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[101086701] Discovery Space:

An AI-Enhanced Classroom for Deeper Learning in STEM

[D.2.1 STEM Education Future Challenges Report]

[WP2 Discovery Space Innovation Model: Vision and Reflection]

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Executive Summary

This document (deliverable D2.1) is a result of the actions taken within the Work Package (WP) 2, under the task T2.1 and consists of a series of concept notes, the challenges and opportunities working papers, each of them discussing in detail a different topic connected to the Discovery Space project, along with the Introduction, Recommendations and Conclusions sections. In more detail, in the Introduction of the report the future challenges in the integration of artificial intelligence (AI) in STEM (Science, Technology, Engineering Mathematics) education are discussed, as well as ways that AI can contribute to the development of a students' Collaborative Problem Solving (CPS) skills. The AI-Enhanced Deeper Learning Classroom will be the guide to achieve the previous goals. Based on work conducted so far, important aspects connected to the Deeper Learning Classroom are addressed, like how AI can be leveraged and exploited for the common good in education, how the use of AI for educational practices can be ethical, inclusive and equitable, and of course which is the best way to prepare humans to co-exist with AI.

In Section 2 the transformation of STEM pedagogy from the traditional deductive model to an inquiry-based and problem-based educational model is discussed, along with the reasons dictating such a change towards student-centered approaches and the potential benefits accompanying this transformation. The main goal behind this approach is for students to develop a deeper learning competence, thus academic knowledge, cooperation and creativity, problem-solving skills and the growth of an academic mindset. Inquiry-based methods are known to increase students' interest for science, address gender segregation, while leading students to a deep understanding of the different subjects discussed within a science classroom. In the concept note the limitations in the application of inquiry-based and problem-based teaching have also been addressed, stressing the important role that teachers play towards the adoption of new methods in STEM pedagogy. Teachers should upgrade their own skills in order to be able to incorporate inquiry-based and problem-based learning in the limited time given to them by the syllabus. One more crucial factor here is to prioritize in-depth understanding over high exam scores, so that students don't read to the test. Inquiry-based education will be in the heart of the Discovery Space project and will be formulated through personalized scientific experiments, with the support of an AI-Lifelong Learning Companion and the use of AR/VR interfaces.

Section 3 focuses on the importance of bridging the gap between the different ways of STEM learning, namely formal, informal and non-formal. After defining formal, informal and non-formal learning, the concept note emphasizes on the positive outcomes that can be gained from the interconnection of the three learning approaches, e.g., a deeper appreciation for the importance of STEM in daily life, the fostering of STEM in underrepresented populations and the growth of students' motivation for science. Once more teachers could be game changers in the effort to connect formal and informal education, but this will require specific competencies. The importance of the creation of a network between formal educational foundations and local communities is noted, so that high level knowledge can be communicated in a simple and understandable way to society, bringing STEM subjects closer to it. Finally, the methodology for a proper assessment of informal learning approaches is discussed, while the potential consequences of an inadequate assessment are pointed out.

Moving forward to Section 4, the spatial configurations of the future science classroom are described, so that inquiry-based and problem-based educational models can be favored from the classroom's layout. The setup of a future STEM classroom should integrate modern technological applications, allow for hands-on experimentation of the students and in general be designed in such a way to inspire curiosity and engaging the students. Moreover, collaborative learning should be in the spotlight of the classroom's spatial configuration, in opposite to the traditional configuration promoting a teacher who acts as a content deliverer. As was the case in the two immediately previous sections, teachers are expected to have a major contribution in this transformation of the traditional classroom, to a classroom which encompasses the needs of IBSE and PBL. It is up to the teachers to figure out an optimal setup which will support an inclusive learning community, stressing one more time the need to upgrade their current competencies. This concept note sets the basis for the development of the Deeper Learning Classroom within the Discovery Space project.

Section 5 puts the role of teachers in the spotlight. The gaps and the needs for the professional development of a teacher are thoroughly discussed and the skills that the 21st century STEM educators should have developed are explained. These include a solid understanding of the subject matter, the know how in adopting an inclusive and diverse attitude, the encouragement of experimental learning, good communication skills, constantly updating one's knowledge and be willing to learn how to use digital tools and promote teamwork. Subsequently, the expected skills that students should develop are highlighted e.g., to identify questions and problems in real life situations and draw evidence-based conclusions, to understand the characteristic features of STEM disciplines as forms of human knowledge and finally the willingness to engage into STEM related research. Accordingly, the section discusses the importance and the state-of-the-art of STEM education, as well as the role of teachers in STEM education. Previous works in the field of teacher preparation for STEM education are revised and the current trends of the latter topic are presented. Finally, several recommendations are given in order to better prepare the teachers to cope with the challenges of STEM teaching, while the contribution of the Discovery Space towards this direction is extensively discussed.

Having covered the pedagogical part of the project in the previous sections, a discussion of the technical details of the project follows. In more detail, in Section 6 we discuss the use of extended reality (XR) laboratories in order to make STEM education more appealing to students. XR includes virtual reality (VR), augmented reality (AR), as well as mixed reality (MR) laboratories, and its use has the potential to increase the interest and the engagement of primary and secondary education students for STEM. On top of XR laboratories, remote laboratories (RL), another tool that enhance students' motivation for STEM learning and helps them reach a deeper level of understanding and are also covered within Section 6. Furthermore, in what concerns XR, its intrinsic characteristics are identified, along with the requirements for the development of XR technology and the future challenges towards that end. The concept note is also briefly describing two important architectures of XR laboratories emphasizing the breakthroughs and limitations of each. XR is introducing a rapid change in the dynamic landscape of education and the learning process using XR online laboratories. The concept note introduces and describes the main research and development areas of XR online labs, namely the *Rise of Immersive Learning*, the *Diverse Applications Across Disciplines*, the *Collaborative XR Learning Environments*, the *Real-time Data Integration and Analysis*, the *AI-Driven Personalization in XR Labs*, the *Gamification and XR Labs*, the *XR Labs for Soft Skills Development*, the *XR Labs for Workforce Training* and the *Accessibility and Inclusivity in XR Learning*. Finally, the section ends by mentioning and explaining the crucial requirements for the development of the future XR laboratories, which are *universality*, *low-cost*, *up-to-date*, *multilingual*, *usability* and *accessibility*.

Section 7 covers the technical details of the project, in what concerns the integration of AI in the learning process. Four areas of connection between AI and education, labeled as: "Learning with AI", "Using AI to learn about learning", "Learning about AI" and "Preparing for AI", have been identified, thus AI can act as a supporting tool for students, teachers, as well as the educational foundations themselves, by offering administrative support. In Section 7 the first area is discussed, so the document mainly focuses on the use of AI as a tool by the students, within the framework of the Discovery Space project. The concept note explains the two approaches that have been applied so far for the development of AI systems in education namely the symbolic and sub-symbolic AI. Accordingly, the use-cases of AI within education are presented, classified as student-facing AI, teacher-facing AI and system-facing AI, where again the emphasis has been given in the first case, which includes student-teaching and student-supporting AI. Moving forward, the different applications of AI in learning technologies in education are presented, chatbots, intelligent tutors, personalized learning systems and advanced simulations and visualizations and a detailed description for each of them is given. Finally, after going over several of today's digital assistants and the tasks that they execute, we address the AI challenges that could potentially disrupt the educational experience, namely the need for dynamic learning pathways, for the support of various data modalities and for the embedding of pedagogical models and approaches.

Finally, in the Recommendations at Section 8 we mention the future challenges of the project and the steps we are taking in order to cope with them. In more detail, the project will provide good practices in the form of scenarios to teachers and students in order to equip them with the necessary skills to use technology in a creative way. The Deeper Learning Classroom will be developed which will establish inquiry-based and problem-based learning, help the students develop key skills and adopt a modern and versatile setup favoring teamwork and motivating students to engage with STEM, combining at the same time the advantages of formal, informal and non-formal learning. The AI-driven lifelong learning companion is a key element of the Discovery Space project and will provide guidance to the students, while also designing a personalized learning pathway for each student addressing his/her own needs and misconceptions. With the help of the AI conversational agent the teacher will be able to monitor each student's progress at any time, a non-trivial task in a typical classroom. The teachers will guide the shift of the learning process from a typical content delivery to an active engagement of the students in the understanding of the phenomenon under study. The future technical directions of the project are also discussed and in particular the integration of XR laboratories, satisfying the requirements described in Section 6, as well as technical details in the use of AI in the pedagogical process, while the architecture of the Discovery Space system is presented.

The document ends with the Conclusions in Section 9, where a summary of the most important points of the Discovery Space project is given.

List of Terms and Abbreviations

Term/Abv.	**Definition**
AI	Artificial Intelligence
AR	Augmented Reality
CPS	Collaborative Problem Solving
DGBL	Digital Games Based Learning
EDEH	European Digital Education Hub
ELE	Exploratory Learning Environment
IBL	Inquiry-Based Learning
ICT	Information Communication Technology
MR	Mixed Reality
PBL	Problem-Based Learning
PISA	Program for International Student Assessment
PLS/E	Personalized Learning Systems and Environments
PSC	Problem Solving Competence
RL	Remote Laboratories
STEM	Science Technology Engineering Mathematics
TA	Teachable Agent
VLE	Virtual Learning Environment
VR	Virtual Reality
XR	Extended Reality

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1. Introduction

It is well known that STEM education is at the heart of sustainable socio-economic development, playing a crucial role for the future prosperity of the European Union (EU) [1]. It is of great importance for EU citizens to have a background in STEM provided by primary and secondary education, which in turn will help them make well-informed decisions and develop critical and scientific thinking [1]. Nevertheless, the previously mentioned reasons for the importance of STEM seem to not appeal to today's students who according to a recent study [1] are not particularly interested in STEM education. It has become obvious that the burden of finding the causes of this problem, communicating the importance of STEM and attracting students towards it, is now on the different educational stakeholders, like schools, teachers, universities, etc.

One of the causes that students avoid STEM subjects is the way they are taught in many schools around Europe, which is mainly focusing on memorizing strict scientific definitions and problem-solving methodologies and reproduce parts of them in a final exam, instead of a step-by-step guidance towards a deeper understanding of the subject. The latter can be achieved by employing inquiry-based learning (IBL) and problem-based learning (PBL), which in turn can develop the Problem-Solving Competence (PSC) skills of the students. PSC is a crucial parameter for the development of CPS [2], a central skill among those considered as 21st century skills, e.g., critical thinking, Information and Communication Technology (ICT) skills and others.

According to the definition of CPS in the 2015 Program for International Student Assessment (PISA) [2], two or more agents should effectively engage in a process in order to solve a problem. This process involves the processing of both cognitive and social skills; thus, CPS offers the possibility to monitor the cognitive processes of the different individuals in the group, as well as the way they perform within a team. Such monitoring can take place by testing the way that communication takes place with other group members, as well as by checking the level of knowledge of an individual. At this point we stress again that for the previously mentioned argumentation to be valid, two or more agents should be engaged in the process. According to PISA 2015 [2], an agent can be either a human or a computer simulated participant, which in the framework of the Discovery Space project will be an AI-driven lifelong learning companion, combined with AR/VR technologies.

Introducing AI to education is a matter of discussion already from the 1970s [3], yet before proceeding with such an initiative, several key factors concerning AI must be considered, like what can AI offer in a STEM classroom, issues of ethics, equity and sustainability and of course an in-depth reevaluation of our understanding of AI is necessary [3]. Even more important, the role of the teacher should be also re-considered, as certain tasks previously performed by the teachers can now be taken care of by AI. Nevertheless, communication between the teachers and the students is of fundamental importance and cannot be replaced. Teachers should be aware of the different ways AI is introduced in education and use them in order to enhance the learning experience of the students. AI can be found in education through chatbots, intelligent and dialogue-based tutoring systems, as well as through the emerging exploratory learning environments (ELEs) [3], the latter being the case for the Discovery Space project.

ELEs, contrary to the other AI educational methods mentioned above, are providing automated guidance and feedback, based on knowledge training and machine learning, minimizing in this way the cognitive overload and favoring the IBL and PBL models. Students are guided and receive feedback from a computer simulated conversational agent targeting at their misconceptions and trying to help them create and understand by themselves knowledge which would have been taught in a conventional science classroom. The ELE approach could significantly enhance the user experience if combined with AR/VR innovations. In the first case (AR), computer-generated images are superimposed on real images perceived by the user, while in the latter (VR) the user gets completely isolated by the real world and is immersed in a computer-generated environment. In this case students could get an experience of an environment (like the deepest point of an ocean) or perform an experiment (e.g., operating a high-power laser), the realization of which would have been very difficult if not impossible in the real world. Finally, we note here that beyond the potential advantages in the learning process of an individual student (student-facing AI), AI could have a major impact on CPS.

As mentioned above, CPS is an important skill that students need to develop. CPS has been shown to lead to more learning outcomes, through collaborative learning. AI could help in the development of collaborative learning as well [2], by identifying student groups which could achieve high learning performances, contribute to group discussions or distribute specific tasks to specific groups according to the learning profiles of the group members. Moreover, AI's contribution in assessing the CPS competency of students could be impeccable. An impartial assessment of an individual student's CPS skills would require the student to participate in different groups, consisting of students with different backgrounds and repeat this process for each student, without changing of course the group members [2]. The variability of the group members' characteristics is a crucial parameter in order to ensure a fair measurement and as can become easily understood, it is a very demanding task to be performed by a few individuals (teachers, administrative personnel), especially when it comes to large-scale international assessments [2]. Such a task though could be easily performed using AI in the form of one or several computer-based agent(s), which could represent different members of a group having different skills and educational backgrounds. In this way the assessment will be based on a fully controlled and standardized process.

According to PISA 2015 [2], for the evaluation of the CPS skills of the students, as well for an individual's understanding of a problem, a problem scenario will be presented to the students and their skills will be monitored by the agent, while the assessment will be based on the answers provided to multiple choice questions, how they perform on predefined tasks and in general their actions towards the solution of a problem. The scenario will be structured as a sequence of different phases and the agent will monitor the student at every phase, while planning an optimal learning pathway for him/her, on the go, according to the provided answers and performed actions. Integrating AI in the learning process is of great importance for the estimation of an optimal learning pathway tailored to each student's needs. This could in turn cause confusion about the role of the teachers as AI is becoming part of the educational process. Some might even consider that AI could potentially replace teachers making their part in the learning process obsolete. Teacher-facing AI should be directed towards supporting teachers meet their goals by performing time-consuming tasks such as plagiarism detection, handling administrative issues, etc. In this way, teachers will have the chance to focus on the content of their teaching and new ways it can be taught. We should keep in mind that the final decision about what and how will be taught, will always be made by the teachers.

The fact that AI cannot replace teachers certainly does not mean that teachers should not develop new competences in order to be able to better cope with AI. According to the European Digital Education Hub's (EDEH) squad on AI in education briefing report [4], there are three segments that competences can be divided to, namely teaching for AI, teaching with AI and teaching about AI. The first segment describes the competences citizens should have in order to safely engage with AI. The second, in which we focus here, is detailing how AI systems can be used for educational goals and the third reports on the preparation of the future AI experts.

In what concerns teaching with AI, the EDEH report identifies six key areas [4], each having its own competences. These areas are the following. First is *Professional Engagement*, where the teacher should be able to describe the positive and the negative impacts of AI, while being aware of the basics of AI. The second area refers to *Digital Resources*, referring to the teachers' awareness on the sensitive issue of the processing of personal data by the AI systems. A teacher should be aware that all AI systems are subject to national EU regulations and be able to explain the key principles of data quality in AI systems. The third area concerns *Teaching and Learning* and includes competences related to Models of learning, Objectives of education, Human agency, Fairness, and Humanity. In other words, a teacher should make sure that the designed learning practices using AI have ethics at their core. The fourth area is about Assessment. Here a teacher should understand sources of unacceptable bias in AI systems and know that AI assesses how students progress based on pre-defined models of knowledge. Moreover, teachers should always be vigilant of new ways that AI can be tricked into making false assessments. Finally, the fifth and sixth areas include competences about *Empowering Learners* and *Facilitating learners' digital competence*. In the former area a teacher's competence in acknowledging the fact that AI is addressing the different learning needs of each student is included, while the latter is associated with the ability of a teacher to develop students' AI literacy.

