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Designing and developing a training system basedon the STEM approach; case of physical science teaching: research methodology

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Abstract

This article explores the design and evaluation of a pedagogical device based on the STEM (Science, Technology, Engineering, Mathematics) approach to renovate the teaching of physical sciences. Using a mixed methodology (quantitative and qualitative), the research is studying the impact of this system on teachers' teaching practices, as well as on learners' learning and motivation. The expected results include a significant improvement in the understanding of physics concepts, the development of cross-curricular skills (creativity, critical thinking, communication, collaboration, problem solving), and an increase in learner motivation and engagement. The study also highlights changes in teaching practices, enhanced by the use of technology and active teaching methods. The STEM approach is a promising strategy for transforming science teaching, promoting practical and interdisciplinary learning adapted to the challenges of the XXI^{e} century.

Keywords: Active learning; Cross-disciplinary competencies; Innovative teaching practices; Teaching in the 21st century; Physical sciences; STEM approach

1. Introduction

Science teaching, particularly the physical sciences, plays a fundamental role in developing learners' critical and technical skills. In the n today's global context, characterised by the rise of technology and the interconnection of scientific disciplines, education must respond to the challenges of training learners capable of solving complex problems, thinking critically and adapting to a constantly changing world. This requires a review of traditional teaching methods, which are often deemed inadequate to meet the demands of modern society [1].

In Morocco, physical science teaching faces major challenges, such as low learner motivation, lack of interest and concentration, the ineffectiveness of certain traditional teaching methods, and limited access to modern teaching resources [2]. The introduction of innovative teaching approaches, such as STEM (Science, Technology, Engineering and Mathematics), could provide a response to these challenges. The STEM approach, which is based on an interdisciplinary approach and on active learning through the resolution of real problems and the use of technology, seems to offer a promising way of renewing science teaching and developing essential cross-disciplinary skills for learners in the 21st century [3].

The STEM approach has been widely adopted in various international educational contexts for its positive effects on learners' motivation, their understanding of scientific concepts and their ability to apply knowledge to concrete

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situations [4]. It stands out for its ability to integrate the different scientific disciplines, to encourage project-based learning and to promote the use of digital technologies, all of which are crucial for training learners capable of responding to the scientific and technological challenges of today's world [5].

The integration of the STEM approach into physical science teaching offers an opportunity to improve these results by proposing an innovative training and learning framework. This work is part of a theoretical framework based on research in science pedagogy, active learning theories, and models for integrating technology into teaching [6].

2. Purpose of the article

The aim of this article is to present the design and development of a training device based on the STEM approach, specifically adapted to the teaching of physical sciences. The system is an innovative teaching tool designed to improve understanding of physical concepts while encouraging a practical and experimental approach to learning. It is an integrated model that combines scientific theory with technological applications, simulations and laboratory experiments, with the aim of making the physical sciences more accessible and relevant to learners.

3. The place of the STEM approach in today's world

The STEM (Science, Technology, Engineering, Mathematics) approach is at the heart of contemporary educational strategies, both nationally and internationally. Faced with an increasingly complex and interconnected world, where technological innovations and global challenges are multiplying, the need to adopt an educational approach that prepares the younger generations to meet these challenges is paramount. The teaching of the physical sciences, in particular, plays a crucial role in this process, as it is the foundation on which many of the technical and scientific skills essential to modern society are built.

3.1. A world in constant technological evolution

Rapidly evolving technologies are transforming all sectors of activity, from industry and health to agriculture and transport. This technological revolution calls for a new form of education: one that transcends traditional disciplinary boundaries and integrates practical and analytical skills. In this context, the STEM approach, which links the basic sciences to their technological application, is more relevant than ever.

The work of Beers (2011) highlights the importance of integrated STEM education, capable of developing critical complex problem-solving skills, while cultivating innovation and adaptability in learners [3]. This pedagogical model enables learners to understand not only scientific theory, but also how this theory is translated into technological development, practical applications and the design of innovative tools.

