# AI-Enabled Experiential Learning in Physics: Enhancing Conceptual Understanding and Engagement

Priyanka, Assistant Professor, Department of Physics, Government PG College, Ambala Cantt.

Email: priyankachug2013@gmail.com

## Abstract

Physics education plays a crucial role in developing analytical thinking, scientific reasoning, and technological competence required to address modern scientific and industrial challenges. However, traditional lecture-based approaches often limit student's ability to connect abstract theoretical concepts with practical applications. This paper discusses an integrated pedagogical approach that combines Experiential Learning (EL), Project-Based Learning (PBL), and Artificial Intelligence (AI)-enabled educational tools to enhance conceptual understanding and student engagement in physics.

The study provides an analysis of frameworks for incorporating hands-on experiments, interdisciplinary projects, virtual laboratories, simulation tools, augmented reality applications, and AI-supported adaptive learning platforms. These tools provide personalized feedback, promote active learning, and facilitate deeper comprehension of complex physics concepts. The approach also emphasizes academic–industry interaction, internships, and skill-oriented training to bridge the gap between classroom instruction and professional practice.

By integrating experiential pedagogy with intelligent technologies, the proposed model aims to foster critical thinking, creativity, research aptitude, and employability. This paper presents a conceptual review of literature on practical insights and implementation strategies for experiential learning, project-based learning and adopting an AI-integrated, application-driven model of physics education for enhancing student engagement and conceptual understanding.

**Keywords: Physics Education; Experiential Learning; Artificial Intelligence; Project-Based Learning; Technology-Enhanced Learning**

## 1. Introduction:

Research in physics education has evolved considerably over the past several decades as educators and researchers have attempted to better understand how students learn scientific concepts and how teaching practices can be improved. Early research in physics education mainly focused on identifying the misconceptions and intuitive ideas that students bring to the classroom when learning fundamental physical principles. As a result, understanding student thinking and conceptual development became a central concern in physics education research. Experienced physics educators have also recognized several practical challenges associated with teaching physics in large and crowded classrooms where instruction is typically delivered by a single teacher. In such settings, it often becomes difficult to address individual learning needs and promote meaningful conceptual engagement among students. As noted by Edward F. Redish, physics is often perceived by students as a difficult subject that is not easily understood or connected with everyday life. Many students struggle to relate physics concepts to real-world experiences and fail to develop the scientific reasoning skills required for advanced study in physics. To understand these challenges in detail, physics education researchers have focused on investigating how physics learning occurs and identifying students' misconceptions or alternative conceptions in specific topics. The identification of these misconceptions has led to the development of research-based instructional strategies and teaching materials designed to improve conceptual understanding.

However, this approach sometimes lacks a strong connection between physics education and practical aspects of everyday life. Students often end up memorizing derivations and concepts and reproducing them in examinations rather than developing meaningful understanding. Traditional educational practices also do not always provide sufficient opportunities for personalized learning or for relating physics concepts to real-world experiences. With the advancement of educational technologies, the use of computer-assisted instruction

and digital learning environments in physics teaching has increased. Researchers have explored how simulations, computer-based laboratories, and interactive instructional tools can enhance student engagement and conceptual understanding. In recent years, there has also been growing emphasis on inquiry-based and activity-oriented instructional approaches that encourage students to actively participate in the learning process. The COVID-19 pandemic further accelerated the adoption of digital platforms and technology-enhanced learning in education. The increasing digitalization of education has encouraged more interactive and exploratory learning environments, promoting deeper conceptual engagement through experimentation, discussion, and collaborative learning.

Despite these advancements, an important challenge remains regarding the structure and content of physics curricula. In many cases, physics courses appear to students as a collection of separate topics rather than a coherent framework for understanding the natural world. In many instructional contexts, physics teaching emphasizes solving numerical problems using memorized formulas, which may lead students to perceive physics as a purely mathematical exercise rather than a meaningful tool for explaining real-world phenomena. Such perceptions can negatively influence student motivation and interest in the subject.

In addition to addressing conceptual challenges, twenty-first-century educational frameworks must focus on developing a wide range of competencies, including critical thinking, creativity, collaboration, and advanced problem-solving abilities.