In the next two subsections we shall present the steps and actions taken within the Discovery Space project to address the challenges imposed by the integration of AI in the educational systems of different EU countries. First, we go through the key points of the project's methodology and accordingly describe the actions performed so far. In the second subsection a bulleted list mentioning the concept notes written here and schematics of the document's structure are given.

1.1. Purpose and scope

The three main pillars of the Discovery Space project are the design of the Deeper Learning Classroom and a new way to assess a student's performance, the integration of AI in the Deeper Learning Classroom and the development of an innovation model in order to achieve the goals of the project. The project's ELE is expected to host several scenarios within the different STEM subjects, the Discovery Space Scenarios. To this end, several actions will be and have already been performed within the different work packages of the project and more specifically WPs 2, 3 and 4. At this point it is important to acknowledge that the use of AI for learning and assessment raises various concerns that need to be properly addressed. Such concerns include challenges about the effective integration of AI in the educational practice, the lack of robust evidence for its efficacy and potential impact on teachers' roles and broader ethical questions.

The main points of the project were discussed during the consortium meeting which took place at Bilbao, Spain in June 2023. During the meeting, the challenges of the project were identified and divided into two main parts, a pedagogical part and a technical part. In the former case a series of educational scenarios should be developed, structured in a way which will allow students to create knowledge by themselves, face contradictions with the previously created mental images that they have in mind and eventually reach a deeper level of understanding through consecutive reevaluations of their knowledge.

A crucial factor for the success of the project is the way that the assessment of an individual student takes place. More specifically, the AI-driven learning companion (conversational agent) will guide the student through an optimized learning pathway tailored to his/her own needs. For the creation of the learning pathway, the conversational agent will be able to evaluate the student's level based on how the student performs on the initial phases of the scenario. Accordingly, the agent will be able to select the next step (next phase of the scenario) according to the student's profile. This is a major challenge of the project as in order for the AI conversational agent to design the learning pathway some initial conditions should have been given to it, which will distinguish between low, medium and high performers, as is the case in PISA 2015 [2]. Such an initial assessment was discussed during the consortium meeting at Bilbao and specific examples from Physics were presented, where both the pedagogical and technical details were addressed, and indicative learning pathways were shown.

Up this point, several scenarios have already been developed by the consortium partners, as well as by a group of graduate students which participated in the summer school organized by Ellinogermaniki Agogi (EA), with the participation of all the consortium members, in July 2023 at Marathon, Greece. During the summer school the students were introduced to the Discovery Space project and by the end of it they created different scenarios which will be implemented in the project, and they cover different STEM subjects. In the course of the project, several students will go over different scenarios and according to their performances the AI agent will collect more and more data in order to be able to predict an ideal pathway for each student. Next, we briefly discuss the actions that are taking place within each of the above-mentioned WPs.

Starting from WP2, the project team is working towards the AI-enhanced classroom for Deeper Learning in STEM by applying IBL and PBL, and by incorporating useful elements of formal and informal learning. Our ambition is to develop a future science classroom which will resemble a living laboratory. The aim here is for students to be introduced to the actual scientific exploration instead of memorizing science. Furthermore, as mentioned in the grant agreement, the assessment will be based on the Deeper Learning Paradigm, establishing a continuous monitoring of the student's learning process. Within the Deeper Learning Paradigm both the intellectual and the motivational abilities of a student are addressed in order to accomplish STEM mastery. The AI-driven conversational agent will contribute towards this direction, as it allows for the evaluation of abilities being in the core of deeper learning and the subsequent creation of students' Deeper Learning Competence profiles, with the latter falling in the upcoming field of Learning Analytics.

The scenarios are of fundamental importance for the success of the project, they are treated as case studies and are expected to be tested in real conditions. In more detail, within the framework of WP4 it is expected that around 1000 teachers and 10000 students will participate in the implementation of the project, which will take place in two cycles. In the first cycle we will monitor and analyze the users' reactions to the approach and accordingly modifications and improvements will be applied both to the pedagogical and the technical components. This will be the departure point for the second cycle, where the users will be tested in more advanced and complicated scenarios, the latter being the result of the collaboration between the consortium members working on the pedagogical and technical parts of the project and the users. Finally, the ELE of the Discovery Space will be developed within the framework of the WP3, by utilizing and integrating the elements described above.

1.2. Structure of the document

As mentioned above, the document has been structured as a series of concept notes/individual papers explaining the different tasks taking place within the Discovery Space project. In the Introduction (section 1) we give a general overview of the document. The pedagogical papers come first in the text (sections 2,3,4,5), followed by the technical ones (sections 6,7). Then the future directions of the project are mentioned along with the most important points (sections 8,9). Here we only mention the titles of each section of the document:

- Section 1: Introduction
- Section 2: Advancements in STEM education: Embracing inquiry-based and problem-based learning for a sustainable future

- Section 3: Bridging the gap between formal, informal and non-formal STEM education: A holistic approach
- Section 4: Spatial configurations of the future science classroom: Fostering student-centered learning
- Section 5: Preparation of the teachers to become the key players in the renewal of STEM education: Developing and upgrading their STEM skill-set
- Section 6: Development and operation of extended reality laboratories for educational practices
- Section 7: Emerging technologies of the future in the learning process: AI as an educational tool
- Section 8: Recommendations
- Section 9: Conclusions

A schematic of the document's structure is shown in Figure 1-1:

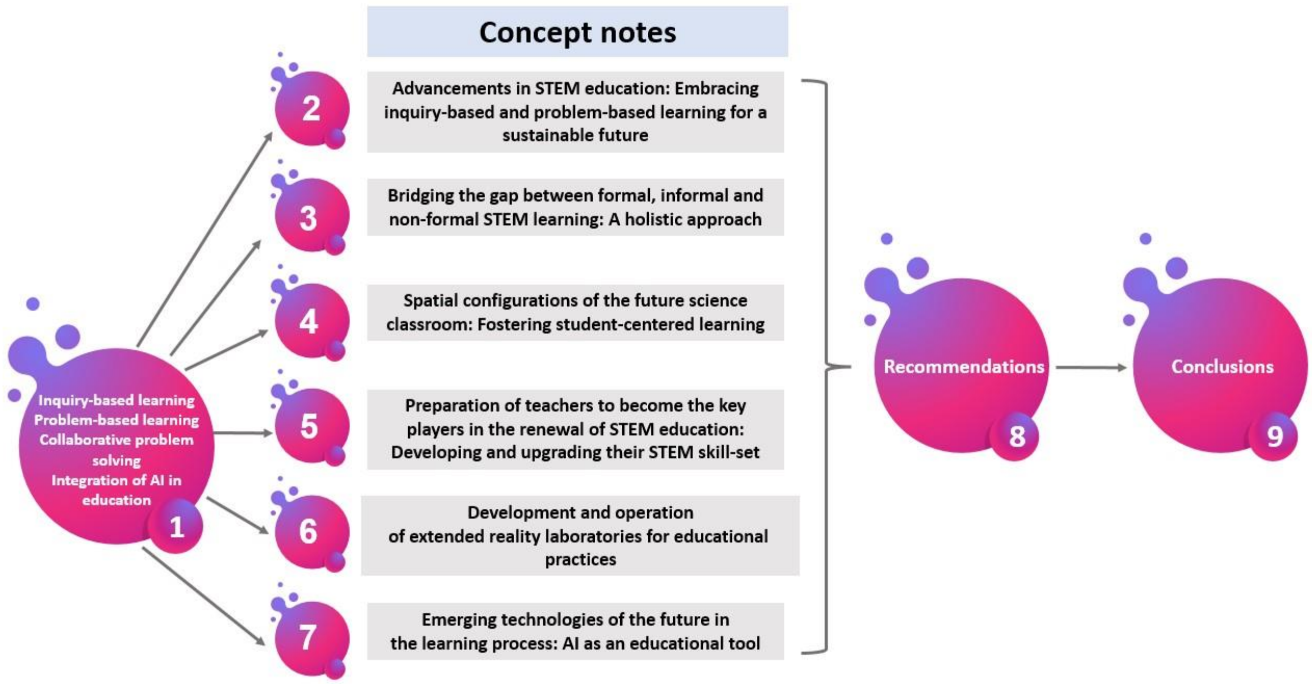

Figure 1-1: A schematic representation of the document's structure

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2. Advancements in STEM education: Embracing inquiry-based and problem-based learning for a sustainable future

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2.1. Introduction

STEM education has witnessed a transformative shift in recent years, shifting from traditional deductive teaching methods to embracing inquiry-based and problem-based learning approaches. This paradigm shift aims to foster critical thinking, problem-solving skills, and a deeper understanding of STEM concepts among students. This essay explores the advantages and implications of this transformation, as well as the challenges and current trends associated with IBL and PBL in STEM education.

2.2. Current trends in STEM education

The field of STEM education is continually evolving, and several trends shape its current landscape. Firstly, there is a growing emphasis on active learning approaches, where students take an active role in constructing their knowledge through hands-on activities, investigations, and problem-solving. This trend promotes engagement, critical thinking, and a deeper understanding of STEM concepts. Technology integration is another prominent trend in STEM education, where educators use digital tools, simulations, virtual laboratories, and online resources to enhance inquiry and problem-based learning experiences. This allows for more authentic and immersive learning opportunities.

Collaborative learning and teamwork are becoming increasingly important in STEM education, encouraging students to work in teams and engage in collaborative problem-solving, discussions, and project-based activities. This reflects the collaborative nature of STEM fields and prepares students for future careers [1]. In recent years, there has been a shift towards authentic assessment methods aligned with inquiry and problem-based learning [2]. Traditional exams are supplemented by performance-based assessments, portfolios, projects, and presentations that evaluate students' ability to apply knowledge, think critically, and solve real-world problems [3,4].

Furthermore, the role of the teacher is evolving from that of a sole provider of information to that of a facilitator of learning. Teachers guide and support students in their inquiry and problem-solving processes, encouraging independent thinking, questioning, and exploration. This trend highlights the importance of student-centred teaching [5,6]. Integration of real-world contexts and authentic problems in STEM education is gaining momentum [7]. Students are encouraged to relate STEM concepts to real-life situations, promoting relevance and application [8]. This trend fosters a deeper understanding of how STEM knowledge can be used to address societal challenges [9].

Finally, there is a growing focus on promoting equity and inclusion in STEM education. Efforts are being made to ensure that inquiry and problem-based learning approaches are accessible to all students, regardless of background or ability. This trend aims to reduce inequalities and provide equal opportunities for all learners [10].

2.3. Advantages of inquiry-based and problem-based learning in STEM education

Inquiry-based learning encourages students to actively explore real-world questions and phenomena, transforming them into active participants in their learning journey. Inquiry-based learning improves students' problem-solving skills [11]. This student-centred approach nurtures a sense of ownership over their learning, leading to heightened motivation and interest in STEM subjects. It should be emphasised that the inclusion of STEM learning in inquiry-based teaching improves students' science skills and attitudes, making it a valuable model for hands-on activities and addressing competitive issues in education [12].

Furthermore, inquiry-based learning offers flexibility in choosing methods and less emphasis on teaching specific problem-solving paradigms, making it appealing to a wide range of vocational training and professional education programs [13]. Moreover, it fosters soft skills such as collaboration and self-directed learning, preparing students for the complexities of future STEM professions [14]. Students engaged in inquiry-based STEM learning demonstrate improved critical thinking skills, meeting the criterion for effective learning [15].

Problem-based learning, on the other hand, involves students tackling complex, authentic problems that resemble real-world STEM challenges. This approach connects STEM concepts to real-life scenarios, making the learning experience more authentic and relevant. By applying their knowledge and skills to develop creative solutions, students gain a deeper understanding of how STEM knowledge can be applied to address societal problems and improve the world around them [12]. In a modern heterogeneity-valuing society, it is particularly significant that problem-based learning, by emphasising its interdisciplinary nature, encourages students to see connections between different subjects [13], with cross-curricular thinking being beneficial not only in STEM professions. In addition to fostering critical thinking and problem-solving skills, both inquiry-based and problem-based learning approaches promote collaborative work and effective communication. Students engage in teamwork and idea exchange, honing essential collaborative skills essential for real-world STEM professions [13].

2.4. Challenges and limitations

While the advantages of inquiry-based and problem-based learning are evident, educators must be mindful of potential challenges. Many teachers self-report enacting inquiry-based science teaching without a well-structured knowledge of inquiry, leading to potential mismatches between their beliefs and actual practices [16]. Additionally, time constraints and pressures from high-stakes testing may hinder the full implementation of inquiry-based and problem-based learning methods [13]. To sustain these pedagogical changes, a shift in the value system that appreciates and understands the value of education beyond test scores is needed [12]. IBL and PBL approaches can be time-consuming, requiring ample class time for open-ended exploration, investigations, and problem-solving [13]. Additionally, educators may require adequate professional development training and support to successfully transition to these student-centred pedagogical approaches [9].

The time allocated to additional teaching content in IBL/PBL should not be compared directly to teacher-centred teaching, which primarily emphasises content delivery alone. In IBL, the focus extends beyond content, encompassing the development of critical competencies and deeper understanding, making it essential to consider the broader impact and long-term benefits of this approach. However, it should be remembered that some fast learners may reproduce 100% of what they have learnt in a lecture, but this only affects a few exceptionally gifted students. All students remember very little after only six weeks. With self-study, on the other hand, knowledge remains stable for years [17,18]. In addition, only a few skills are practised in teacher-centred lectures, mainly listening. All the active competencies in working life, however, are not taught or even practised in a lecturer-centred talk. The time required for IBL lessons should therefore be counted not only for the technical content but also for the competencies and the sustainability of what has been learnt [19].

Differentiating instruction and providing scaffolding are necessary to support students at various skill levels, as not all students may be initially equipped with the necessary skills and knowledge to engage fully in inquiry or problem-solving activities [12]. Assessment in inquiry-based and problem-based learning can be more complex than traditional forms, necessitating alternative assessment methods to evaluate student progress accurately [13].

Moreover, teachers require expertise in classroom management and awareness of the principles of group dynamics to create an effective inquiry-based and problem-based learning environment [20,21]. These approaches may introduce elements of unpredictability and collaboration into the classroom, requiring clear expectations, scaffolding, and an organised learning environment to manage effectively [22]. Group work in problem-based learning may present challenges related to group dynamics, necessitating guidance and support from teachers to promote positive collaboration [13,20,21].

2.5. Recommendations for a successful establishment of IBL/PBL

There is also evidence to support that interventions that follow STEM education principles reinforce students' problem-solving and creativity [23]. In other words, inquiry-based learning offers a promising blueprint for other subjects. Therefore, when implementing Inquiry-Based Learning (IBL) or Problem-Based Learning (PBL) lessons, it is crucial to consider not only the time needed for covering technical content but also the time required to develop these essential competencies and ensure the long-term sustainability of what has been learned. By prioritising active learning experiences and fostering the development of practical skills, IBL can better prepare students for success in their future careers and promote enduring knowledge retention.

The traditional lecture-based teaching approach may lead to high short learning performance for a few exceptionally gifted students, but for all, knowledge retention diminishes significantly after only six weeks. In contrast, self-study fosters more stable knowledge retention for years [5]. Moreover, lecture-centered teaching primarily focuses on text comprehension and listening skills, neglecting the development of essential competencies needed in the professional world. Implementing IBL lessons not only enhance technical content but also cultivates crucial competencies such as critical thinking, problem-solving, collaboration, and creativity, ensuring deeper learning and better preparation for future careers [1].

2.6. Conclusions

The shift in STEM education from deductive teaching methods to inquiry-based and problem-based learning has significantly transformed the learning experience for students. These student-centred approaches promote curiosity, improved critical thinking, collaboration, and problem-solving skills, deeper learning of STEM content and with the relevance for the student the get prepared to become active contributors and problem solvers in the STEM fields of the future. While inquiry-based learning and problem-based learning offer numerous benefits, educators must navigate potential challenges related to time constraints, teacher preparation, student readiness, assessment complexity, and classroom management. By proactively addressing these challenges and embracing current trends, educators can create inclusive and effective learning environments that empower students to become lifelong learners, critical thinkers, and problem solvers. Ultimately, the integration of inquiry-based and problem-based learning in STEM education supports the development of a sustainable society where diverse perspectives and collaboration drive innovation and progress. As STEM education continues to evolve, embracing these transformative approaches will be crucial in preparing the next generation of STEM professionals to tackle the complex challenges of the 21st century.