3.2. The challenges of teaching physical sciences today

Despite its crucial importance, the teaching of the physical sciences is often perceived as abstract and disconnected from the concrete concerns of learners. Numerous studies, such as that by Duit (2009), have shown that learners find it difficult to relate theoretical concepts to real-life applications, which undermines their engagement with and understanding of scientific subjects. In addition, the lack of appropriate pedagogical tools and the failure to integrate technology into teaching practices contribute to this gap [7].

Faced with these challenges, teaching approaches based on interdisciplinarity and the use of innovative technologies can offer solutions. For example, digital simulations and online collaborative work can significantly improve learning in the physical sciences. The STEM approach is therefore a pedagogical response to these challenges, offering a teaching framework in which theory is constantly confronted with concrete practice, enabling learners to see the applicability of scientific concepts in their everyday lives.

3.3. Integrating technology into education

The integration of digital technologies, interactive simulations, augmented reality and collaborative tools into physical science teaching is a powerful lever for modernizing teaching practices. Technologies offer unique opportunities to experiment with concepts that would otherwise be difficult to access in a traditional setting (e.g. experimenting with nanoscale phenomena, simulating complex physical phenomena). Tools such as PhET Interactive Simulations from the University of Colorado (2024) [8], enable learners to visualize and manipulate physical phenomena in a virtual environment, creating a direct link between theory and practice. As part of the STEM approach, these tools are particularly effective in encouraging active learning and fostering inquiry-based, problem-solving pedagogy.

Simulations make it possible to model experimental situations that are impossible or costly to carry out in the laboratory, while fostering a deeper understanding of physical laws.

3.4. A necessity to meet global challenges

STEM education is also essential for meeting the major global challenges of the 21st century, such as climate change, the energy transition, global health and food security. The United Nations (UN) has clearly identified STEM education as a driver of sustainable development in its Sustainable Development Goal 4 (SDG 4), which promotes quality, inclusive and equitable education for all. The acquisition of skills in science, technology, engineering and mathematics is therefore seen as a key element in enabling young people to make an active contribution to solving global problems [9].

For example, the "Engineering for Change" (2020) initiative highlights the importance of training engineers and scientists capable of designing technical solutions adapted to social and environmental problems [9]. This approach is particularly relevant to the teaching of the physical sciences, which enables learners to develop an in-depth understanding of the scientific principles underlying the innovative technologies that can solve these global challenges.

In today's world, where technology and innovation are central to economic, social and environmental issues, the STEM approach offers a coherent and indispensable educational response. By integrating this approach into the teaching of the physical sciences, we are not simply preparing learners for a scientific or technical career, but giving them the keys to understanding and actively participating in the transformation of the world around them. The training programme presented in this article aims to meet this requirement by combining innovative teaching methods, advanced technologies and an interdisciplinary approach to make the teaching of the physical sciences more relevant, dynamic and adapted to the challenges of the 21st century.

4. Issues

The teaching of the physical sciences, both worldwide and in Morocco, is facing major challenges in a context marked by rapidly changing technologies and educational expectations [10]. These disciplines, which are fundamental to strategic sectors such as engineering, technology and applied sciences, struggle to engage learners because teaching methods are still largely focused on theoretical approaches and disconnected from practical applications [11].

Today's teachers are faced with a generation of learners who have an increased inattention deficit when confronted with traditional teaching approaches. These learners also find it difficult to solve real-life problems, as the disciplines required for these solutions, such as science, mathematics, technology and engineering, are often taught in isolation.

In Morocco, these problems are accentuated by specific challenges: overcrowded classes, limited integration of digital tools into teaching practices, and the abstract nature of physical science concepts. This last point, compounded by the lack of practical illustrations and concrete links with interdisciplinary applications, hinders the engagement of learners, particularly those from disadvantaged backgrounds [12].