Developing instructional approaches that create meaningful conceptual bridges between classroom learning and real-life applications therefore remains an important objective for educators. In particular, experiential learning through projects based on real-world problems can make physics learning more accessible and meaningful for students. Such approaches allow learners to apply theoretical concepts to practical situations, thereby improving conceptual understanding while also developing problem-solving and critical thinking skills. Moreover, engaging students in real-life problem–based projects can make physics education more relevant to future careers and contribute to making learning more skill-oriented and job-oriented.

Although experiential learning, project-based learning, and artificial intelligence–supported educational technologies have been widely discussed individually in educational research, their integrated role in transforming physics education has received comparatively limited conceptual analysis.

In this context, there is a growing need to adopt innovative pedagogical approaches that connect theoretical knowledge with practical applications in physics education. Experiential learning and project-based learning offer opportunities for students to actively engage with scientific concepts through investigation, experimentation, and collaborative problem solving. At the same time, recent advances in artificial intelligence provide new possibilities for enhancing learning through adaptive instruction, intelligent feedback systems, and personalized learning pathways. Integrating these approaches can create dynamic and interactive learning environments that promote deeper conceptual understanding and stronger analytical skills. Therefore, this paper presents a conceptual review of experiential learning, project-based learning, and AI-supported educational technologies in physics education and discusses strategies for developing an application-oriented learning framework that enhances student engagement, conceptual clarity, and skill development in higher education.

## 2. Literature Review and Discussion

The rapid development of artificial intelligence (AI) has created new possibilities for improving teaching and learning in physics education. AI-based educational technologies can support adaptive learning environments, where instructional materials and feedback are tailored according to individual student needs. Such systems can analyse learning patterns, identify conceptual difficulties, and provide targeted guidance to learners. The growing

integration of artificial intelligence in education also aligns with the vision of the National Education Policy 2020, which emphasizes the transformative potential of digital technologies in improving the quality, accessibility, and inclusiveness of education.

Alongside technological advancements, learner-centred pedagogical approaches have gained increasing recognition in science education. In physics classrooms, there has been a gradual shift from purely lecture-based instruction to more active learning environments. Teaching strategies such as collaborative problem solving, simulation-based activities, case studies, and experimental demonstrations encourage students to participate actively in the learning process rather than passively receiving information. Approaches such as experiential learning and project-based learning have been widely discussed as effective methods for improving student engagement, strengthening conceptual understanding, and promoting long-term retention of knowledge.

## 2.1 Project-Based Learning

Scientific literacy has become increasingly important in modern societies where technological progress and environmental challenges influence everyday decision-making. A sound understanding of physics helps individuals interpret scientific information, evaluate technological developments, and engage in discussions related to issues such as climate change, renewable energy, and environmental sustainability.

Recent educational research highlights the importance of connecting physics learning with real-world problems and societal challenges. Instructional approaches that incorporate sustainability themes and modern technologies can encourage students to apply physics concepts in meaningful contexts. Project-based learning provides one such approach by allowing students to explore authentic problems while developing analytical and collaborative skills.

Project-based learning is an instructional strategy in which students investigate complex questions or problems through inquiry, research, and collaborative activities.

In this approach, learners formulate questions, gather and analyse information, develop explanations, and communicate their findings through presentations or project reports. These processes promote deeper conceptual understanding while helping students develop important competencies such as teamwork, communication, and critical thinking.

Joseph S. Krajcik and his colleagues describe project-based learning as a constructivist approach that emphasizes inquiry-driven learning and meaningful engagement with real-world issues. In PBL environments, students work collaboratively to investigate problems, formulate hypotheses, design investigations, and analyse results. Through these activities, learners actively construct knowledge rather than simply memorizing information.

Research by Hetty Roessingh identifies several essential features of project-based learning. These include sustained inquiry over extended periods, meaningful dialogue among learners, opportunities for both independent and collaborative work, and the development of a final product that reflects students' understanding of the subject. Effective implementation of PBL requires instructors to design clear guiding questions and structured learning activities that encourage students to investigate complex and relevant topics.