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3. Bridging the gap between formal, informal and non-formal STEM learning: A holistic approach

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3.1. Introduction

Bridging the gap between formal, informal, and non-formal STEM learning is essential for creating a comprehensive and well-rounded educational experience for students [1,2]. Formal learning occurs within the structured confines of the classroom, while informal learning takes place outside these walls through visits to museums, science centres, or participation in STEM clubs. On the other hand, non-formal learning happens in organised settings but without the traditional structure of formal education, such as workshops or online courses. Each of these learning approaches offers unique benefits and opportunities to students (Table 3-1). By integrating these different contexts, students can develop critical thinking, problem-solving skills and a deeper appreciation for the relevance and application of STEM in everyday life. This essay explores the importance of bridging the gap between formal, informal, and non-formal STEM learning, along with the competencies teachers need to facilitate this integration and appropriate assessment methods in inquiry-based learning environments.

3.2. Importance of bridging the gap between learning approaches

Formal education provides students with a solid foundation of knowledge, but it is essential to complement this with informal and non-formal learning experiences. Informal and formal learning environments can be interconnected to offer a more holistic approach to STEM learning across settings and over a lifetime [2]. Studies highlighted the significance of structured informal learning activities, like STEM project-based approaches, in assisting students to grasp science concepts and develop 21st-century learning skills alongside formal education [3].

Informal STEM learning experiences have been found to play a vital role in fostering STEM identities among underrepresented populations [4]. Moreover, integrating informal learning settings into formal education has augmented students' motivation to explore STEM subjects [5]. By linking formal education with informal learning experiences, students gain practical application and hands-on experiences, bridging the gap between theoretical knowledge and real-world applications [6].

3.3. Current trends and recommendations

The current trends in STEM education emphasise the integration of different learning approaches. Integrated STEM education frameworks that incorporate problem-centred, inquiry-based, and design-based learning along with cooperative learning have shown promising results [7]. Additionally, informal STEM education frameworks have been proposed to guide outreach efforts and align activities with learning goals and learner engagement theories [8]. Project-based learning not only could enhance vocational school students’ learning motivation but facilitate students’ problem-solving ability [9]. Students benefit from implementing informal instruction on concepts in science, technology and problem solving into a project-based program [10]. Policymakers have recognised the importance of integrating future-oriented skills like problem-solving and critical thinking into science curricula [11]. To achieve this integration, long-term in-service education based on collaborative knowledge creation has been proposed to develop teachers' competencies in linking formal education with informal and non-formal education [12].

Table 3-1: Advantages and disadvantages of formal, informal and non-formal STEM learning

	Formal	Informal	Non-formal
e.g.	*Classroom*	*Out of School, e.g. museums, science centres, home*	
	often teacher-centred	*based on learner-driven exploration and curiosity*	*structured by educational institutions, e.g. visiting a museum*
Advantages	Structured Curriculum: ensuring comprehensive coverage of STEM content.	Engaging and Interactive: hands-on activities and interactive exhibits that engage students and make learning enjoyable.	Diverse Learning Environments: various settings, e.g. after-school workshops, online platforms, providing a wide range of learning opportunities.
	Certified Teachers: possess subject expertise and pedagogical knowledge.	Real-World Context: real-world connections, helping students understand the practical applications of STEM concepts in everyday life.	Practical Application: often emphasises hands-on, experiential learning, enabling students to apply STEM knowledge in real-world contexts.
	Standardised Assessments: benchmark student achievement and facilitate accountability.	Informal Networks: with experts and peers built by students, fostering collaborative learning and mentorship opportunities.	Flexibility: allowing learners to tailor their educational experiences to their interests and pace.
Disadvantages	Reliance on Traditional Instruction: may not fully engage students or foster critical thinking and problem-solving skills.	Lack of Structure: a less structured curriculum making it challenging to ensure comprehensive content coverage.	Limited Standardization: assessing and comparing student achievements across different non-formal programs or platforms is challenging.
	Limited Practical Application: more theoretical concepts, with limited opportunities for hands-on, real-world applications.	Limited Accessibility: especially for students in remote areas or with financial constraints.	Lack of Formal Recognition: may not offer recognised certifications or qualifications valued in academic or professional contexts.
	Lack of Flexibility: rigid structure may limit the ability to customise learning experiences to individual student needs.	Variable Quality: The quality may vary, making it essential to ensure the credibility and effectiveness of the chosen learning opportunities.	
Examples		1. Everyday Interactions: Learning through informal conversations and observations with peers, family, friends. 2. Exploring exhibits, participating in interactive activities. 3. Nature Exploration: Learning about the environment and wildlife through outdoor experiences like birdwatching or nature walks. 4. DIY: Engaging in hands-on activities, experimenting, and creating in maker spaces. 5. Informal Research: reading books, articles, blogs, and watching educational videos online. 6. Hobby clubs: interest-based communities.	1. Training Programs: Professional development workshops, skill-building sessions, and training programs organised by institutions or employers. 2. Continuing Education Courses: offered by universities or prof. organisations for personal or career advancement. 3. Language Classes and Learning Centres outside the formal school system 4. Job Training and Vocational Programs: designed to provide specific skills and training for job-related purposes.

3.4. Competencies required for bridging the gap

Teachers need specific competencies to effectively bridge the gap between formal, informal, and non-formal STEM learning. Flexibility and adaptability are vital qualities, enabling teachers to seamlessly transition between different learning contexts and instructional strategies. Building partnerships with informal learning institutions and community organizations fosters collaboration and networking. Integrating authentic problems, field trips, and industry visits links formal STEM content with real-world applications. Teachers must also be proficient in utilising educational technologies to enhance learning experiences, including digital tools, online resources, and simulations. Competence in designing and implementing assessments that capture students' progress in diverse learning experiences is crucial [13,14]. Reflective practice allows teachers to improve their instructional approaches and identify areas for growth continuously [15].

3.5. Appropriate Assessment Methods in Inquiry-Based Learning Environments//Appropriate assessment methods in the context of integrating informal learning approaches

Inquiry-based learning environments that integrate informal learning approaches require suitable assessment methods [16]. Assessment is not the only driver of learning; rather, there is a danger that inadequate assessment can inhibit learning and even lead to school anxiety [17].

Assessment is not the only driver of learning, as the influence of informal and hidden curricula, often related to exposure to role models, can have a significant impact on the outcome of learning [18]. Performance-based assessments evaluate students' ability to apply knowledge and skills in real-world scenarios. Project-based assessments allow students to work collaboratively on extended projects, showcasing their understanding and problem-solving abilities. Self-assessment and reflection encourage students to assess their learning progress and set goals [19]. Informal observations offer insights into students' interactions and problem-solving approaches. Rubrics and criteria-based assessments provide clear indicators of success for specific tasks. Sustained performance assessments capture students' progress over time. Open-ended questions and interviews reveal thought processes and critical thinking skills. Frequent feedback and formative assessments support students' learning progress in inquiry-based and informal learning environments.

3.6. Conclusions

Bridging the gap between formal, informal, and non-formal STEM learning is crucial for providing students with a well-rounded and comprehensive educational experience. By integrating these different learning contexts, students can develop critical thinking, problem-solving skills, and an appreciation for the practical application of STEM knowledge [20]. To achieve this integration, teachers need to possess specific competencies, including flexibility, collaboration, and technology proficiency. Moreover, appropriate assessment methods, such as performance-based assessments and project-based assessments, are essential in inquiry-based learning environments. By fostering an interconnected learning ecosystem, educators can effectively bridge the gap and equip students with the skills and knowledge needed to succeed in the dynamic world of STEM.

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4. Spatial configurations of the future science classroom: Fostering student-centered learning

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4.1. Introduction

The future science classroom is envisioned to be a dynamic, adaptable, and student-centred space that promotes collaboration, inquiry-based learning, and hands-on experimentation. The varied, adaptable nature of flexible learning spaces coupled with the use of student-centred pedagogies, facilitated a higher proportion of class time interacting, collaborating and engaging with the lesson content [1]. Departing from traditional rows of desks facing the front, the classroom of tomorrow will feature flexible furniture arrangements that can be easily rearranged to accommodate various learning activities. Technology integration will be prominent, with interactive displays, virtual simulations, and access to digital resources transforming the learning experience. The physical layout will be designed to inspire curiosity, support inquiry-based learning, and foster authentic scientific practices. This essay explores the elements and advantages of the future science classroom, recommendations for equipping such a modern motivating classroom, the impact of spatial configurations on student outcomes, and the competencies teachers need to facilitate effective instruction in these innovative learning environments.

4.2. Elements of the future science classroom

The teacher plays a vital role in creating an atmosphere of inquiry learning by encouraging open-ended questions, supporting students in developing research questions, and encouraging discussion and debate. A supportive and inclusive learning community is fostered, where students feel comfortable sharing their ideas and engaging in constructive debate, so that authentic scientific practices can flourish.

On the one hand, this requires teachers to be specially trained to move away from being an all-knowing provider of material to a tutor and trainer who provides the opportunity and space for learners to discover science, its insights and their personal talents [2,3]. On the other hand, it helps if the space is not set up like a lecture theatre, with the teacher at the centre, rather than divided into research modules where learning takes place. Since a plenary session is certainly helpful for opening or closing a topic or for discussing results [4], a modular classroom that can be reconfigured quickly and flexibly would be an ingenious solution.

The modern science classroom prepared for future science students is equipped with state-of-the-art technology and scientific tools, encouraging hands-on exploration and experimentation. Digital resources and virtual laboratories will expand students' access to scientific knowledge and research opportunities [5]. The physical layout of the classroom will be flexible and adaptable, allowing for easy rearrangement to accommodate different learning activities and group collaborations [6]. This flexibility empowers students to take charge of their learning environment, promoting a sense of ownership and agency [7]. Displays of scientific discoveries, posters, and models showcasing the wonders of the natural world, sparking curiosity and fuelling students' interest in scientific exploration.

4.3. Recommendations for equipping a modern motivating classroom

Furniture in a modern classroom should be designed to support learning objectives and create an engaging and collaborative learning environment. Flexible and easily reconfigurable furniture allows for different learning activities and group sizes. Modular furniture offers versatility in arranging the classroom to meet the needs of various lessons and student groups [8]. Chairs and desks should be comfortable and ergonomically designed to promote good posture and reduce physical strain. Adjustable furniture can accommodate students of different heights and body types. Standing desks and alternative seating options, such as exercise balls or beanbags, provide movement to reduce stress and provide variety in seating choices.

Furniture should support collaborative learning, such as tables for group work and discussion, promoting teamwork, communication, and problem-solving skills [8]. Technology-friendly furniture supports using laptops, tablets, and other devices for digital learning activities. Cable management solutions keep cords organized and reduce clutter. Materials that absorb sound reduce noise levels, encouraging teamwork and collaboration. Adequate storage options help keep belongings and learning materials organized, maintaining a tidy and efficient learning environment. Learning zones with appropriate furniture for different activities, such as a reading corner, project area, or presentation room, avoid a relapse into old-fashioned teacher-centred lectures and allow students to organize their learning independently based on their needs.

Involving students in the design process or seeking their feedback on furniture preferences creates a student-centred learning environment for which students feel responsible. Finally, aesthetics and sustainability are important aspects of classroom design. A welcoming and visually appealing atmosphere, along with environmentally friendly, sustainable, and repairable furniture, contribute to teaching environmental awareness and responsible consumption.

4.4. Impact of spatial configurations on learning outcomes

The impact of classroom design on student behaviours and outcomes is significant. Environmental theories, such as behaviour setting theory, suggest that the learning environment significantly influences human behaviours. Diverse classroom configurations lead to varied in-class behaviours in learning environments. Environmental affordances, features that promote specific behaviours, can be identified, and traced within the classroom. Learning centres act as behaviour settings that foster specific in-class behaviours, such as social interaction among the learning community. A flexible and student-centred spatial configuration can encourage active learning, collaboration, and engagement, improving student outcomes and learning experiences.

4.5. Competences needed to facilitate effective instruction

Adapting to modern spatial configurations and facilitating effective instruction requires teachers to acquire new competencies. Professional development is essential in embracing a modern approach as an agile and guiding facilitator rather than a teacher-centred lecturer. Teachers need to be proficient in utilising new furniture and technology, as well as adapting instructional methods to maximise the benefits of the flexible space. Ongoing support and training are crucial to ensure effective implementation. Clear expectations, guidelines, and routines should be established to maintain order and focus on the classroom. Technical support and troubleshooting resources are necessary to address potential technology challenges.

Balancing individual preferences within a flexible environment can be challenging, but it promotes an inclusive learning environment. Teachers must create a supportive and collaborative community where students feel comfortable sharing their ideas and engaging in debates. Empowering students to work independently and collaboratively within these new settings fosters effective and motivated learning. Overall, professional development and acquiring relevant competencies will enable teachers to create a dynamic and supportive learning environment, promoting collaboration, critical thinking, and growth among their students.

4.6. Conclusions

The spatial configurations of the future science classroom will revolutionise traditional educational settings, creating a dynamic and student-centred environment that fosters collaboration, curiosity, and authentic scientific practices. Equipping the classroom with flexible furniture, state-of-the-art technology, and diverse learning zones supports a modern approach to teaching and learning. The impact of spatial configurations on student outcomes underscores the importance of creating a conducive environment that encourages active learning and engagement. Teachers' competencies in facilitating effective instruction within these innovative learning environments are essential for maximising the benefits of modern classroom design. By embracing a student-centred and flexible approach, educators can empower their students to become active learners, critical thinkers, and lifelong scientific explorers.

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5. Preparation of the teachers to become the key players in the renewal of STEM education: Developing and upgrading their STEM skill-set

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5.1. Introduction

STEM education as an interdisciplinary approach can be traced back to the 19th century in the United States[1] as some disciplines started to be delivered to students in an interdisciplinary format and with the aim of supporting the preparation of the work force for innovation. However, the integration of all the four main areas, science, technology, engineering and mathematics and the acronym STEM only emerged in the 21st century when this interdisciplinary approach was included in the curriculum in the United States[2]. Since then, it has been largely adopted in some parts of the world as a key driver for innovation, economic growth and social development [1]. However, many students around the world are not achieving the expected levels of STEM literacy and competence and are losing interest in pursuing STEM careers. This lack of interest might be related to the effectiveness of their STEM learning experience [2].

Teachers are beyond a shadow of a doubt the most important facilitator of learning and travel companion of any student. They are frequently responsible for introducing to their students the wonders of nature and its implications for our lives. However, this is not an easy task, it requires, on the part of educators, a healthy attitude towards the related content and its rapid evolution, the knowledge of various pedagogical models to attract the interest of their learners, and a good understanding of the interdisciplinary nature of subjects [3]. Educators also face various challenges and barriers to their professional development and in their classroom practice. It can be the lack of resources, of time, lack of interest of colleague to collaborate, lack of feedback and support, lack of recognition, etc.

Students live in an era where their future is constantly being reshaped and reinvented. Their learning needs to be adapted to these changes and adequately prepare them for the unknown world of work they will encounter when leaving school. They often consider school boring and a daily burden, missing completely the fact that learning is a right and eventually enables us to embrace our desired future where dreams will be transformed in challenges and achievements.

In this document we present the current state of the art and suggest possible future directions for the preparation of educators for STEM education. We review why STEM education is so important, present the gaps and needs for teachers' professional development and highlight the role of teachers in STEM education.

What is STEM education?

[1] https://onlinelibrary.wiley.com/doi/abs/10.1002/jee.20256

[2] https://www.britannica.com/topic/STEM-education

According to P21[3], or Partnership for 21st Century Learning, an organization that advocates for the integration of 21st-century skills into education, STEM enables an interdisciplinary and applied approach that helps students develop the skills and knowledge necessary to solve real-world problems. The overall methodology fosters critical thinking and problem-solving skills as well as empowering learners to be creative and innovative while tackling real-world challenges. STEM education is more than each of its component subjects handled in isolation; it encourages educators to jointly deliver their curriculum content while exploring the interconnectedness of the subjects and exposing learners to situations that are closer to their daily life experiences.

STEM can be delivered by exposing learners to hands-on activities, project based-learning experiences and by involving students in collaborative work with their colleagues and whenever possible with stakeholders of the community. STEM learners are encouraged to engage in experimental work, to generate their own hypothesis, design their own experiments and propose solutions to the challenges at hand. STEM nurtures students' curiosity while promoting a deeper understanding of scientific and technological principles and concepts. Students exposed to such a model for learning will be better prepared, with the necessary skill set to embrace future challenges and become drivers of innovation.