Translated with DeepL.com (free version) In this context, the STEM (Science, Technology, Engineering and Mathematics) approach, which promotes interdisciplinary integration and active learning, appears to be a promising solution [13]. This approach emphasises real-world problem solving and collaboration, linking theoretical concepts to practical applications, which has the potential to transform physical science teaching [14]. However, its integration in Morocco requires adaptation to local realities and raises several questions:

- How can we design a teaching system that integrates the STEM approach and is at the same time adapted to the specific realities of the Moroccan education system?
- What teaching strategies and tools can effectively link the abstract concepts of physics to relevant concrete and interdisciplinary applications?
- To what extent can the STEM approach improve Moroccan learners' understanding of and engagement in learning the physical sciences?
- What institutional, economic and cultural opportunities and challenges influence the implementation of this approach in Moroccan schools?

These questions reflect the need to reform teaching practices in response to local and global challenges. The integration of the STEM approach could thus contribute to the transformation of education, while aligning the skills of learners with the demands of a rapidly changing labour market.

5. Research objectives

The main objective of this research is to design, develop and evaluate a pedagogical device based on the STEM approach for teaching physical sciences in the Moroccan context. More specifically, the objectives of this study are as follows:

- Design a teaching system that integrates STEM: develop a training model that combines theoretical and experimental teaching in physics with technological and practical applications within the framework of interdisciplinary projects.
- Analyse the effectiveness of the STEM approach: Evaluate how the integration of science, technology, engineering and mathematics concepts into physical science teaching can improve learners' understanding of concepts, their engagement and their ability to solve real-world problems.
- Examine the obstacles and opportunities for implementation: Identify the challenges faced by teachers and learners when using the pedagogical device developed and the resources needed to implement it in different educational environments (secondary schools, colleges, universities).
- Propose recommendations for wider deployment: On the basis of the results obtained, formulate practical recommendations for the integration of STEM teaching devices into physical science curricula, taking into account the cultural, social and technological specificities of the various teaching contexts.

6. Hypotheses and research questions

- Hypothesis 1: Integrating the STEM approach into the teaching of physical sciences w i l l improve children's understanding of physical concepts. by making learning more concrete and linked to real-life applications.
  - Research Question 1: How do learners respond to the integration of technological, engineering and mathematical elements into physical science teaching?
  - Research question 2: How effective is the STEM approach in fostering a better understanding of abstract physics concepts?
- Hypothesis 2: The use of teaching methods based on interdisciplinary projects increases t h e commitment and motivation of learners in learning the physical sciences.
  - Research question 3: To what extent does the use of interdisciplinary practical projects stimulate learner motivation and commitment?
  - Research Question 4: What specific pedagogical tools are most effective in fostering learner engagement in a STEM learning environment?
- Hypothesis 3: Teachers encounter difficulties in adopting and implementing a teaching system based on the STEM approach, but training and support are available to them. adapted resources can facilitate this transition.
  - Research Question 5: What are the main difficulties encountered by teachers in implementing the STEM approach to teaching physical science?
  - Research question 6: What types of training and teaching resources are needed to support teachers in adopting the STEM approach?
- Hypothesis 4: The STEM pedagogical device designed as part of this research is perceived positively by learners and teachers, but needs to be improved. Adjustments to be optimised in different educational contexts.
  - Research question 7: What is the impact of using the STEM teaching device on learner and teacher satisfaction?
  - Research question 8: What adjustments need to be made to the system to adapt it to different teaching and technological contexts?

7. Theoretical framework

The theoretical framework of this research is based on several pedagogical and theoretical approaches that underpin the integration of the STEM (Science, Technology, Engineering and Mathematics) approach into physical science teaching. These approaches help to structure the relationships between disciplines, active learning practices, the use of technology and complex problem solving. This theoretical framework also explores the benefits and challenges of teaching physical science through this integrated approach

7.1. The STEM approach: An interdisciplinary education

The STEM (Science, Technology, Engineering, Mathematics) approach aims to provide a coherent link between the various scientific and technical disciplines in order to meet the challenges of modern society. This approach encourages practical learning, innovation and problem-solving by combining the knowledge of these different disciplines. The link between these fields is particularly relevant in the teaching of the physical sciences, where theoretical concepts are often abstract and need to be contextualised in concrete applications.