The theoretical foundations of project-based learning can be traced to the educational philosophies of John Dewey, who emphasized learning through purposeful inquiry into real-life experiences, and Lev Vygotsky, who highlighted the importance of social interaction and collaborative learning in cognitive development.

A case study conducted by Olzan Goldstein examined the implementation of project-based learning in a "Fundamentals of Physics" course designed for pre-service elementary teachers. In this study, students worked in small groups to complete physics-related projects that required investigation, discussion, and presentation of results. The findings indicated that the PBL approach increased student engagement and motivation. Many participants reported that

working on projects helped them understand physics concepts more clearly and reduced their anxiety toward the subject. The collaborative nature of project work also contributed to the development of communication skills, teamwork, and effective use of digital learning tools.

Another study by P. Parreira and colleagues explored the use of project-based learning in introductory physics laboratory courses. In this experiment, traditional laboratory exercises were replaced with an open-ended group project in which students designed and built a weather monitoring station. Over several weeks, students integrated concepts from electronics, sensor calibration, programming, and data analysis while planning and documenting their work. The results showed that project-based laboratory activities increased student engagement and encouraged the practical application of theoretical knowledge. In addition, students developed transferable skills such as collaboration, communication, and project management, which are important for professional practice in scientific and engineering fields.

## 2.2 Experiential Learning

Experiential learning represents another important pedagogical approach in physics education. This model emphasizes learning through direct experience, reflection, and experimentation. According to David A. Kolb, experiential learning occurs through a cycle consisting of concrete experience, reflective observation, abstract conceptualization, and active experimentation.

In physics classrooms, experiential learning often takes place through laboratory experiments, demonstrations, and hands-on investigations. Such activities enable students to observe physical phenomena directly and connect theoretical concepts with observable outcomes. By engaging actively in experimentation and reflection, students develop scientific reasoning skills and a deeper understanding of physical principles.

Several studies have reported positive outcomes associated with experiential learning in science education. Hands-on experimental activities have been shown to improve students' science process skills, conceptual understanding, and attitudes toward physics. The use of simple experimental kits and practical demonstrations can make abstract concepts more accessible and encourage learners to participate more actively in classroom activities. These approaches help create learning environments where students explore ideas, test hypotheses, and reflect on their observations.

Research by A. H. Johari and Muslim also demonstrated that experiential learning activities using simple physics kits can significantly improve students' attitudes toward physics. Their findings indicated that students who participated in hands-on experimental learning showed higher levels of engagement and interest compared with those who learned through traditional instructional methods.

## 2.3 Artificial Intelligence in Physics Education

The integration of artificial intelligence into physics education provides new opportunities for enhancing teaching and learning processes. AI-based educational systems can analyse patterns in student performance, provide targeted feedback, and recommend personalized learning pathways that help students overcome conceptual difficulties. Such technologies can complement traditional teaching practices by offering additional support for learners with diverse backgrounds and learning styles.

Various types of AI-supported tools can contribute to interactive and personalized learning environments. Adaptive learning platforms can adjust the difficulty level of instructional materials according to individual student progress.

Intelligent tutoring systems can guide students step-by-step through problem-solving processes and provide immediate feedback. AI-based simulations and virtual laboratories also allow learners to explore complex physical phenomena that may be difficult to demonstrate in conventional classroom settings. In addition, data-driven learning analytics can help instructors monitor student performance and identify areas where additional support may be required.

AI technologies can also be combined with project-based learning to promote inquiry-based and application-oriented education. In physics courses, students may work on projects such as analysing solar energy efficiency, developing sensor-based environmental monitoring systems, or using simulation tools to study wave motion and electric circuits. These activities encourage learners to apply theoretical knowledge to real-world problems while developing research and problem-solving skills.

A study conducted by Hassane Kemouss and Mohamed Khaldi investigated the use of artificial intelligence in supporting personalized physics learning. Their research focused on how AI-based educational tools could assist students with different learning preferences identified within Kolb's experiential learning framework. The findings suggested that interactive simulations, automated feedback systems, and educational chatbots can help learners explore concepts more actively and receive guidance tailored to their learning progress.