What are the skills a STEM educator should have?

Although the concept of STEM education has been circulating in the world of education since 2001, not many teachers currently integrate the methodology in their teaching. There are several reasons for that. According to Margot et al. [4] the implementation of the STEM methodology is hindered by educators not appreciating its potential and finding it a pedagogical challenge. They do not understand how to properly embrace interdisciplinary learning while delivering curriculum content. The pressure of preparing students for the summative assessments, peer pressure, etc. also present barriers. It is common to find among educators an incorrect perception of what STEM learning really means. Often schools will claim that their students are being exposed to STEM learning but, the experience is not delivered in an interdisciplinary manner, but each subject is taught in isolation, which defeats the purpose of truly interdisciplinary STEM education.

Many teachers feel unprepared for a proper implementation and often lack motivation due to lack of time, resources, materials support etc. [5]. The best course of action to ensure the adoption of the methodology is by properly training, supporting and empowering educators to adopt STEM as a way to facilitate the delivery of content related to specific subject areas. Actions should focus not only on training in the specific concepts and pedagogical models but also on providing support to implement it in real classroom situations. The involvement of other colleagues and support from the school leadership is equally important to ensure a proper adoption and the involvement of students in real STEM learning opportunities.

To prepare an educator to adopt the STEM approach a set of skills needs to be in place. It is not only the knowledge of the related curriculum content topics, but also the understanding on how to inspire and motivate students to learn about different topics and have the resilience and persistence to embrace the proposed challenges. Some of the skills that should be part of a STEM educator profile include:

- A solid understanding of the subject matter being delivered. An in-depth understanding of the scientific principles, concepts, digital apps and technology applications.

[3] https://www.battelleforkids.org/networks/p21/frameworks-resources

- Knowledge on how to adopt an inclusive and diverse attitude, to embrace the different learning styles of the students, and a good understanding on how to foster critical thinking and problem-solving skills in all their students.
- A good understanding on how to encourage experimental learning through project-based learning activities and how to integrate real-world situations into the students' STEM learning path.
- Good communication skills, allowing the presentation of complex concepts in a clear and understandable manner.
- Being prepared to embrace the unknown and to update their knowledge and experience on the use of the technology/software applications or integration of innovative developments emerging in the STEM field.
- Being familiar with digital tools and resources to enhance students learning experience including virtual simulations, online labs, interactive platforms, etc.
- Being able to promote teamwork amongst their students and capable of facilitating collaborative work.

What are the skills a STEM learner should acquire or improve?

A true STEM education should increase students' understanding of how things work and improve their use of technologies [3]. Students should develop the following [6]:

(1) Knowledge, attitudes, and skills to identify questions and problems in real life situations, to explain the natural and designed world, and to draw evidence-based conclusions about STEM related issues.

(2) An understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design.

(3) an awareness of how STEM disciplines shape our material, intellectual, and cultural environments

(4) A willingness to engage in STEM issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen.

In the following we will pursue a more in-depth understand of the state of the art in the field, the needs of educators and the challenges they face. Plus, the challenges encountered creating and delivering professional development opportunities. We will review some current trends and give our recommendations.

5.2. Background analysis

Why is STEM education so important?

A STEM-skilled workforce is more prepared to drive innovation, to promote economic growth and contribute to sustainable societal development. The current challenges faced by our society require from all of us a set of skills that can eventually lead us to a more fair and sustainable future. STEM education fosters the development of critical thinking, creativity, problem-solving and innovation among other important key skills to ensure humanity is able to develop a high level of scientific understanding and are able to engage in an informed way with the challenges of a rapidly changing world.

A sustainable future for our planet will depend on a global change in the attitudes humans adopt towards our planet and the preservation of the conditions necessary for survival. Many of these changes will certainly depend on development in STEM fields, in their transformational technological advances.

The preparation of the future generations with an effective STEM education program will greatly depend on the preparation of educators to properly provide a learning path to their students that uses an interdisciplinary approach and engages them in deep and meaningful learning experiences.

According to Tyler [7], an educator's level of preparedness to deliver STEM learning experiences greatly impacts the students' learning outcomes and career choices. The paper presents results pointing to direct and indirect effects of a well-prepared STEM instructional designer and the students' STEM knowledge and skills achievements.

The active participation of relevant community stakeholders, in the preparation of STEM professional development can certainly lead to innovative approaches to teacher training, adopting and adapting real research experience to the students learning path. A good understanding of educators' fears, barriers and opportunities can greatly help the design of efficient interventions and eventually lead to the continuous professional development of prepared and self-confident STEM educators.

What is the state of the art of STEM education?

Global challenges and the fast growth in technology and associated innovations makes STEM education a global priority. Preparing students with the necessary knowledge and the necessary skills is now of the uttermost importance. In classrooms nowadays are sitting the future drivers of our planet, the ones who will find themselves living and working in a complex and rapidly changing world [1].

However, the implementation of the necessary measures and the level of education, in particular STEM education is significantly below what is expected in the 21st century. In Europe there is a significant skills deficit in STEM subjects compared to other regions of the world[4].

Another worrying reality is that STEM disciplines in schools across Europe continue to be delivered in isolation and not in an interdisciplinary format[5]. Professional development interventions are necessary in order to empower educators to collaborate and deliver a genuine interdisciplinary STEM learning experience to their students.

If we consider the latest results of PISA [8], only one in four students reached the desired level in science and mathematics, where they demonstrate that they have the necessary competencies to embrace real life challenges and solve problems in the STEM domain. Only one in five reach a level where they can creatively and autonomously apply their knowledge and skills to a wide variety of situations. The same survey reports a low

[4] https://www.euractiv.com/section/digital/linksdossier/the-future-for-stem-in-europe/

[5] https://steamit.eun.org/

level of interest and motivation from students in pursuing a STEM career, a very worrying result if we consider the challenges ahead for the sustainable future of our planet.

All these reports and results are clearly indicated that STEM education should acquire a new level of importance within the educational arena in all countries and one of the key ingredients to achieve this is the improvement and effectiveness of STEM professional development programs for teachers.

What are the gaps and needs in teacher professional development for STEM education?

Many pre-service teachers are not prepared to integrate STEM curricula in their students' learning experience. This is often a consequence of a lack of effective training and exposure to authentic STEM activities in their preparation courses [9]. This is perhaps the most important gap to be filled, the proper preparation of pre-service teachers to become proficient and confident facilitators of STEM learning for their students. One way of addressing this gap is to involve these pre-service teachers in STEM-based activities which has the potential to increase their interest and motivation in STEM teaching and learning [10].

Lack of proper STEM professional development for educators is a recognized issue in education [11]. The STEM approach has been largely adopted in the USA and as a consequence the majority of papers analysing its impact and importance focus on USA based studies. However, our constant contact with educators from Europe and other parts of the world, via multiple training sessions, demonstrate that in many countries, the problems are the same.

In addition to the poor preparation for implementing STEM practices in classrooms is the challenge for STEM teachers to stay up to date with the technological developments in the area and the rapid changes in both technology and the content of the field due to new research result and the inherent innovative nature of the subjects. In-service teachers, especially the ones that were not exposed to hands-on experience on how to facilitate STEM learning, tend to have a more negatives beliefs and attitudes towards STEM disciplines and tend to have a greater gender bias towards future professions in the area for their students [12].

According to Bybee [3] there are several gaps and needs related to STEM education, including the lack of a clear vision that can guide the design and delivery of pre-service and in-service educators. Lack of content and practices of STEM disciplines that can support the adoption and integration of STEM in classroom. Often the lack of ready to use materials that are an appropriate fit for the curriculum is mentioned as a challenge along with a paucity of assessment strategies that support the integration of STEM across different grade levels and contexts [13].

The role of teachers in STEM education

Educators play a major role into facilitating STEM learning to their students. As such it is of the uttermost importance that they are well prepared and confident to properly adopt the methodology. Needless to say, the confidence of educators, the quality of their methods and a successful STEM experience for the students are a key influence on students' achievements in STEM fields and on the likelihood that students will pursue a career in STEM. According to Bybee [3], STEM teaching involves not only the proper integration of science, technology, engineering and mathematics concepts in ones learning narrative, but it also requires the active involvement of students in their learning experience by solving problems, following the scientific method, thinking critically, collaborating with their colleagues and improving their communication skills. Teachers have to adopt a variety of instructional strategies, ensure that personalisation and differentiation are in place, that assessment is in line with the learning vision associated to STEM and that each student will improve their competence profile in an autonomous and profound manner.

Teachers have to be proficient not only in the chosen methodology but also in providing constant guidance and feedback to support the students learning and skills development according to their needs. A positive learning environment will foster students' self-confidence, increase their curiosity and boost their resilience and persistency towards facing the presented challenges.

5.3. Work carried out

In this section, we will describe the work done by other researchers and practitioners in the field of teacher preparation and support for STEM education. A recent study [14] presents numerous contributions of researchers, educators and institutions to the field of STEM and highlights the importance of integrating real-world applications and problem-solving into teacher training programs. Engaging teachers in authentic scientific investigations can better convey the relevance and excitement of STEM subjects to students. The same study evaluated the effectiveness of professional development programs for STEM educators and concluded that intensive training greatly improves teachers content knowledge and instructional practices, with a measurable improvement of students' learning outcomes.

Bringing genuine experiences for educators and learners via the organisation of collaborative efforts between higher education institutes, industry, schools and other relevant stakeholders greatly enhances the learning experience and helps bring cutting-edge research and emerging technologies to school classrooms, bringing as such students closer to the reality of their future careers in STEM areas [15,16].

The globalisation of our economies is also an aspect of our daily lives that can't be excluded from the school environment. In fact, cross-borders collaboration can greatly enrich educators' professional development through the exchange of best-practice, sharing of concerns and solutions adopted to overcome existing challenges and barriers. Innovative teaching strategies frequently emerge in such collaborations. The globalisation of our economies will also require that future generations have an increased awareness about different global perspectives in STEM and different approaches on how to solve complex world problems with solutions that are localised and firmly rooted in social and environmental sustainability and justice [17]. We may then conclude that global STEM education is desirable and necessary for a healthy and sustainable future. It is in fact viewed by the United Nations as "an enabler for development and peace" [18].

We should not overlook the importance of STEM Communities of Practice. They can act as the drivers to bridge the divide between researchers and educators. Communities of practice that are not restricted to educators but on the contrary include several stakeholders who jointly collaborate in the design of the STEM learning activities in schools, and equally benefit from these efforts, are a powerful way to foster innovation, dissemination, and sustainability of STEM education reform [19].

The use of OER (Open Educational Resources) can greatly support educators in keeping up to date in current results and having access to recent materials to deliver content to their students. Educators can adopt and adapt OERs to their current practices and use them to a variety of learning environment and students' specific needs [19]. For STEM areas, where changes are happening very fast, OERs are an optimal way to ensure the integration of up-to-date educational materials. They are also an opportunity to integrate materials that are relevant to the specific country or even school location. OER are also an optimal choice to help educators promote differentiation and personalisation in their classrooms.

Effective professional development of educators with key elements are halfway for a success STEM learning implementation. According to Darling-Hammond et al. [2] effective professional development should include the following elements:

- Content Knowledge focus (up to date content available)
- Pedagogical knowledge (how to facilitate STEM learning)
- Use of student-centred methodologies such as modelling, Inquiry Based Learning, etc.
- Ready to use activities such as laboratory experiments and problem-solving activities as a way to enhance teachers understanding of the STEM approach and improve their motivation to adopt the methodology.
- Organisation of interdisciplinary collaborative work and beyond school collaboration.
- Coaching and expert support plus instructional strategies to facilitate STEM learning are essential to boost educators' self-confidence and empower them to implement the approach.
- Co-creation of activities and reflection on goals achieved and lessons learned are also an optimal driver for the integration of STEM in educators' practices.
- Aligning the professional development with the curriculum goal and school contexts.
- Improve educators' expertise in conducting scientific investigation and designing project.
- Involve teaches in solving real-world problems using STEM methodology.

In addition to the lack of appropriate education and training educators also face structural challenges. These have been identified by several studies and need to be considered in any professional development initiative aiming to bring STEM education to the classroom. The key challenges are:

- Lack of preparation time.
- Lack of resources.
- Absence of school planning.
- Lack of specific equipment needed for the implementation of certain STEM projects.
- Students' preparedness to embrace STEM methodology and to work on the problems and challenges presented. This can spark negative attitude of learners towards STEM learning.

5.4. Current trends

There are some interesting trends emerging in the field of STEM education. These trends include integration of hands-on and project-based learning, emphasis on the digital transition, and a strong effort into gender equity, inclusivity, diversity and accessibility within STEM classrooms. Furthermore, as a result of the implementation of the DigiCompEdu[6], the European framework for a digital competence profile for educators and learners, educators are more proficient in accessing and assessing Open Educational Resources (OERs) and more open to

[6] https://joint-research-centre.ec.europa.eu/digcompedu_en

collaborate with their peers at a global level, in Europe, as a result of the multiple opportunities provided by the Erasmus+[7] program for schools and educators.

The integration of real-world applications and problem-solving into teacher training programs is a game changer in the preparation of educators. To involve their students in solving real problems, for instance, in their local community. This is a methodology, for instance, used in projects adopted by the Open Schooling Methodology, where schools become a central hub for the community and joint efforts are built towards the well-being of its members. Students adopt the role of change makers in their communities and with the support of their educators, choose the challenge to be addressed, propose and materialise solutions and finally share their success stories with all members and stakeholders of the community [20]. Educators participating in such projects receive training on the adoption of STEM methodology for their classrooms and how to use the Design Thinking for Education methodology to support their students. This model of training and support for educators greatly improve the teachers' confidence and boost the student's motivation for STEM subjects. These projects also greatly benefit from the involvement of research institutions, industry, policy makers and other relevant stakeholders.

The time has come for the education sector to rethink traditional curriculum boundaries, where knowledge and skills are segregated according to subjects. The International Bureau of Education [21] has led a series of discussions to identify and make explicit the competences that transcend knowledge areas with a view to assisting member states to develop competency-based curricula that prepare young people with the required competences to live sustainable, fulfilled and healthy lives in the rapidly changing world of the 21st century. The project provides a conceptual framework that defines the key competences and indicators for integrated STEM education in the 21st century. The whole view starts from the Big Ideas of Science [22] and moves forward to present a series of competencies starting from STEM knowledge, STEM skills and STEM attitudes and values.

The project also suggests some assessment tools that can measure students' competences in four domains of integrated STEM education: scientific inquiry, mathematical reasoning, engineering design, and digital literacy. The project also provides guidance and support for teachers and policymakers on how to use the assessment results to improve integrated STEM teaching and learning. The study proposes a shift from expository teaching to student centred STEM learning (Table 5-1).

[7] https://erasmus-plus.ec.europa.eu/

Table 5-1: Shift from expository teaching to student centred STEM learning

Shift From	Shift to
Learning about topics	Engaging with phenomena to develop explanations and solve problems
Focusing primarily on "content" knowledge	Equally valuing STEM practices and disciplinary knowledge to build future competence
Teaching subjects in isolation	Teaching through challenges that reflect interdisciplinary connections
The teacher delivers knowledge	The teacher strategically supports students to build knowledge, promoting the development of student agency and critical and creative thinking
Students learn individually	Students learn through interactive dialogue and group collaborations
Considering knowledge and procedures as objective and value free	Incorporating values and futures thinking
Using assessment as judgement	Using assessment to inform instruction

The shift in assessment implied by a curriculum that is focused on constructive and interactive learning involves a significant shift in assessment practices, illustrated in Table 5-2.

Table 5-2: New assessment methods

Assessment is no longer:	For a competence approach, assessment now is:
• something that measures only what is easy to measure • something that happens only at the end of a task or topic or term. • only tests and examinations • used only to judge or categorise learners • focused only on the past—on what has been learned • used only to categorise and limit the number of students who are assigned access to limited resources, e.g., to University, College, or a new school	• focused on what matters, to help young people make progress in learning. • integrated into the planning, teaching, learning and evaluation process. • primarily formative and concerned with enhancing progression in learning • structured to offer opportunities for learners to demonstrate progress in a range of knowledges and practices • focused on building from what has been learned in the past to inform what should be learned in the future. • purely summative only when used to assign access to limited resources, e.g., to University, College, or a new school.