The integration of the STEM approach into physical science teaching is based on the belief that learners learn best when these disciplines are connected and confronted with real problems. According to Sanders (2008), this approach fosters creativity and problem solving by encouraging learners to see the connection between science and technology in the world around them [15].

7.2. Constructivist learning

Constructivism, as expressed by Piaget (1973) and Vygotsky (1978), is based on the idea that learning is an active process in which learners construct their own understanding of the world, based on their experiences and interactions with the environment. In the context of physical science teaching, this theory argues that learning is most effective when learners are involved in practical and experimental activities, where they can observe, experiment and test hypotheses. The STEM approach, by integrating interdisciplinary projects, encourages this active learning process, while linking scientific concepts to concrete situations [6, 16].

7.3. Project-based learning and active teaching

Project-based learning (PBL) and active pedagogy are effective teaching strategies for science education. PBL allows learners to work on real, complex problems that require the application of scientific concepts in practical contexts. These methods are compatible with the STEM approach, which emphasises practical problem solving. Kolb (1984) and Dewey (1938) have shown that experiential learning, and in particular project-based learning, is an effective method for enhancing understanding of scientific concepts [17, 18].

The project-based approach also emphasises collaboration and the exchange of ideas between learners, essential skills for the world of work. This is in line with the vision of physical science teaching, which should not only aim to teach theories, but also to prepare learners to apply these theories in real-life situations.

7.4. Integrating technology into science teaching

The use of technology in physical science teaching makes concepts more accessible and concrete for learners. Tools such as interactive simulations, digital modelling platforms, and virtual and augmented reality environments offer opportunities for experimentation that traditional resources do not. These tools make it possible to experiment with complex physical phenomena in safe conditions and at low cost. The use of technology is particularly relevant in the STEM approach, which seeks to link science, technology and engineering in practical projects.

Research by Jonassen (1999) and Gee (2003) shows that technology-supported learning environments enable learners to interact more actively with the content, thus promoting a better understanding of scientific concepts [19, 20].

7.5. Formative assessment and feedback in STEM learning

In the STEM approach, formative assessment plays a crucial role in the learning process. Unlike traditional assessments which focus on final outcomes, formative assessment enables learners' progress to be monitored in real time and teaching to be adapted to their needs. As Black and Wiliam (1998) point out, formative assessment enables teachers to provide immediate and constructive feedback that helps learners to improve their understanding [21].

The use of formative assessment in a STEM environment also increases learner engagement, as it gives them feedback on their performance in projects and practical activities, rather than just on theoretical tests.

7.6. Complex problem solving and the systems approach

One of the major objectives of the STEM approach is to prepare learners to solve complex, often multidisciplinary, problems. The systems approach, described by Senge (1990), is particularly well suited to this type of problem, as it enables a phenomenon or problem to be analysed from different angles, integrating several disciplines [22]. This approach is essential for teaching the physical sciences, where concepts often need to be analysed in real-life contexts involving multiple, interconnected factors (National Research Council, 2012). Learners learn to solve problems using a systems approach, which enhances their ability to deal with complex situations and work collaboratively [23].

This theoretical framework demonstrates that the integration of the STEM approach into physical science education is based on a set of well-established pedagogical principles, ranging from constructivism and project-based learning to the use of technology and complex problem solving. The STEM approach overcomes traditional barriers in science education by providing a more hands-on, engaging and interdisciplinary learning experience. By combining best pedagogical practice with the latest technological advances, this approach creates unique opportunities to make physical science education more relevant and accessible to today's learners.