Similarly, research by Zachary B. Spector and Douglas Fields examined the potential of generative AI tools for creating physics simulations. Their work demonstrated that large language models can be used to generate simple browser-based simulations that allow students to manipulate variables and observe the behaviour of physical systems in real time. Such simulations provide flexible opportunities for exploratory learning; although the authors emphasize that AI-generated models must be carefully verified to ensure scientific accuracy.

## 3. Ethical and Practical Considerations

While artificial intelligence offers many opportunities for enhancing physics education, its use also raises important ethical and practical considerations. AI systems rely on large datasets, and biases present in these datasets may influence the outcomes generated by algorithms. Issues related to transparency, accountability, and explainability are therefore important when AI tools are used in educational environments.

Concerns about privacy and data protection are also significant because AI-based educational platforms often collect and analyse large amounts of student data. Ensuring responsible data management and clear institutional policies is essential for protecting student rights.

At the same time, AI technologies can support inclusive education by providing assistive tools such as automated translation systems, speech recognition, and text-to-speech applications.

These tools can help learners from diverse linguistic backgrounds and students with disabilities participate more effectively in learning activities.

However, unequal access to digital infrastructure remains a major challenge, particularly in rural or under-resourced educational institutions. Without adequate technological infrastructure and teacher training, the benefits of AI-supported learning may not be evenly distributed. Therefore, careful planning and policy support are required to ensure that the integration of AI in education promotes equity and improves learning outcomes for all students.

## 4. Conclusion

This paper examined the potential role of artificial intelligence in strengthening physics education when combined with learner-centred pedagogical approaches such as experiential learning and project-based learning. The review of literature indicates that AI-supported educational tools can create adaptive learning environments, provide personalized feedback, and support interactive simulations that help students engage more deeply with complex scientific concepts. When integrated with hands-on experimentation and inquiry-based projects, these technologies can contribute to dynamic learning environments that promote exploration, problem solving, and conceptual understanding in physics.

The discussion also highlights that project-based learning and experiential learning approaches enable students to connect theoretical physics concepts with real-world applications. These pedagogical strategies encourage active participation, collaborative investigation, and the development of scientific reasoning skills.

Integrating AI technologies within these approaches can further support individualized learning pathways, facilitate data analysis and simulations, and allow students to investigate complex physical phenomena that may be difficult to demonstrate in traditional classroom settings. Despite these potential advantages, several challenges remain in the effective implementation of AI in physics education.

Concerns related to the reliability of AI-generated information, possible overdependence on automated systems, and ethical issues such as data privacy and algorithmic bias require careful consideration. In addition, successful integration of AI technologies depends on adequate teacher training, curriculum alignment, and appropriate digital infrastructure. Addressing these challenges is essential to ensure that AI tools support meaningful learning rather than simply replacing traditional instructional practices.

Future research should therefore focus on developing practical frameworks for integrating artificial intelligence with experiential and project-based learning in physics education. One promising direction involves exploring the use of embedded or stealth assessment tools within AI-supported learning environments to better understand how students develop conceptual understanding and problem-solving abilities during inquiry-based activities. Further investigations may examine how AI can strengthen active learning strategies in physics classrooms by supporting experimentation, simulations, collaborative projects, and data-driven analysis. Comparative studies across different institutions and educational systems may also help identify effective practices for integrating AI into science and engineering curricula. Such studies could highlight both successful implementation strategies and challenges related to infrastructure, training, and curriculum design.

In addition, future work should consider the role of international collaboration and knowledge exchange in advancing AI-supported educational models. Partnerships among universities, research institutions, and technology developers may contribute to the development of innovative learning environments that better prepare students for scientific and technological challenges. Finally, future research should also examine individual differences among learners, including their prior experience with technology, motivation, and attitudes toward artificial intelligence, as these factors may significantly influence how students interact with AI-supported learning systems.

Overall, the integration of artificial intelligence with experiential and project-based learning offers significant potential for transforming physics education. With careful implementation, appropriate training, and continued research, these approaches can support deeper conceptual understanding, foster scientific inquiry, and contribute to more engaging and inclusive learning environments.

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