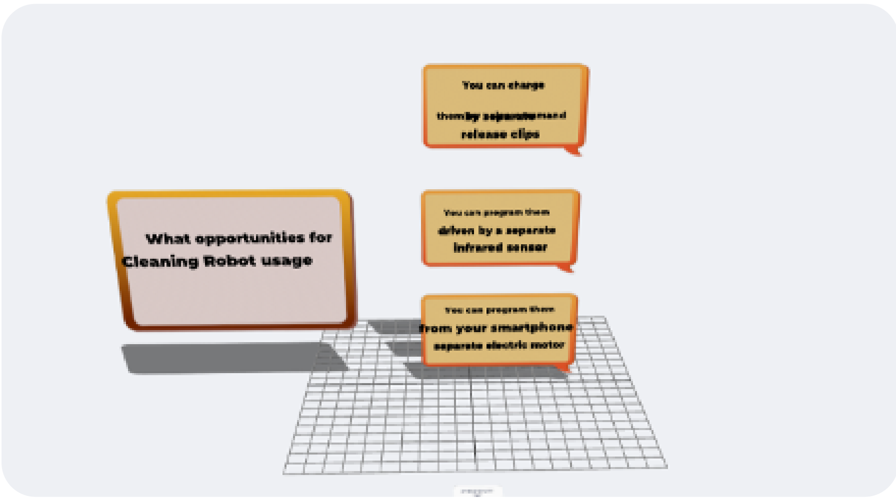
Building digital skills:



As AR is a digital technology, it is essential that teachers also train students on the skills needed to use these tools effectively. This includes teaching the use of AR platforms and encouraging creativity through the design of personalized AR content.

Figure 5 - 3D Bear Homepage

Interactive assessment:



Teachers can adopt AR tools to conduct more engaging formative assessments, such as interactive quizzes or activities where students solve problems within an AR environment. This makes assessment an active part of the learning process.

Figure 6 - Assembler World Studio App

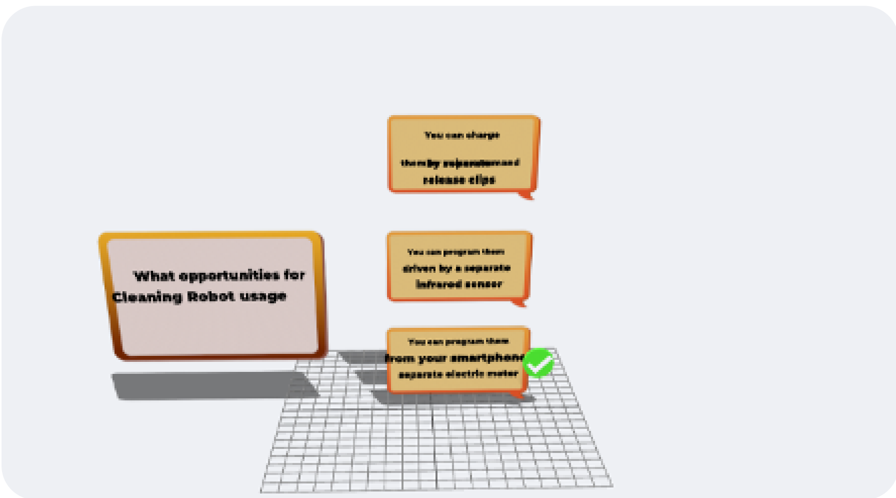


Figure 7 - Figure 6 - Assembler World Studio App 2

Augmented reality in classrooms: requirements and strategies

The goal of these strategies is to make learning more dynamic, accessible, and engaging, enhancing concept comprehension and developing crucial digital skills for the future.

In the following grid there are six examples of strategic activities to carry out with augmented reality (AR) in education:

Strategies	Examples	Descriptions
Encouraging experiential learning	Exploring historical or geographical environments	Students can use AR apps to explore virtual reconstructions of historical or geographical locations, such as ancient Rome or planetary systems. This activity allows students to immerse themselves in environments that would otherwise be inaccessible, making the study of history or geography more engaging and visually stimulating.
Building digital skills	Virtual science lab with 3D model and AR	In a biology or chemistry lesson, students can use AR to visualize and design and manipulate 3D models of cells, molecules, or organisms. For example, they can explore the internal structures of a cell or observe chemical reactions by simulating experiments that might be difficult or dangerous to conduct in a real lab.
Promoting collaboration	Creating interactive stories	Students, divided into groups, can collaborate to create a story or narrative using augmented reality content. Through AR tools, they can overlay images, videos, and animations onto real-world spaces, bringing their stories to life. This activity fosters creativity, collaboration, and digital skills, while also enhancing storytelling and writing abilities.
Interactive assessment	AR-Based Quizzes and Problem-Solving Activity	Students can use AR to complete a treasure hunt where they find and solve questions or problems embedded in the physical environment around them. Each correct answer might unlock additional clues or virtual elements related to the subject matter.
Personalizing Learning	Custom AR Learning Pathways	In a maths lesson, students can use AR to visualize and manipulate geometric shapes based on their level of understanding, with varying levels of complexity and support based on their progress. This customization helps cater to different learning preferences and paces, ensuring that each student receives the appropriate level of challenge and support.
Designing Interactive lessons	AR Simulations and Virtual Labs	In a biology class, students can use AR to explore and interact with a virtual ecosystem, observing how different factors affect it. In a physics class, students might use AR to experiment with virtual simulations of physical phenomena like gravity or motion.

Figure 8 - Strategic Activities Grid

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