8. Research methodology

The methodology of this research aims to develop an integrated pedagogical device based on the STEM (Science, Technology, Engineering, Mathematics) approach for teaching physical sciences. This research uses a mixed methodological approach (quantitative and qualitative) to design, implement and evaluate the device in question. This combination makes it possible to collect data both on the measurable effects of the system (academic performance, skills developed) and on the perceptions and experiences of the teachers and learners involved [24].

8.1. Methodological approach

The mixed approach combines quantitative methods (such as knowledge tests and surveys) and qualitative methods (such as interviews and classroom observations). This approach enables a comprehensive analysis of the scheme, using both statistical data and subjective feedback from participants [25]. The aim is to gain a better understanding of the impact of the STEM system on physical science learning and the perceptions of teachers and learners.

8.2. Design of the STEM teaching system

The first stage of the research consists of designing the teaching device based on the STEM approach for teaching physical sciences. This phase includes:

- Identification of pedagogical needs and gaps in current physical science teaching (through a literature review and interviews with teachers).
- Definition of clear teaching objectives linked to the skills targeted by the STEM approach: understanding of scientific concepts, problem-solving skills, ability to apply science in real-life situations.
- Creation of STEM teaching modules: The modules will be designed around interdisciplinary projects that challenge learners to solve complex problems by combining science, technology, engineering and mathematics.
- Selection of technological tools: Digital platforms (such as simulations, modelling software) or other tools can be selected and integrated to support learning projects [26].

8.3. Sampling and Implementation Context

8.3.1. Selection of participants

The sample will be made up of secondary school pupils or university science students in voluntary classes where the device will be tested. The participants will be divided into two groups:

- Experimental group: A group of learners who will benefit from the STEM approach t o teaching physical sciences.
- Control group: A group of learners who will be taught using traditional teaching methods (traditional lessons, theoretical exercises).

8.3.2. Inclusion criteria

The learners must be in a physics class and must have a comparable level of basic knowledge before the intervention (measured by a pre-test) [27].

8.4. Data Collection

8.4.1. Quantitative data

- Knowledge tests: Pre- and post-tests will be administered to measure learners' progress in understanding physical concepts before and after using the STEM device [28].
- Satisfaction surveys: Questionnaires will be distributed to learners and teachers to assess the perceived effectiveness of the system, their level of satisfaction and their commitment to the projects [29].

8.4.2. Qualitative data

- Semi-structured interviews: Interviews will be conducted with teachers to gather their perceptions of the impact of the scheme, how easy it is to implement, and any difficulties encountered.
- Classroom observations: Direct observation of classroom interactions during the implementation of the system will enable us to understand how learners use the technological tools and participate in the projects [30, 31].

8.5. Data analysis

8.5.1. Quantitative Analysis

Descriptive and inferential statistics will be used to analyse the pre-test and post- intervention results (for example, t-tests to compare the means of the experimental and control groups). The aim is to measure the impact of the STEM system on the understanding of scientific concepts [32].

8.5.2. Qualitative analysis

The interview and observation data will be analysed using thematic analysis, a method for identifying, analysing and reporting patterns in qualitative data. Tools such as NVivo or Atlas.ti can be used to organise and code the data [33].

The results will be discussed in the light of pedagogical theories and the objectives of the STEM approach. Practical recommendations will be formulated for the integration of similar systems in other educational contexts, based on the results obtained [34].

9. Expected results

The expected results of this research concern both the pedagogical effects of the STEM device on the teaching of physical sciences, and the repercussions on the learners and teachers involved in the experiment. These results should lead to a better understanding of the impact of the STEM approach on learner learning, learner motivation and engagement, and teacher practice.

Here is an overview of the main results expected in the various areas of the study.