The whole idea is very interesting, but a more global approach needs to be taken in order to understand how to transform the adoption of interdisciplinary learning at a global level, considering the specific curricula of each country and location.

STEM has also a very important role in the development of a Circular Economy [23] where products are designed to produce as little waste as possible during the entirety of their use cycle, including their ability to be reused or recycled. STEM disciplines can empower learners to be active participants in the design and development of sustainable technologies, that promote the efficient use of resources and a smart way to reduce waste. Experiments can take place in a classroom or in a school maker space, for instance, where materials are tested and chosen according to their durability. Resources can be chosen according to the possibility of being recyclable and for requiring less energy to be produced. Learners can explore solutions that are not only durable and recyclable but also locally produced and environmentally friendly. Exposure to such thinking and attitudes has the potential to greatly impact the future of industry. Remember that the next generation of the work force is currently sitting in schools in every country.

Data analysis should be an integral part of students' training preparing them to identify appropriate materials and predict their impact in terms of waste generation, on the environment and in the economy in general. Programming and robotics are also a key element of STEM learning enabling students to enhance the reach of their experiments and the integration of technology in their final outcomes. By working on topics, challenges or problems of their communities will help learners amplify their awareness related to certain topics and expand their learning to their community, often improving the chosen situation or at least ensuring that various stakeholders become aware of the studied situations and possible solutions to mitigate them.

The integration of the design thinking methodology in the STEM integration process is also a source of exploration of successful STEM integration [24]. The marketing methodology has become increasingly important for the development of STEM related solutions and is now attracting adepts in the field of STEM education. The adoption of this methodology in the classroom, in its traditional format (Emphasize, Define, Ideate, Prototype and Test), usually adopted to the development of prototypes or in its educational version (Feel, Imagine, Create and Share) [20] is a great development in recent years, brining students much closer to the reality of the world of work. Needless to say, that professional development programs need to integrate such methodologies in order to boost teachers' confidence in its adoption. Design thinking allied with the adequate teacher support can greatly improve the students' learning experience [25].

As mentioned earlier in this text, there is an intrinsic gender bias related to STEM fields. There are also concerns for historically marginalised students who due to their location or societal status have been prevented from fully engaging with the topic. Teachers should tailor STEM learning through a multicultural lens, enabling rich opportunities to all students, in particular minorities and the historically marginalised. Such inclusive experiences can foster a sense of belonging in the students and reinforce their beliefs in the possibility of a future career in STEM related areas. Recommendations should be made to policy makers for the adoption of a diverse, inclusive and equitable STEM educational program as a path to social justice [17].

Trending technologies should also be integrated in the students learning experiences such as virtual and augmented reality. These solutions are becoming more affordable and accessible to schools and can greatly benefit STEM education. Students can explore virtual worlds and visualise experiments that could not be done in real life, due to its costs or dangerous operations for instance. Augmented reality can bring a different flavour to learning and also become a model for the creation and exploration of possible future solutions.

The integration of Artificial Intelligence (AI) in STEM fields has the potential to revolutionise the way we solve problems and how we approach problems with innovative solutions. The ability to analyse large amounts of information in real time can facilitate the decision-making process. When properly integrated it can make STEM education more appealing and accessible to students [23]. AI can be adopted by students as a travel companion and an optimiser of personalised solutions. It can provide real-time feedback and suggest tools and solutions that can be used in students experiments.

Caution should be taken when analysing and considering the adoption of these current trends in STEM education, firstly, and already mentioned several times, due to the lack of professional development on the integration of these trending features. Secondly due to the cost of emerging technologies and the difficulty many schools might face towards their acquisition and adoption. Last but not least, it is important to avoid these trending innovation and appealing solutions becoming an enhancer of the digital divide that is already faced by students in many parts of the world. The solution is not of course to hold back on their use, the contrary, to adopt it strongly and with a vision of collaboration and cooperation building bridges that will address such challenges.

5.5. Recommendations

Considering that STEM education has a transformative role in equipping future generations to embrace the complex challenges ahead. Knowing that providing quality professional development and support for educators is key to achieve this mission. And considering the current trends emerging at a global level to boost preparations of future leaders of our planet, we present the following recommendations.

STEM learning, in particularly when contextualised, is certainly one of the approaches to be used in educational systems, transforming learners into active problem solvers and change makers for their communities. **STEM knowledge content** is continually evolving, technological advancements are happening every day and students' demographics and future challenges they will face are evolving at the speed of light. Preparing educators to open the pandora box of learning to their students is a very important task. They should be able to integrate students centred methodologies that require students to have hands-on problem solving. Be able to **design and deliver engaging activities** that encourage and motivate learners to actively explore and apply STEM concepts. STEM instruction should be enriched with education technology and students should actively learning during immersive experiences.

Globalisation is an undeniable reality. Fluxes of migrants and refugees are also affecting the dynamics of schools, in Europe. **A diverse and inclusive learning environment** is essential to an equitable STEM education. Professional development programs should incorporate cultural responsiveness and equity-focused pedagogies. This will enhance a sense of globality to the experience of students and will transform diverse backgrounds into cultural enrichment of learning experiences. Furthermore, to enable educators to keep up with the fast-evolving innovations and the challenges they are trying to address, **professional development on content knowledge** should be frequently offered and updated. **Partnerships between schools, industry, research institutes** and exposure of educators to real-world applications should be part of their practical training.

Part of the strategy to deliver curriculum content should go through **digital tools and resources.** They easily enable **differentiation and personalisation** of students learning experiences. Educators should be prepared for the digital transition and be equipped with the necessary competence profile to embrace existing and emerging opportunities opened by the digital world. The use of online platforms, virtual simulations, online laboratories can greatly enrich the students STEM learning experience.

Students should be interested and motivated to solve the challenges and problems presented to them, to test their ideas and give wings to their creativity. Methodologies such **as inquiry-based learning, problem-based learning, design-thinking for education and other methodologies** that invite students to learn STEM content with their hands and minds on should be adopted.

Learners should develop their **collaboration and cooperation skills**, their classroom should expand to inter-classroom collaboration, and if possible, even international joint projects participation. Technological and scientifical development greatly benefits from collaborative efforts. Learning how to collaborate should be an essential part of the student's competence profile at the end of mandatory education [26].

Facilitating STEM learning shouldn't be an isolated action, educators should collaborate with their colleagues from the other subject domains and even conduct intergrade opportunities where students are learning their specific curriculum content while targeting topics that are of their interest and perhaps contributing to solutions existing in their school and local communities. Considering the importance of peer collaboration, **professional development programs should prepare educators to also support their colleagues to embark on the same experience.** Peer-to-peer support for the professional development of teachers is a growing trend as can be seen in studies such as OECD [27].

Considering the typical workload of educators [28]. it is advisable for any STEM education project to **provide ready-made instructional material** that they can immediately use with their students or use as inspiration for their own lessons. School heads should consider allocating **some time for educators to collaborate** with their colleagues in the development of the students STEM activities. In time, this strategy will help educators save time, will soften their learning curve and will hopefully boost their confidence and motivation.

Involvement of the school and local community in the students' learning experience is strongly advisable. Ensuring that they understand the importance and the value of a well-orchestrated STEM strategy and if possible, making the community an integral part of the students learning experience. Co-creators of students' experience are more likely to be accept and enrich students' experiences. **International collaborations** should be often embraced as a mean to boost the creation of a community of practice that will constantly feed good ideas, discuss problems and create best practices. Educators and learners participating in international collaboration opportunities will acquire a growth mind-set that is more open to societal challenges and to acceptance of the difference.

Design thinking should be an approach adopted to better support the school collaborators. Nothing is so powerful than knowing the personal, cultural and social reality of a team, knowing their preferences and needs. This will help local educational authorities or school management to establish a solid professional development plan that will target directly their staff needs and use their strengths to further enrich the school's vision and mission.

Teaching and non-teaching staff should be involved in **summer professional development programs.** These are great opportunities for them to interact with colleagues from other countries and establish new partnerships. The Erasmus+ programme is an excellent source of opportunities and funding for educators to participate in bespoke training programmes designed to support the use of new technologies including AI supported activities such as those developed by the Discovery Space Project.

Teachers should have the opportunity to be constantly **exposed to real world experiences** by collaborating with several stakeholders in the community. Teachers' placements in industry, research facilities, policy making institutions, etc should be a constant opportunity transforming their views and eventually bringing their students learning experiences closer to the real world.
Inclusion, diversity, equity and accessibility should be a strong part of the professional development of educators, connected to integration of STEM as an interdisciplinary learning solution for their students.

Discovery Space in the cutting edge of current trends

Discovery Space is bringing STEM to a new level of innovation by the integration of AI-Enhanced classroom to promote deeper learning. It aims to transform traditional lessons and classrooms into innovative environments, enabling scientific exploration and supporting the development of students' key skills while proposing a unique mode of assessment of their progress and learning results.

The project is bringing AI to the reality of student's learning experience enriching their projects with VR/AR interfaces, introducing virtual and remote laboratories and introducing a completely new mode to assess students' cognitive skills. A carefully designed learning environment will integrate these different possibilities while exposing students to inquiry and problem-solving opportunities. Along with these facilities a series of STEM scenarios will be made available facilitating the adoption of Discovery Space by educators. A well-designed training academy will be organised with the aim to prepare educators to adopt the Discover Space AI-enhanced classroom.

Discovery Space training academy will target STEM education from its grass roots and will carefully bring educators towards its adoption and adaptation to their classroom. The scenarios developed by the project will help educators with up-to-date content knowledge and will provide the means to support them in the construction of their own interdisciplinary scenarios and integrate AI as a supporting tool to the design of their own lessons. Educators participating in the project will be invited to collaborate with other colleagues and schools and invited to engage other stakeholders from their community in the enrichment of the students' learning experiences. Another part of the Discovery Space academy will be the integration of the design thinking and universal design for learning methodologies, enhancing the motivation and participation of students and better preparing educators to use and adapt these important methodologies.

Discovery Space will bring student's assessment to a whole new level by activating conversational agents and adopting AI as a mean to support educators in the validation of students learning progress.

5.6. Conclusions

Schools' reforms are taking place across the world. The correct recipe is highly dependent on local circumstances, community and students' needs and preferences and a vision for a better future. No change can occur without a vision to prepare students for a different world, where priorities are changing every day, challenges are emerging constantly and solutions to face them must become available very fast. This reality can't take place if innovation is not happening in classrooms across the world. Students need to be motivated and empowered to become change makers of their generation. This can only be achieved if educators become a top priority and key players in the renewal of education. STEM learning among other important interdisciplinary experiences are key drivers of this reality. By providing professional development for educators to embrace this reality we are bringing a better future closer to reality and enabling the empowerment of the next generation of scientist, engineers, creative and critical thinking problem solvers.

Collaborative efforts between different stakeholders such as educational institutions, research infrastructure, policy makers and other stakeholders is a vital element for a success story for school reforms. In this paper we have presented the current trends and some recommendations for future actions that support STEM education. We also presented a few recommendations and highlighted how Discovery Space provides an important contribution to the development of the field. The next steps will determine the best path for a successful trajectory. Discovery Space is targeting an emerging field with a very important role in the construction of sustainable development for mankind.

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6. Development and operation of extended reality laboratories for educational practices

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6.1. Introduction

The United Nations has designated quality education as its 4th sustainable development goal [1]. The year 2020 witnessed the rapid spread of the COVID-19 pandemic, leading to the temporary closure of schools in many countries, affecting over 91 percent of students worldwide. As a result, there was an urgent need to incorporate online technology into education. Numerous educational tools were swiftly developed and implemented to support remote learning during this challenging time [2-4]. However, the transition to remote education presented difficulties for some students and teachers who were unprepared for this new learning scenario. Consequently, it became crucial to identify and utilize more effective educational resources to bridge the gap caused by the pandemic and to equip people for the realities brought about by these special circumstances.

One of the solutions to the above challenge, as well as the key objectives under the quality education goal is to significantly increase the number of youth and adults equipped with relevant skills, including technical and vocational expertise, to enable them to secure employment, decent jobs, and foster entrepreneurship. Globally, there is a noticeable shortage of professionals in STEM (Science, Technology, Engineering, and Mathematics) fields, mainly attributed to a lack of interest in these disciplines and limited educational opportunities for aspiring learners [5,6]. The Organization for Economic Co-operation and Development (OECD) highlights that numerous students perceive STEM subjects as uninteresting and struggle to grasp the concepts presented by their teachers [7]. According to the OECD, the lack of practical activities during STEM classes is a major factor contributing to students' difficulty in understanding concepts. This shortage often results from the absence of science laboratories in many schools, particularly in rural and disadvantaged districts, where there is a lack of infrastructure and adequate equipment for educational purposes [7,8]. The absence of proper equipment denies students the opportunity to engage in scientific practices, leading to disinterest in pursuing careers in related fields as they perceive these subjects as unsuitable for them.

6.2. Background analysis

In this context, New Information and Communication Technologies (NICTs) offer significant benefits to education with learning technologies. The learning technologies enable students to access information in diverse ways, providing remote opportunities to practice and reinforce concepts from their classes [7]. Resources such as simulations, Extended Reality (XR), and Remote Laboratories (RL) provide students with a practical understanding of their coursework [9], fostering greater interest in these subjects as they overcome difficulties through experimentation [10]. This paper aims to analyze the state-of-the-art frameworks that integrate XR with RLs, with the goal of defining a new general architecture that facilitates the development of educational platforms by RL developers. Within the context of XR, two main concepts exist: Augmented Reality (AR) and Virtual Reality (VR).

AR involves overlaying meaningful interactive information onto a live video stream, creating an enriched visual experience for users [11]. When integrated into education, AR provides students with a highly interactive learning experience. Numerous publications have demonstrated the successful use of AR in educational activities [12]. Wen [13] highlights the utility of AR across various stages of students' academic journeys, from kindergarten to higher education. Ibanez et al. [14] showcase an application of AR in secondary education for STEM subjects, where this technology proved effective in motivating students to pursue STEM-related fields in the future.

On the other hand, VR entails the use of three-dimensional models and virtual environments, engaging users through specialized devices [15]. VR holds great promise as an educational technology, offering various learning benefits. The adoption of VR as a learning tool has challenged traditional notions of learning environments. Several authors have published papers on the application of VR in STEM [16-19], reaching the consensus that this digital resource is increasingly accessible and valuable in the educational realm [10].

An RL, is a physical laboratory accessible from a distance through a secure web system, allowing users to remotely run specialized equipment with minimal risk [20]. In the case of an RL, the same interactive experience as in a conventional laboratory takes place, but with the assistance of remote infrastructure. This interaction typically occurs through a web interface, where the laboratory is live streamed using a webcam and presented on a website with user controls, enabling them to observe or manipulate experiments in real-time. To draw an analogy, the webcam serves as the student's eyes, while the mouse and keyboard function as their hands. This novel layer bridges the gap between the user and the laboratory equipment, facilitating the transmission of user actions and receipt of sensory information from the equipment [21].

Nevertheless, a primary concern with RLs is their limited immersion, as they typically offer no more than a real-time video stream for students to observe and occasionally interact with. Consequently, incorporating XR technology can address this immersion deficit by enhancing reality through augmented elements or bringing the experiment into a virtual reality environment with authentic data. Then, XR refers to a collective term that encompasses AR, VR, and MR technologies. These immersive technologies merge the physical and digital worlds, providing users with a multisensory experience that blurs the lines between real and virtual environments. XR laboratories leverage these capabilities to create an enriched and interactive learning space where students can actively participate in educational simulations, experiments, and experiences.

By integrating AR, VR, and MR technologies into traditional learning environments, students acquire new dimensions of exploration, fostering deeper understanding, and encouraging active engagement with complex subject matter. From scientific experiments in virtual worlds to historical recreations in augmented realities, XR laboratories present diverse applications across various disciplines. The benefits of XR laboratories extend beyond traditional classroom settings, allowing students to access remote resources, collaborate with peers globally, and gain hands-on experience in fields that were previously limited by physical constraints. As technology continues to advance and become more accessible, XR laboratories hold the promise of transforming education and empowering learners to navigate an ever-evolving, technology-driven world.

6.3. Work carried out

Building on the comprehensive background introduction and drawing from the insights presented in the paper by Nardi et al. [22], our analysis now shifts towards exploring the most relevant and recent architectures for XR labs. Our aim is to identify intrinsic characteristics of XR, development requirements, and challenges that must be addressed. While the specialized bibliography offers various references, we have honed in on two primary architectures for extended reality labs based on their impact. Trentsios et al. [23] propose an architecture that maximizes the potential of current infrastructure and compatible front ends, catering to both desktop and VR-based modes (Figure 6-1). They introduce two visualization methods to offer varying degrees of immersion and independence from specialized virtual reality hardware. The first method utilizes a combination of 360-degree images, replicating the physical laboratory environment. In contrast, the second method presents the RL as a 3D model-based virtual replica. Both approaches utilize the Unity engine, ensuring seamless utilization of protocols and algorithms. The authors emphasize Unity's advantage in cross-platform compatibility.

The work by Trentsios et al. exhibits several advantages, including compatibility with web browsers and VR equipment, enhancing accessibility. Additionally, the architecture is developed with current technologies, reducing the risk of obsolescence. However, certain limitations merit consideration. The architecture is tailored to a specific RL scenario, restricting its universality and adaptability to diverse contexts. Furthermore, the focus solely on VR may neglect the inclusion of AR remote labs, thereby limiting its potential to accommodate different technologies. Additionally, the integration of Labview with Unity for communication to RL data may bring some disadvantages, such as hardware compatibility, frequent maintenance, and a learning curve associated with Labview, which, though user-friendly, may necessitate proper training and support.

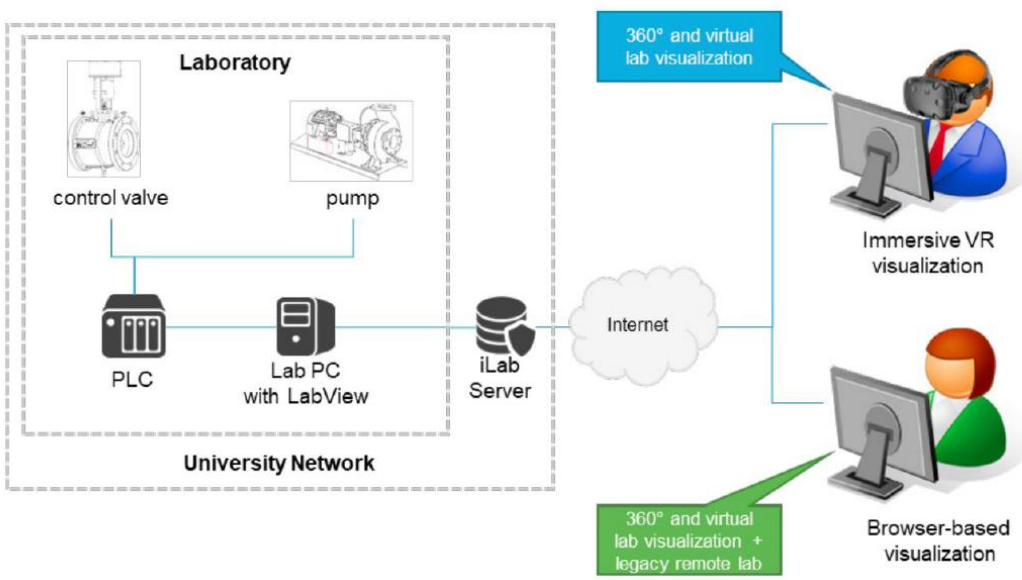

Figure 6-1: Tensions et al.'s architecture

Nicolete [24] developed a specialized architecture for an Augmented Remote Laboratory, harnessing the capabilities of Unity and C#. This mobile application incorporates AR technologies through the Vuforia framework, facilitating the integration of AR markers. By leveraging Vuforia's API, the app detects markers using the device's camera and generates corresponding 3D models on the screen. To enable bidirectional interaction between AR and the RL's hardware, a communication protocol was devised, establishing a connection between the AR app and the RL. The communication process utilizes a web sockets system, allowing user interactions in the AR app to trigger the transmission of information packages from the client to the server. The server then processes and applies the changes in the real experiment accordingly. This implementation relies on SocketIO, a JavaScript library, and a C# library in Unity, facilitating seamless real-time communication between clients and servers over the web. A prototype based on Nicolete's architecture is illustrated in Figure 6-2.

However, Nicolete's architecture for AR remote labs exhibits certain disadvantages. Firstly, its scope is limited to AR remote labs, lacking universality to accommodate other XR technologies. Moreover, the reliance on an external framework and the use of websockets introduce potential issues related to network stability. Unstable network conditions may compromise the user experience, leading to delays or disruptions in the RL interaction. Furthermore, there are valid security concerns, especially when handling sensitive data or conducting experiments requiring stringent access controls. Implementing proper security measures becomes imperative to address these risks and ensure the integrity of the XR laboratory environment.

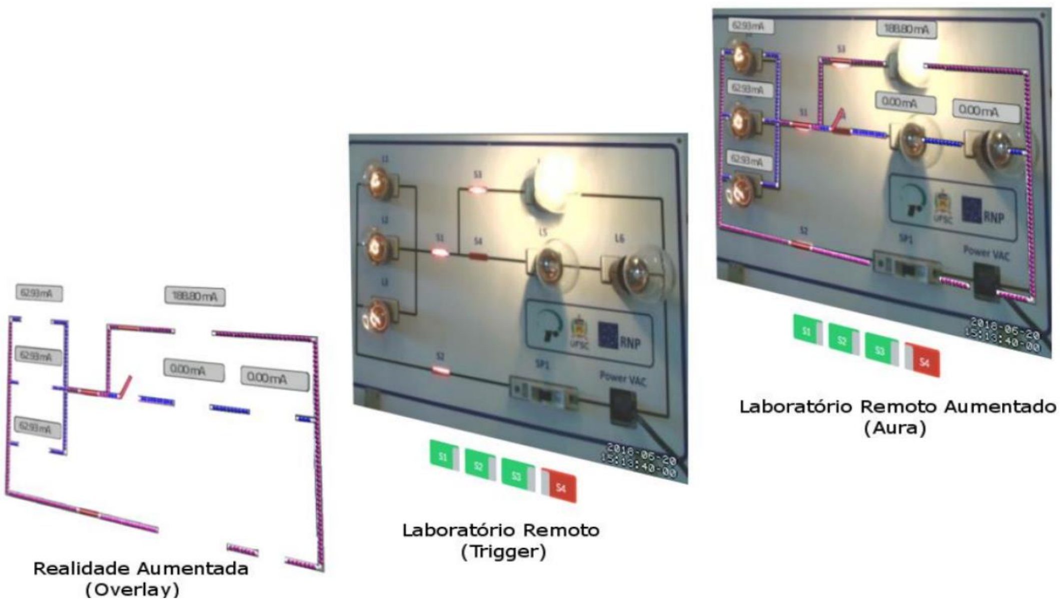

Figure 6-2: Nicolete's architecture

6.4. Current trends

The dynamic landscape of education and training has witnessed a transformative force in the form of XR Online (i.e., RL and VL) Labs, where the fusion of AR, VR, and MR technologies has unlocked a new area of immersive learning possibilities [25]. These labs have gained traction as educators seek innovative ways to enhance student engagement and comprehension [26]. Currently, the areas of research and development being carried out in the field of online laboratories are as follows:

1. *The Rise of Immersive Learning*: As learners increasingly demand engaging and interactive experiences, XR Online Labs have risen to the occasion, fostering deeper understanding and retention through immersive learning [27].
2. *Diverse Applications Across Disciplines*: XR Online Labs are being integrated into diverse educational domains, including STEM, healthcare, architecture, and engineering, showcasing the practical applications of XR technology in real-world learning scenarios [28].
3. *Collaborative XR Learning Environments:* The transformative impact of virtual collaboration in XR Labs has been witnessed, enabling students from different locations to interact, share ideas, and conduct experiments together [29].

4. *Real-time Data Integration and Analysis:* XR Online Labs leverage real-time data integration and analysis, enabling learners to interact with authentic information and make data-driven decisions [30].
5. *AI-driven Personalization in XR Labs*: Incorporating AI algorithms into XR Labs personalizes learning experiences based on individual preferences and performance, catering to diverse learning styles [31].
6. *Gamification and XR Labs*: The fusion of gamification elements with XR Online Labs enhances motivation and engagement, transforming learning into an enjoyable and rewarding experience [32].
7. *XR Labs for Soft Skills Development*: XR Labs play a significant role in fostering soft skills development, including communication, collaboration, and problem-solving, effectively nurturing these essential competencies [33].
8. *XR Labs for Workforce Training*: Industries are increasingly adopting XR Labs for employee training, bridging the gap between theoretical knowledge and practical application, effectively upskilling and reskilling the workforce [34].
9. *Accessibility and Inclusivity in XR Learning*: Efforts are made to ensure XR Labs are accessible and inclusive for all learners, regardless of their abilities, by designing XR experiences that accommodate diverse needs [35].

XR Online Labs represent a paradigm shift in education, providing learners with unparalleled immersive experiences. As XR technology continues to advance and become more accessible, educators, researchers, and policymakers must collaborate to unleash the full potential of XR Online Labs, shaping a future where immersive learning is a ubiquitous reality.

6.5. Recommendations

The below provided requirements are characteristics that are fundamental for designing XRs, including challenges and issues to be considered while designing them. The main requirements for the development of successful XR Labs are listed as follows:

- Universality: most of the laboratories were based on architectures that specifically concern AR or VR, and that considered specific technologies that would eventually become outdated, or that could not be so easily replicated in other online labs.
- Low-cost: some XRs are hard to replicate because they use technologies with a paid license, or expensive gadgets.
- Up to date: several laboratories became, or risk becoming, obsolete, because they use technologies that would soon be out of date.
- Multilingual: some of the laboratories are only available in specific languages, rendering them hard for developers to replicate, and unattainable for some users.
- Usability: most studies reported poor or negligible XR usability. Improving XR usability is vital for effective and engaging learning.
- Availability: this is related to universality and being up to date, because several XRs are no longer available, because technology became obsolete, or the developers did not maintain the availability of Remote Labs or Virtual Labs.

6.6. Conclusions

In conclusion, the development and operation of XR laboratories have opened exciting possibilities for educational practices, offering immersive and interactive learning experiences for students. Through the integration of AR, VR, and MR technologies, XR laboratories have enhanced student engagement and comprehension across STEM disciplines.

The implementation of XR laboratories has shown promising results in bridging the gap between theoretical knowledge and practical application, fostering a deeper understanding of complex concepts. Learners have benefited from remote experimentations, virtual simulations, and real-time data integration, which have proven to be valuable tools for enhancing knowledge retention. Furthermore, collaborative XR learning environments have helped to eliminate geographical boundaries, enabling students from different locations to collaborate, exchange ideas, and conduct experiments together. The integration of AI has allowed for personalized learning experiences tailored to individual preferences and learning styles.

Despite the evident benefits, challenges such as cost, technological barriers, and ethical considerations need to be addressed to fully leverage the potential of XR laboratories. Ensuring accessibility and inclusivity remains essential to accommodate diverse learners and promote equal opportunities for all. As XR technology continues to evolve, the future of XR laboratories holds even more promise, with trends like gamification, cloud-based platforms, and extended haptic feedback shaping the immersive learning landscape. It is crucial for educators, policymakers, and researchers to collaborate and explore the full potential of XR laboratories to revolutionize educational practices and prepare learners for the demands of the 21st-century digital world.

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7. Emerging technologies of the future in the learning process: AI as an educational tool

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7.1. Introduction

AI has been considered as an enabler to many of education's core challenges which range from the lack of qualified teachers to student underachievement and to the growing achievement gap between rich and poor learners [1-3]. This extensive range of potential applications raises the need to consider multiple issues: the aims of using AI in education, where it is used, by whom, how it is operationalized, how it works and so on [4]. Especially generative AI technologies, such as large language models, have the potential to revolutionize much of our education teaching and learning [5].

AI as an educational tool offers a wide range of possibilities. Intelligent tutoring systems can provide personalized guidance, adapt content to individual learning styles, and identify knowledge gaps in real-time. Virtual reality and augmented reality technologies can create immersive learning environments, enabling students to explore complex concepts and subjects in an interactive and engaging manner. AI-powered chatbots and virtual assistants can provide immediate feedback and support, fostering independent learning and empowering students to take ownership of their education.

Furthermore, AI can also assist educators in administrative tasks, such as grading assignments and analyzing student performance data. This automation of routine tasks can free up valuable time for teachers to focus on personalized instruction and mentoring, strengthening the teacher-student relationship and fostering a more collaborative learning environment.

Although the boundaries are not rigid, the connections between AI and education (AIED) have been grouped under four headings: 'Learning with AI', 'Using AI to learn about learning', 'Learning about AI' and 'Preparing for AI' [6]. In this deliverable we focus on 'Learning with AI', which involves the use of AI-driven tools in teaching and learning; specifically, we concentrate on the use of AI to support learners and we do not address the use of AI to support administrative systems or the use of AI to support teachers. We investigate emerging AI technologies, explore the potential opportunities and challenges associated with their implementation and draw recommendations for their uptake in Discovery Space.

7.2. Background analysis

There is an increasing interest in the use of AI in tasks that go beyond the simple, though vague and controversial, idea of automating teacher tasks to the radical transformation of augmenting human learning [7]. Two alternative approaches have been used in order to develop AI systems for education, which follow the overall approaches to AI: "symbolic" or knowledge-based and "sub-symbolic" or data-driven [7,8].

The symbolic approach focuses on encoding principles of human reasoning and the knowledge of experts and has led to the development of expert systems. It takes inspiration from programming languages and computational logic. In symbolic AI, large knowledge bases and rules are built to describe how the world related to a given problem is working. By using such rules, it is then relatively straightforward to build systems that can support reasoning. In this case, learning is a major hurdle since the creation of rules and new knowledge can be quite laborious.

The data-driven approach was inspired by the way the human brain is structured and allows drawing inferences from large amounts of data. Machine learning approaches can learn without being explicitly programmed and have been impressively successful in topics where human expertise does not exist or humans can't explain their expertise, but their application usually requires massive amounts of data. Recently this approach has produced impressive results in areas like image processing, language translation, robotics, and many others.

In general, one can distinguish four use-cases of AI in education [9]: student teaching, i.e., using AI to teach students (student-facing); student supporting, i.e. using AI to support student learning (student-facing); teacher supporting, i.e. using AI to support the teacher (teacher-facing); and system supporting, i.e. using AI to support diagnostic or system-wide planning (system-facing). We focus on student teaching and specifically on dialogue-based systems in which the learner follows a sequence of tasks through conversation in natural language. In student facing systems the major focus of AI has been in supporting "mastery learning', the pedagogic model initially advanced by Benjamin Bloom [10]. The objective of Bloom's model is to get all students to a level of competence that allows them to effectively move ahead, along the learning path described in the curriculum. Bloom argued that students need different amounts of instruction to get to the same level of mastery in a given topic. AI systems can provide the required individual-level of personalization of instruction.

The next section explores the different applications of AI in learning technologies for education.

7.3. Work carried out

The use of AI in education raises a significant number of ethical issues and there are many approaches in the development of ethical guidelines [11,12] and related policies to address these issues [13,14]. For example, the European Commission recently published the "Ethical Guidelines on the Use of AI and Data in Teaching and Learning" [9]. These guidelines provide a foundation on the potential that applications of AI and data usage can have in education and raise awareness of the possible risks in order to enable educators to engage positively, critically and ethically with AI systems and to realize their full potential.

At the technological front, there is a wide range of AI learning technologies utilized in education. Figure 7-1 highlights how each of these technologies contributes to enhancing the learning experience and shaping the future of education. From chatbots to intelligent tutors, personalized learning systems, and visualizations, these AI-driven tools offer innovative ways to address individual learning needs and promote academic achievement [15]. By exploring these applications, we gain valuable insights into their impact on the educational environment.