9.1. Improving understanding of physical science concepts

9.1.1. Academic progress measured by knowledge tests

One of the major expected results is a significant improvement in learners' knowledge of the physical sciences, measured by pre-test and post-intervention tests [21]. Comparing the results of the experimental group (taught with the STEM device) and the control group (taught in the traditional way), we expect significant progress in the following areas:

- Understanding of physical concepts: Learners should demonstrate a better grasp of key concepts in physics, such as kinematics, dynamics, electricity, etc.
- Ability to apply theoretical knowledge to practical situations: Through STEM projects, learners should be able to solve complex problems by applying their scientific knowledge in real or simulated contexts (for example, by designing experimental set-ups or using simulation software).

9.1.2. Developing cross-disciplinary skills

Another expected outcome is the improvement of cross-cutting skills among participants (learners), such as :

- Problem-solving skills: Learners need to develop their ability to tackle complex scientific problems, in particular by combining knowledge from several disciplines (science, technology, mathematics and engineering) [35].
- Teamwork skills: As STEM projects are often carried out in groups, students are expected to improve their social and collaborative skills, such as communication, project management and cooperation [36, 37].
- Creativity and innovation: learners must demonstrate a greater ability to propose original solutions to the problems posed, thanks to the practical and exploratory approach of STEM modules [38].

9.2. Learner motivation and commitment

9.2.1. Increased motivation to learn science

Another expected result is an increase in learners' motivation to learn physical sciences. The integration of technology and hands-on projects is expected to make learning more interesting and relevant for learners. Several aspects of this motivation should be monitored:

- Intrinsic motivation: Learners should develop a deeper interest in the subject, stimulated by practical activities, simulations and real-life problem-solving [39].
- Reducing science-related anxiety: The STEM approach, using concrete projects, could help learners overcome any apprehensions they may have about science, by showing them the practical and creative dimension of the discipline.

9.2.2. Engagement in learning tasks

Learners are also expected to be more engaged in learning activities, as evidenced by active participation in class, investment in projects and more autonomous learning behaviour. This could be measured by :

- Involvement in projects: The degree to which learners are involved in group projects, their enthusiasm for carrying out experiments and finding innovative solutions.
- Autonomy in learning: Learners should show a greater ability to work independently, to use digital tools to solve problems, and to make informed decisions during projects [39].

9.3. Teachers' perceptions and teaching practices

9.3.1. Positive perception of the STEM approach

Expected outcomes also include positive changes in teachers' perceptions of the STEM approach. After using the pedagogical device, teachers should report :

- Greater satisfaction with traditional teaching methods: By observing their pupils' progress, teachers may be more enthusiastic about continuing to use active and interdisciplinary approaches.
- Ease of use of technological tools: Teachers will also have to express their degree of comfort with the use of technologies (such as simulations, modelling software), and their ability to integrate these tools into their daily teaching practices.

9.3.2. Changes in teaching practices

Teachers should report an evolution in the way they teach, marked by greater interdisciplinarity, student-centred teaching, and an emphasis on cross-disciplinary skills. Teaching should become more collaborative and focused on solving real problems, rather than simply transmitting theoretical knowledge [26].

9.4. Long-Term Impact on Physical Science Teaching Practice

9.4.1. Support for sustainable educational innovation

STEM could have a long-term impact on the way teachers approach the teaching of the physical sciences. If the scheme is judged to be effective, it could be incorporated into teaching practice in a sustainable way, not only in experimental classes but also in other classes, with the gradual introduction of the STEM approach into the school curriculum.

9.4.2. Fostering a culture of innovation in science teaching

Finally, this experience could encourage a culture of educational innovation, where teachers would be more inclined to experiment with new approaches and collaborate with colleagues from other disciplines (technology, engineering, mathematics) to enrich science teaching.

10. Synthesis

This research explored the design, development and evaluation of an innovative teaching device based on the STEM (Science, Technology, Engineering, Mathematics) approach for teaching physical sciences in a Moroccan context. The aim was to analyse the impact of this approach on learners' academic performance, motivation and commitment, as well as on teachers' teaching practices.