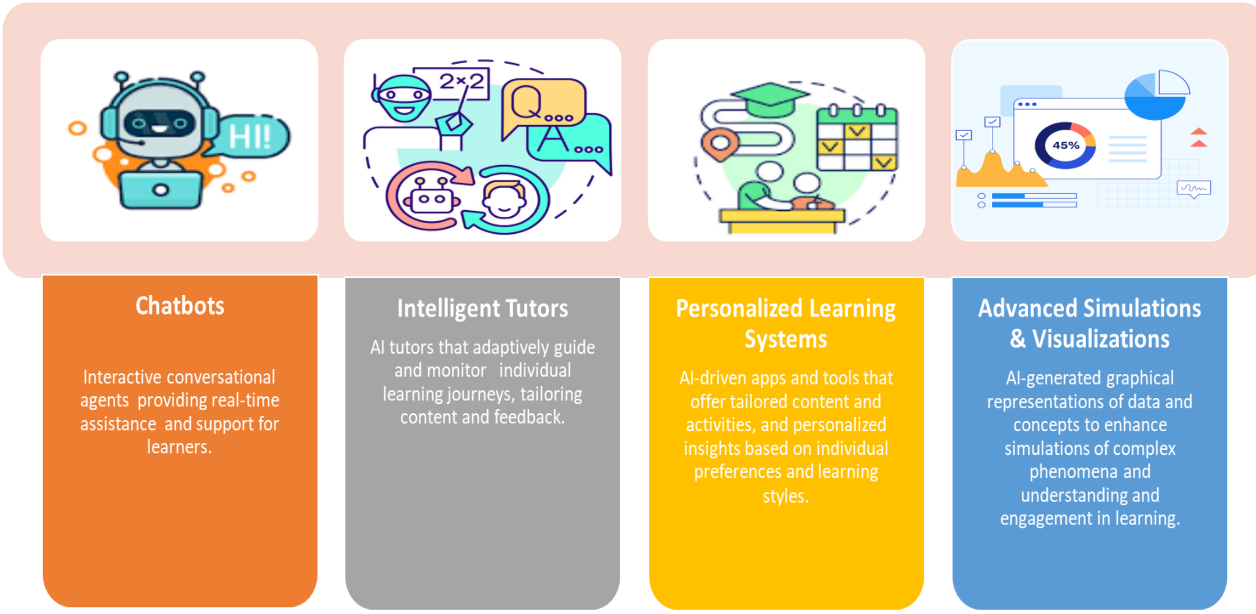

Figure 7-1: AI applications in education

7.3.1. Chatbots

In the educational setting, chatbots are frequently used for both teaching and learning. As conversational agents can give users correct information, research studies have shown that chatbots can convey course content through online platforms efficiently. Teachers are aware of the benefits of using chatbots in learning environments to increase student engagement. Chatbots let students ask questions, get answers, and get personalized assistance. With the development of chatbot systems in education, online learning has become more individualized, giving students access to course materials from any location at any time. The use of chatbots and other forms of AI in teaching and learning is considered as a response to the changing nature of the educational landscape. To model students' learning preferences and customize their learning experiences, chatbots can be used in tutoring sessions.

According to several studies [16-18], chatbots increase students' interest in learning, help them develop their cognitive skills, and improve their academic performance. Studies have also shown that chatbots can do administrative tasks in educational institutions. A chatbot system [19] that serves as a virtual assistant for academic staff and automatically responds to questions from students regarding the educational system is one illustration. Another example is a conversational agent [20] that assists students with administrative issues, such as orientation, recruitment, and retention. Additionally, chatbot technology has been developed to help with administrative and educational activities like evaluating assignments, grading, and giving comments. Students can easily get crucial information on admissions policies, scholarships, and tuition expenses thanks to the usage of chatbots in administrative chores [21].

By autonomously analyzing, scoring, and delivering quick feedback on student assignments, chatbots can speed up the assessment process [22-24]. This not only preserves time for educators but also guarantees fair and uniform assessment procedures. Additionally, chatbots can improve student engagement by giving interactive and customized evaluations, adjusting to specific learning preferences, and generating customized feedback. Chatbots can help in formative evaluations by giving students the chance to evaluate themselves. Additionally, chatbots can give students immediate feedback, assisting them in identifying areas for development and directing their learning process. Overall, the use of chatbots in educational assessment results in more effective, efficient, and individualized evaluation procedures that are advantageous to both teachers and students.

The advisory support that chatbots offer to pupils in various educational contexts is vital. Students now have access to a virtual advisor who can provide advice and support throughout their academic path thanks to chatbot technology. These chatbots can offer details on degree prerequisites, course selection, academic rules, and campus resources. Students can get tailored advice and recommendations by asking questions regarding career preparation, internships, and extracurricular activities [25]. Additionally, chatbots can help with appointment scheduling, reminding students of critical due dates, and giving updates on academic achievement. The availability of chatbot advisers guarantees that students have quick access to reliable information, enabling them to make more informed decisions and successfully navigate their academic experience. Chatbots improve student support services and contribute to a more accessible and responsive advisory system with their round-the-clock availability and capacity to handle many enquiries at once.

Chatbot systems have been recognized as useful resources for helping students with problems relating to their academic study in the field of research and development. For the postgraduate curriculum, chatbots offer direction and support in navigating the research process. For instance, Ureta and Rivera [26] created a chatbot system with the express purpose of teaching students the fundamentals of research in the STEM fields. A chatbot that can retrieve information from websites like Wikipedia was also identified during the review, helping students from many knowledge domains learn useful knowledge pertinent to their job [27]. These chatbot programs aid in improving and boosting the research experiences of students by supplying them with useful resources and academic direction all along the way.

The integration of content, quick access to instructional materials, increased student motivation and engagement, and support for many users are just a few advantages that chatbots in education can provide. Teachers and instructors can easily upload all the necessary resources and data about a particular subject onto an online platform with content integration. This guarantees a seamless learning experience by enabling approved students to quickly access the required resources. Additionally, chatbots offer quick access to instructional information, allowing students to quickly access learning resources and acquire the answers to their questions. Chatbots' interactive features encourage student motivation and engagement by offering individualized and engaging learning opportunities. Chatbots may support numerous users at once, which promotes collaborative learning and a sense of community in the educational environment. Chatbots integrate content, offer quick access to information, boost student motivation, and promote collaborative learning environments, which all help to increase the efficiency, accessibility, and efficacy of education [28-30].

7.3.2. Intelligent tutors

Research on intelligent tutors or agents emphasizes their capacity to give students personalized, pertinent, and timely resources, direction, and feedback. The impact of Teachable Agents (TA) on elementary pupils in various grades has been the subject of numerous research [31]. This research discovered that even without the use of AI technologies, TA encouraged learning and equipped students to understand new scientific concepts. Researchers found in a study of preschoolers [32] that children viewed the TA as a separate entity, indicating that the TA facilitated metacognitive scaffolding. Another study [33] used a TA to teach metacognitive scaffolding to 7th and 8th grade students, and it found that the three TA interventions improved students' problem-solving skills. Further evidence points to the possibility that arithmetic performance may be improved by TAs who share the same level of self-efficacy as the target students. The necessity of practice and useful feedback in improving reading comprehension is highlighted by certain research that revealed that metacognitive cues offered by intelligent tutoring systems did not increase student performance [35]. A different study found that for students with little prior knowledge, a kind web tutor resulted in greater learning than a conventional web instructor [34]. These results highlight the need for more research in this field and show the various effects intelligent tutors or agents can have on learning outcomes.

7.3.3. Personalized Learning

The effectiveness of personalized learning systems and environments (PLS/E) in strengthening educational interactions and enhancing e-learning experiences has been demonstrated by Xu & Wang [36]. PLS/E are used to deliver individualized and adaptable learning experiences by utilizing AI technology. AI is used typically to analyze educational data, including student performance and learning patterns, and to produce insights and suggestions for instructional tactics that are specifically tailored to each learner.

The beneficial effects of PLS/E on learning outcomes and experiences in various situations have been highlighted by several research. For instance, 110 undergraduate students who were enrolled in computer programming classes for two semesters participated in a study by Turkish researchers Kose and Arslan [37]. The researchers discovered that the deployment of a PLS system resulted in positive learning outcomes and enhanced general participant learning experiences. Kose [38] conducted a different study to examine the advantages of personalized mobile learning that integrates AI and Augmented Reality (AR) in open computer education. The results showed that individualized mobile learning had a positive impact on both learning processes and results. In addition, a study carried out in Hong Kong utilized the AI-enhanced SmartTutor e-learning system, which tailored to the unique demands of over 1300 participants. According to study [39], professors and students both highly appreciate customized learning tools and materials since they make a substantial difference in the teaching and learning process. In a research study with high school students in the USA, it was shown that including students' non-academic personal interests, notably in arithmetic, within an intelligent tutoring system improved learning [40]. This emphasizes how critical highly customized personalization is to encourage learning and, ultimately, student success. The evidence from all this research supports the potential of personalized learning environments and systems to improve education by delivering specialized approaches that consider unique student preferences and needs. These findings highlight the value of utilizing personalized learning strategies and AI technologies in contemporary educational environments to enhance learning outcomes.

7.3.4. Advanced Simulations and Visualizations

Virtual Learning Environments (VLE) supporting simulations and advanced visualizations, often involving AR/VR technologies are frequently combined with AI machine learning, image recognition and natural language processing. Numerous research studies have offered insightful information about the benefits of such pairings on learning experiences and engagement. Ijaz et al. [41] provided evidence from Australia showing a device that combines AI and VR might enhance learning and engage young students. The results of the study showed that undergraduate students who used AI and VR in their learning performed higher on comprehension tasks. Additionally, it has been demonstrated that AI technology that uses visuals, such smart glass systems, is advantageous for both children and adults with autism, serving as a tool for social communication [42]. Overall, research has demonstrated that genuine, high-quality VLEs are those that place a primary emphasis on communication between students and their peers and teachers [43]. Due to the divergent results from different studies, it is necessary to both advance AI technology for visualizations and VLE and conduct more in-depth study in this area. There is a possibility to unlock even more advantages for students as educators and researchers continue to investigate and develop these technologies, making education more interesting, approachable, and efficient in the future. Google has developed more than a thousand VR and AR Expeditions suitable for educational contexts. Meanwhile, digital games-based learning (DGBL) is also increasingly including AI technologies, to adapt gameplay to the individual student [44].

The next section investigates the current trends of AI in education.

7.4. Current trends

The emergence of intelligent digital assistants has taken many aspects of working and living by storm. Digital assistants are virtual devices that help users accomplish tasks through natural language conversations, without having to seek out and wade through various apps and web sites. The technology is designed to assist users by answering questions and processing simple tasks and free users from spending time on routine functions that don't require human intervention. Hence, digital assistants, also called chatbots, have become a popular tool for e-commerce businesses to automate customer servicing tasks, such as answering Frequently Asked Questions, resulting in a more sustainable, productive, and less expensive way of interacting with clients [45]. However, the effectiveness and limitations of simple chatbots remain an area of ongoing research [46].

Beyond e-commerce, digital assistants have started to be used in education to provide personalized support to students and teachers in various educational contexts. Digital assistants can help students learn new concepts, complete assignments, and get answers to their questions in a conversational way, using speech or text-based interfaces. They can also help teachers automate administrative tasks, such as grading and scheduling, so they can focus on teaching and providing personalized support to their students. In this deliverable we focus on student teaching and specifically on dialogue-based systems in which the learner follows a sequence of tasks through conversation in natural language.

During the last decade, digital assistants in education are increasingly being used to improve student experiences and increase efficiency. Digital assistants in education can be integrated with learning management systems, educational apps, and other software to provide a more seamless and personalized learning experience. They can provide real-time feedback to students, recommend learning materials, and offer guidance on how to improve their performance.

There is an increase in the number of digital assistants whose purpose is teaching. The purpose of these assistants is to generate knowledge like a human tutor would. Digital assistants in education can take many forms, from chatbots and voice assistants to avatar-based assistants and virtual reality assistants. They have the potential to transform education by providing more personalized and engaging learning experiences to students. Table 7-1 presents a summary of the digital assistants found in our research.

Autotutor [35] is a complex system that simulates a human or ideal tutor by holding a conversation with the learner in natural language. Chatbot [1] is a software platform designed to introduce high school students to Computer Science concepts in an innovative way, by programming chatbots. A chatbot is a bot that can be programmed to have a conversation with a human or robotic partner in some natural language such as English or Spanish. Edubot [47] is an AI-based Chatbot developed as a plugin to the Canvas Learning Management System. EduBot appeared as a link in the sidebar menu allowing students to click on the link at any time to ask the bot a question. When users asked EduBot a question, the AI sought an answer from a Question & Answer (Q&A) database.

Sara [48] is a scaffolding-based conversational agent that appears during an online video lecture. QuizBot [49] is a dialogue-based agent that helps students learn factual knowledge in science, safety, and English vocabulary. ScratchThAI [50] is a Scratch tutorial chatbot designed to assist young learners directly through a messaging platform. ScratchThAI is used to teach Scratch to students. Among other aspects of its implementation, it includes gamification to increase students' motivation. In addition, it introduces the concept of computational thinking development in students.

CSIEC [51] is a computer assisted English learning chatbot based on textual knowledge and reasoning. CSIEC generates communicative response according to the user input, the dialogue context, the user's and its own personality knowledge, common sense knowledge, and inference knowledge.

Table 7-1: Digital assistants in education

Digital Assistant	Description	Target Age
Autotutor [35]	Encourage learning through conversation with a learner.	12-17
Chatbot [1]	Aims to promote computer science learning	12-17
Edubot [47]	AI chatbot for an introductory computer programming course	18+
Sara [48]	Conversational Agent that can be layered on top of already existing online video lectures	18+
QuizBot [49]	Help students learn factual knowledge in science, safety, and English vocabulary	18+
ScratchThAI [50]	Teach Scratch to students	From children to teens
CSIEC [51]	English language learning	12+
Smart Personal Assistant [52]	Support groups of learners in solving a complex problem	18+
Hubbert [53]	Automate feedback to educators	18+

Amazon Alexa can be used in education to provide students with quick access to information. For example, students can ask Alexa to define a word, solve a math problem, or provide historical information. Winkler et al. [52] used Alexa to support groups of learners in solving a complex problem and showed that learners achieved solutions of better quality. They developed a voice-based Smart Personal Assistant with the help of Amazon's Alexa Skill Development Kit 2.0 with nodeJS. The results indicate that groups interacting with Smart Personal Assistant tutors show significantly higher task outcomes and higher degrees of collaboration quality compared to groups interacting with human tutors.

Hubbert [53] is a chatbot which aims to automate feedback to educators. This chatbot has been mainly used in other domains, such as the recruitment of human resources in companies, doing an initial job interview for filtering candidates, for instance. The next section describes the current trends in AI-driven education.

In conclusion, digital assistants have emerged as transformative tools in the field of education, revolutionizing the way students learn and educators teach. Through the power of AI, these intelligent systems have successfully delivered interactive learning experiences, resulting in increased student engagement and academic achievement. It is important to continue exploring innovative ways to integrate digital assistants seamlessly into educational environments, ensuring that they remain accessible, ethical, and effective in enhancing the overall learning journey. With ongoing research and collaboration between educators, technologists, and AI experts, we can realize further capabilities of digital assistants and further explore their capabilities as enables in education. The next section explores the potential opportunities and challenges associated with the AI technologies in education and draws recommendations for their uptake in Discovery Space.

7.5. Challenges, Opportunities & Recommendations

Initial analyses of the use of AI in educational settings have shown that despite many limitations (like the lack of interpretability, the concerns about bias, the risks of misuse and inadequate or unethical deployment, loss of integrity, and more) AI provides unique opportunities to provide personalized and effective learning experiences to students and to revolutionize assistance in teaching processes [54-57].

The rapid development of highly flexible, reusable AI models is likely to have even more disruptive impact in education, similar to other fields, like in medicine. We claim that three recent research challenges may significantly disrupt the educational experience. First, the ability to facilitate learning pathways and tasks dynamically. Second, the support of flexible combinations of various data modalities. Third, embedding pedagogical models and approaches.

7.5.1. Dynamic Learning Pathways

Personalized learning systems are a prominent trend in AI-driven education, where extensive student data is analyzed by AI algorithms to determine specific learning requirements and preferences of individuals. By utilizing this information, educational platforms can provide tailored content and offer focused assistance to learners, thereby optimizing their chances of achieving academic excellence. Personalization of learning pathways is already addressed both pedagogically and technologically, however, in an often-limited interpretation of personalization [7].