Initially, the design of the teaching tool was based on an interdisciplinary approach, encouraging the integration of different STEM fields through practical and collaborative projects. Digital tools, such as simulations and modelling software, were used to enable learners to solve real, complex problems while developing cross-disciplinary skills such as problem-solving, communication, collaboration and creativity.

Secondly, the research methodology combined quantitative (knowledge tests) and qualitative (observations, interviews) approaches to assess the impact of the system. Among the expected results, we can say that the learners in the experimental group (STEM) make significant progress compared with the control group in their understanding of scientific concepts in physics. Perhaps they will also show greater engagement and motivation for science learning, thanks in particular to the concrete and interactive nature of the projects. In addition, teachers may report an improvement in their teaching practices, with a renewed interest in the use of technology and learner-centred approaches.

The results will thus confirm that the STEM approach, by promoting active learning, interdisciplinarity and the use of technology, can have a positive impact on the understanding of the physical sciences and on the development of essential cross- curricular skills for students in the 21st century.

11. Conclusion and perspectives

This research demonstrated the effectiveness of the STEM approach to teaching physical science. The main conclusions are as follows:

Firstly, improved academic performance; learners who have experienced STEM have shown significant progress in their understanding of scientific concepts. The practical, interdisciplinary approaches have helped to improve knowledge retention and the application of concepts in real-life contexts.

Secondly, increased motivation and commitment; the integration of concrete projects and the use of technology have led to an increase in learner motivation, reducing anxiety about learning science and generating genuine interest in the subject.

Thirdly, a change in teaching practices; teachers have been able to renew their teaching practices by adopting more collaborative and interactive approaches. This has helped to promote teaching that is more learner-centred and focused on the practical application of scientific knowledge.

Thus, the STEM approach appears to be an effective model for modernising physical science teaching, adapting it to the contemporary challenges of society and to the needs of a generation of learners increasingly familiar with technology and interdisciplinary practices.

The positive results of this research pave the way for a number of future prospects, both for continuing to test the system and for developing it on a larger scale:

- Extending the system to other subjects and levels: Although this research focused on the physical sciences, the STEM approach could be adapted to other subjects.
- scientific subjects (geology, biology, mathematics) and even to non-scientific disciplines (for example, the social sciences or the arts). In addition, extending the approach to other levels of education could open up new research prospects.
- Incorporation of new educational technologies: The integration of technologies into STEM education has shown positive effects, but there is still potential
- important for the integration of new educational technologies, such as augmented reality (AR), virtual reality (VR) or tools based on artificial intelligence. These technologies could further enrich learning by creating immersive and interactive learning environments.
- Long-term monitoring of learners' skills: An important research perspective would be to monitor the evolution of learners' skills in the long term after the training period.

- the introduction of the STEM approach. This would make it possible to assess the lasting impact of the approach on the training of cross-disciplinary skills (such as problem-solving, critical thinking and creativity) and on the career orientation of learners towards careers in STEM fields.
- Ongoing teacher training: A key element in the success and sustainability of the STEM approach is the training and ongoing support of teachers. It would be to develop in-service training programmes on the integration of STEM methods, and even a model based on the STEM approach for training (adult) teachers, with practical support on the use of technologies and the management of interdisciplinary projects.
- Large-scale evaluation: A wider, large-scale evaluation of the STEM approach in a variety of schools, both urban and rural, and in contexts

This would enable the results obtained to be validated further and the system to be adapted to local conditions (availability of resources, level of preparation of teachers, etc.).

This research makes a significant contribution to the development of physical science teaching by showing the positive impact of a system based on the STEM approach. By integrating practical projects, the use of technology and active teaching, this approach not only enhances understanding of scientific concepts, but also develops key skills for learners' future. Integrating STEM into educational practices could well be a lever for preparing learners for the challenges of an interconnected and technological world, while promoting a more motivating and inclusive pedagogy.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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