Personalization, more broadly understood, is about subjectification [58] and helping each individual student to achieve their own potential, to self-actualize, and to enhance their agency. This is something that few existing AI tools do. Instead, while they provide adaptive pathways through the materials to be learned, most AI tools tend to drive the homogenization of students, suggesting that they aim to ensure the students pass their exams [7]. Next generation AI can go beyond ensuring students pass their exams; they can help students to self-actualize, to become the best that they can be. To this end, individual pathways should be truly personalized, not based on the averages of prior learners. Moreover, AI should support new learning pathways on the fly, dynamically specifying new learning tasks without requiring AI to be extensively trained in advance. Obviously, AI may struggle to support new learning tasks that involve unknown concepts. However, emergent machine learning approaches, such as in-context learning, allow users (e.g., teachers) to teach the AI about a new concept with just a few examples.

7.5.2. Multimodal inputs and outputs

While education-related data streams may be individually too limited to train dedicated AI, the ability to leverage artificial general intelligence, the plethora of data from outside the domain and make use of data across multiple modalities (e.g., textbooks, mathematical formula, diagrams, video-based tutorials) jointly offers hope for AI that is broadly applicable to educational tasks. Science learning using online labs and in particular accompanying simulations, often use multiple representations. These different representations (graphs, animations, equations, tables, etc.) are dynamic and must be connected by students, a task that can be leveraged by AI technology. Intelligent digital assistants can combine modalities by turning each modality's data into 'tokens', each representing a small unit (for example, a word in a sentence or a patch in an image) that can be combined across modalities [59]. The blended stream of tokens can then be used for the training of AI models to educational material including many diverse inputs.

7.5.3. Embedding pedagogical approaches

Among the prominent pedagogical methods, inquiry-based learning in Exploratory Learning Environments and more specifically in virtual labs is the focus of Discovery Space. Here AI can play a pivotal role supporting the student go through a scientific inquiry cycle, possibly encountering a cognitive conflict between existing ideas and data that come from experiments. Based on such conflicts, AI can stimulate students to adapt their existing knowledge. AI can also help students oversee their own learning process in the virtual lab environment, which, according to theories of social learning, leads to higher motivation and especially to intrinsic motivation, while the students get control over the learning process by planning, monitoring, and reflecting about it. Moreover, AI can facilitate student learning through the process of identifying and representing the components that comprise a phenomenon. These components include objects (e.g., particles), processes (e.g., free fall), entities (e.g., acceleration), and interactions (e.g., how entities interact with objects or processes). In other words, the learner strips down the phenomenon into its components (an analysis process) and then builds up the phenomenon in a modelling environment (a synthesis process).

However, the underlying premises behind each of these approaches could be overly optimistic; for example, sometimes students do not adapt their knowledge in response to anomalous data or they fail to connect representations. In these cases, instructional support, facilitated by AI, can be a key enabler for successful learning by minimizing the cognitive overload and by providing automated guidance and feedback, based on knowledge tracing and machine learning. This feedback will address students' misconceptions and will propose alternative approaches, to support their conceptual change while they explore, and they are performing experiments. Providing effective instruction requires correct reasoning about student understanding and understanding pedagogy. This encapsulates an effective understanding of techniques to guide a student, such as asking Socratic questions or providing analogies/contrasting cases, using encouraging or supportive language, tailoring the difficulty of questions to the student and generating examples that are relevant to a student's interests and background [60]. Alternative ideas for adapting AI to understand good pedagogy for instruction include to consider adaptation using data sources where instruction has a primary role or to use public data sources like textbooks, lecture videos and lesson plans that collectively contain pedagogical behaviors which could be adapted by AI [61].

7.6. Conclusions

AI applications already exhibit impressive results in educational settings by providing personalized learning experiences to students and creating lesson planning and assessment support to teachers. In educational applications, the combination of knowledge-based and data-driven approaches represents a natural path forward. Data-driven AI provides important basic information processing functionality, such as pattern recognition [7]. Education has typically focused on the gradual development of domain-specific theoretical conceptual structures (e.g., [62,63]). Many recent breakthroughs in data-driven AI, such as foundation and Large Language models, are yet to be proven in their ability to improve the learning outcomes of students, rather than simply supporting the tasks of teachers and the administration. AI, therefore, may more constructively be seen as a joint development of human and artificial cognition. This suggests that the future of AIED should be understood from the point of view of AI-supported augmentation of human cognition and learning, an approach that has been an important line of thinking in AI throughout its history [64].

Current research in (a) dynamic learning pathways; (b) multimodality of AI; and (c) infusion of pedagogical models and approaches, paves the way for further strengthening AI-assisted education and possibly disrupting the educational experience. Many researchers claim that the recent developments in AI have the potential to revolutionize education by providing personalized and adaptive learning pathways and enhancing the pedagogical content creation by educators, leading to targeted lesson plans and teaching strategies [65,66]. However, AI also poses significant challenges such as copyright issues, algorithmic bias, issues of trust that educators can put in the models, concerns about the reliance of teachers to models, lack of interpretability, cost of training and maintenance and problems of data security and privacy [67-69]. A multi-disciplinary effort is needed by researchers, educators, and learners to collaborate as AI develops, in order to maximize its potential for improving education while mitigating the associated risks and uncertainties.

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8. Recommendations

The Discovery Space consortium based on rooted research in the field and long-lasting experience in the implementation of ICT-based innovations in education is an approach to respond to the challenges imposed by the integration of AI in the learning process, through the development of a roadmap for the AI-Enhanced Classroom for Deeper Learning in STEM. This will transform the traditional classroom to an innovative environment in which scientific exploration and the development of key skills are prioritized.

Good practices will be provided in the form of scenarios equipping teachers and learners with the necessary skills for the use of technology in creative, critical, competent and inclusive ways, while on the same time we are going to develop an innovative teacher training related with the educational practices in the AI-Enhanced Classroom for Deeper Learning in STEM.

In order to accomplish the above-mentioned target of the project, IBL and PBL will be prioritized, in accordance with the discussion of Section 2, and emphasis will be given to the development of practical skills, so that students are prepared for their future careers. The essential competencies which are necessary for an individual to respond to the challenges of the professional world will be at the heart of the Deeper Learning Classroom, while other crucial competencies such as critical thinking, collaboration, creativity, etc. will be simultaneously developed. The AI conversational agent will contribute to the establishment of IBL and PBL as it will guide the student throughout the learning process and provide help when necessary (low performer), hints and guidance to accomplish a task (medium performer) or a set of more advanced questions for those students that do not face any difficulties. To accomplish that, the Discovery Space Scenarios developed by the pedagogical teams of the consortium are structured in a way that all students can benefit, not only the strongest ones. These scenarios exemplify and operationalize the vision of the proposed approach in the actual classroom in ways which are understandable by the targeted educational communities and will be also a testing for the approach, diversified to fit into a variety of contexts.

The project will prioritize active learning experiences using the XR laboratories discussed in the main text. In contrast to the traditional lecture-based teaching which favors the most gifted students in a classroom, within the Discovery Space project the AI-enhanced classroom for Deeper Learning in STEM is developed, which will apply in practice IBL and PBL, and address the needs of all students. The project team will review scientific evidence from Europe and beyond to identify and analyze emerging trends and technology-enhanced learning that will act as drivers of change in STEM education.

As discussed in Section 3, the bridging between different forms of learning (formal, informal, non-formal) is expected to have a positive impact on the learning outcomes of the students. Informal STEM learning plays a significant role in fostering STEM identities, especially for the underrepresented populations, while its integration with formal learning could enhance students' motivation to engage with different STEM subjects. Tha AI-enhanced classroom for Deeper Learning in STEM will be built on the strengths of both formal and informal learning. Thus, there will be a structured curriculum ensuring comprehensive coverage of the STEM content, the latter being delivered by teachers having subject expertise and pedagogical knowledge. Moreover, the way that each STEM subject is taught will be engaging and interactive, including when possible hands-on activities to make learning enjoyable.

Furthermore, the advantages of informal and non-formal learning will be fully exploited through experiential learning which will allow students to apply the acquired STEM knowledge in real world contexts, while on the same time such real-world connections will help students to understand the importance of STEM in daily life. At the same time the consortium will take specific measures to avoid certain disadvantages of the above-mentioned forms of STEM learning, especially limited accessibility connected with informal and non-formal learning, by making sure that all students can have access to the AI-enhanced classroom either physically or remotely. In addition, the lack of flexibility usually accompanying formal STEM learning will be faced through the development of the Discovery Space Scenarios and the fact that the AI conversational agent will have the option to guide the student through the different stages of the scenario according to his learning capabilities and not in a rigid predefined way.

Within the framework of Discovery Space, our goal is to combine the previously mentioned actions with an innovative classroom setup, as described in Section 4. The design and the furniture in such a setup will favor collaborative learning (e.g., tables for group work and promotion of teamwork), while at the same time it will be technology-friendly supporting the use of various devices for digital learning. In addition, adequate storage options will help to maintain a tidy and efficient learning environment. Furthermore, students will be actively involved in the design of the classroom and will be asked to provide feedback on the classroom setup, so that they feel more comfortable in the classroom. Different group sizes will be handled by modular furniture offering versatility in the arrangement of the classroom and contributing in this way towards the achievement of the learning goals.

Moving forward, the role of the teachers in the Deeper Learning Classroom and the actions that they should take shall be discussed next. As was stressed out at Section 5 of the main text, the role of the teachers is crucial for the success of the project. In this exploratory learning environment, the teacher acts a facilitator of the learning process. Teachers should have AI literacy and develop key skills such as:

- Being able to establish an inclusive and diverse attitude
- Have an in-depth understanding of the subject
- Be able to promote teamwork and experimental learning
- Design and deliver engaging activities

More importantly, teachers will guide the shift of the study process from learning about facts to an active engagement with different phenomena and their understanding. For the purposes of the Discovery Space, teachers will be able to:

- Become familiar with digital tools
- Develop their collaboration and cooperation skills
- Be involved in professional development programs, as was the case with the summer school of July 2023 in Marathon, Greece
- Be able to motivate learners

The AI conversational agent will be a powerful tool in their disposal which will enable them to follow each student’s learning process independently, allowing to target specifically each student’s misconceptions. This role would have been relatively easy in a one-to-one student tutor interaction but scaling it up to the number of students in a typical classroom becomes non-trivial. In our approach teachers will be able to know the students that are making progress, those being off-task and the ones in need of assistance.

Furthermore, a group of teachers will be built who will share leading practices and influence policy development. Teachers with specific change management will operate as change agents in the pilot sites to facilitate the implementation of the Discovery Space Scenarios and the consortium will analyze the shifting role of teachers in the digital transition affecting education and training, as well as their training needs, including digital skills, required in an emerging society of quick technological change. A professional development program which adapts and deploys state-of–the-art learning approaches based on advanced simulations and web-based collaborative learning platforms will be implemented for this purpose. To guarantee sustainability of the proposed approach, the gradual development of the teacher community will be supported by Web 2.0 collaborative learning and knowledge exchange platform. In the framework of the training activities, educators will be involved in shaping and co-designing innovative materials that will offer deeper learning experiences to their students. Such actions will take place in WP5.

In what concerns the project's technical components, the development of XR laboratories will satisfy the requirements of universality, low-cost, up-to-date, multilingualism, usability and availability as they have been described in Section 6. The use of these XR labs will offer an immersive experience to the student/user enhancing in this way the learning outcomes. More specifically, XR technologies will be combined with machine learning and other AI techniques to offer an optimal user experience. By visualizing the invisible teachers will be able to explain to students complex scientific phenomena, while MR interfaces will offer augmentations of graphs or animations related with the phenomenon under study. In this way even low performing students will be engaged in the experimental process. Moreover, in what concerns MR in a learning context, the high integration of computers and trends in digital supporting schooling provides several routes for integration and evolution. The project will follow three main routes to find ways for sensible experiments with interactive MR interfaces. First is a "mobile-first" implementation for devices like smart-phones that are widely used. The second is to employ microcontrollers and single board computers that are widely deployed in education and might be able to run a compelling AR experience on otherwise very versatile platforms with IO-channels and visual programming environments. The third route will be concentrating on "web-first" browser-based integration.

Regarding the technical details in the use of AI, the project will design an ELE (the Discovery Space) to facilitate students' IBL and PBL. The outcome will be for students to reach a deeper level of understanding by reevaluating their current knowledge, while the AI conversational agent can provide automated guidance through knowledge tracing and machine learning. The aim of the consortium is for AI to become a tool in order to help students oversee their own progress and design specific learning pathways according to each student's needs, while simultaneously help to increase students' motivation and minimize the cognitive overload which is often associated with exploratory learning.

As was presented in Section 7, the technical teams of the consortium have identified three challenges that may disrupt the educational experience, which are dynamic learning pathways, multimodal inputs and outputs and the embedment of pedagogical approaches. In the first case, AI algorithms are used for the analysis of student data and then personalized learning pathways can be created. Though there are some AI tools that can achieve a personalization of the learning pathway, in the majority of the cases there is a homogenization of the students, with the main goal be the success in an exam. Within this project we will develop next generation AI tools that will adapt a personalized learning path for each student, after an initial analysis of his/her own learning profile. This work will be performed by the AI-driven lifelong learning companion, which will also support new learning pathways on the fly. To that end emerging machine learning approaches will be employed to train the AI conversational agent using only a small number of examples.

Moreover, in conjunction with embedding pedagogical approaches, AI will become an indispensable tool which will facilitate student learning by helping the students to identify all the components of a phenomenon. In this way the student will have the chance to decompose the phenomenon, get an in depth understanding of the different physical mechanisms at play, as well as the entities and interactions and consequently reconstruct the "big picture". Despite the great pedagogical value of the previous approach, there is always the chance of a negative outcome e.g., when students fail to perform the above-mentioned reconstruction process. In this case guidance will be provided by the AI conversational agent. To achieve that, the adoption of AI platforms and data-based learning analytics as key technologies in building integrated lifelong learning systems to enable personalized learning is necessary.

The technological innovations within the Discovery Space will achieve simplicity at all levels, allowing in this way for lab providers to offer their resources online, for teachers to exploit these resources, for teacher communities to share practices and for students to practice inquiry-based learning. The ELE will be the unique entry point for all educational stakeholders, integrating labs, learning activity spaces and associated resources. The environment will be accessible to everybody from anywhere and at any time. The ELE will be continuously updated in order to fit to the needs of teachers and students, while its overall architecture consists of three parts, the Discovery Space Management System, the AI-driven lifelong learning companion and XR interfaces.

9. Conclusions

In this document we presented the ongoing progress on the Discovery Space project, aiming to integrate AI in the educational process. The challenges of the project were mentioned and the actions that should be taken in order to cope with them were also presented. Discovery Space is expected to have a crucial impact on the learning process as the AI-driven Lifelong Learning Companion will be available for each student, monitoring his/her own performance and accordingly designing a suitable learning pathway for him/her. In this way teachers will have an extremely useful assistant during the lecture which allows them to always follow the progress of each student and even more important address each student's specific misconceptions. The role of the teachers in this AI-Enhanced Science Classroom was also presented within the document, and the competences that STEM teachers need to develop in order to make their teaching more efficient and be able to fully exploit the advantages of AI in educational process were extensively discussed. Furthermore, technical aspects of the project related to the use of AR/VR have also been presented, while a detailed discussion of the technical details of AI can be found here. This document shall act as a reference point for the consortium and a guide for the future course of the project, as it sets the basis for the progress of both the pedagogical and technical components of the Discovery Space.

As stated within the main text of the document, a crucial factor for the successful outcome of the project is the creation of analytical scenarios by the pedagogical teams of the consortium and their implementation to the ELE by the technical team. Accordingly, these scenarios will be presented to numerous teachers (approx. 1000) and students (approx. 10000) in order to enter the trial phase of the project. There the consortium will have the opportunity to amend and improve things according to the feedback that the teachers and the students will provide. Moreover, as the number of the users (teachers, students) will increase, more data will become available which will allow the AI agent to recognize more learning patterns and better fit a learning pathway for each student, thus the participation of as many students and teachers as possible is of fundamental importance.

Finally, one should always keep in mind the issues that come as a consequence of the introduction of AI in the educational process, e.g., ethics, equity, sustainability, etc. dictating a complete understanding of AI from our side. Thus, the risks in the use of AI need to be identified, solutions should be proposed for their elimination and the benefits of AI must be fully described. The Discovery Space project, in accordance with the latest policy recommendations on AI, aims to ensure an inclusive and equitable use of AI in education and leverage AI to enhance education and learning, while targeting at the same time on the development of 21st skills like critical thinking and problem solving.