

STEM and Technology: Transforming Education

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Chapter Highlights

This chapter provides a concise overview of STEM learning as a modern, technology-integrated educational approach that supports student engagement, meaningful learning, and the development of 21st-century competencies.

- Examines the concept, characteristics, and scope of STEM learning as a contemporary approach adaptable to school-based, home-based, and virtual learning environments.
- Explores the integration of emerging technologies, such as robotics, artificial intelligence, simulations, and virtual platforms, in supporting interactive and project-based STEM learning.
- Highlights the role of STEM instruction in improving student engagement, enjoyment, and learning outcomes through hands-on and technology-supported activities.
- Discusses how STEM learning strengthens essential 21st-century skills, including critical thinking, creativity, collaboration, communication, and problem-solving.
- Presents practical examples and case studies of STEM implementation at different educational levels to support effective classroom practice.
- Addresses key challenges in implementing STEM education, such as infrastructure limitations, teacher readiness, and unequal access to technology, while identifying emerging opportunities for STEM development.

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INTRODUCTION

Basic Concepts of STEM in Education

STEM (Science, Technology, Engineering, and Mathematics) education is a learning approach that integrates four main disciplines in an interdisciplinary manner (Maass et al., 2019; McDonald, 2016). STEM not only teaches theoretical concepts but also encourages students to develop critical thinking, problem solving and innovation skills through practice-based projects (Mu'minah, 2021). The STEM approach to education aims to equip students with the 21st century skills needed in the world of work, such as creativity, communication and collaboration (Honey et al., 2014). The basic concepts of STEM emphasize project-based learning and interdisciplinary approaches that enable students to apply scientific concepts in real-world situations (Margot & Kettler, 2019). Thus, STEM education does not only focus on theory but also on practical applications that are relevant to everyday life. This aims to build a more interesting and meaningful learning experience for students.

STEM education also emphasizes the integration of disciplines into a single, complex project or problem. For example, in a mini-bridge building project, students not only learn about the laws of physics and mathematics involved in bridge design, but also use technology to model and engineer the structure of the bridge (Honey et al., 2014). Thus, STEM provides opportunities for students to develop more holistic, cross-disciplinary skills.

One important aspect of STEM education is the role of technology in supporting the learning process. Technology is used to enhance students' understanding of STEM concepts through digital simulations, virtual laboratories, and interactive learning (Abdi et al., 2021; Sari* et al., 2022), as well as artificial intelligence (AI) based software that assists in data analysis and decision making (Xu & Ouyang, 2022). In addition, the use of robotics in STEM education is also a growing trend, students who are involved in robotic activities tend to be more motivated and challenged to explore more deeply. In addition, robotics training has also been shown to be effective in developing various other important skills, such as problem solving, teamwork, and creativity (Ramadhani & Zahrani, 2024).

STEM is an acronym for science, technology, engineering, and mathematics. The term was first launched by the National Science Foundation (NSF) of the United States (US) in 1990 as a theme for the education reform movement to grow the STEM workforce, develop STEM literate citizens, and increase the United States' global competitiveness in science and technology innovation

(Mccomas, 2014). In recent years, research in the field of STEM has proven that STEM can be applied in various forms such as project-based learning, laboratory experiments, and the use of digital technology in the learning process. The main advantage of STEM education lies in its ability to integrate theoretical concepts with practical applications, thus equipping students with the skills needed to face challenges in the industrial world and future technological developments.

The implementation of STEM education in the school curriculum faces various challenges, many factors cause the lack of implementation of STEM project learning in schools. The lack of teacher control over the pace of the curriculum and its consequences for teaching is also considered a challenge for teachers in their efforts to integrate interdisciplinary subjects for authentic STEM lessons (Herro & Quigley, 2017), other barriers include administrative and financial support (Asghar et al., 2012; Ming-Chien Hsu et al., 2011; H. J. Park et al., 2016; M. H. Park et al., 2017), or lack of technological resources for students such as computers (Wang et al., 2011). Student concerns are another barrier to integrating STEM education. Sometimes, teachers feel that students are not capable enough or are not interested enough to be actively involved in STEM integration. Teachers also sometimes underestimate students' ability to solve STEM-related problems (Al Salami et al., 2017; Tuong et al., 2023; van Haneghan et al., 2015). Many teachers find some of the subject matter too difficult for students, which can lead to a decrease in student motivation. Teachers in rural areas are concerned because many of their students have low achievement, and adapting the curriculum to meet the needs of these students is a challenge (Goodpaster et al., 2018). These concerns may influence teachers' intentions, approaches, and success in implementing STEM teaching (Le et al., 2021). The limited number of teaching staff who have expertise in STEM and the difficulty in integrating four disciplines effectively in one learning requires training and professional development for teachers to improve their capacity in implementing STEM learning in the classroom. In addition, the involvement of industry and higher education institutions is also very important in supporting the development of better STEM education.

In some countries STEM education has become an integral part of national education systems. For example, in the United States, education reforms emphasize the need to develop the complex technology and engineering skills that students need to participate in a knowledge-based economy (Börner et al., 2018; van Laar et al., 2017; Wang et al., 2011) but their offerings sometimes misalign with commercial needs and new techniques

forged at the frontiers of research. Here, we analyze and visualize the dynamic skill (mis-. Meanwhile, countries such as Finland and Singapore have systematically implemented the STEM approach in their curricula, with a focus on inquiry-based learning and problem solving (Murphy et al., 2023; Roy, 2019).

In general, STEM education plays an important role in preparing the younger generation to face global challenges in the Industrial Revolution 4.0 era. With the right approach, this education can support students in honing critical thinking, creativity, communication, and collaboration skills that are essential in the future world of work. Therefore, STEM education policies and implementation strategies need to be continuously developed in order to provide optimal benefits for students and the wider community.

The role of technology in STEM education

Technology plays a crucial role in STEM (Science, Technology, Engineering, and Mathematics) learning, acting as a catalyst that enriches the learning experience, increases student engagement, and prepares students for the challenges of the modern world. The integration of technology in education not only facilitates the understanding of complex concepts but also develops essential 21st-century skills, such as critical, creative, and collaborative thinking.

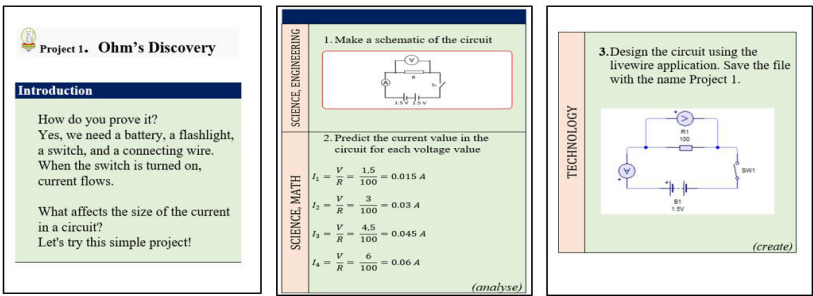


Figure 1. Example of Virtual Experiment and Placement of HOTS Elements (Yennita et al., 2022)Design, Develop, Implementation and Evaluation

The use of technology in STEM learning creates an interactive and dynamic learning environment. For example, augmented reality (AR) applications allow the visualization of abstract concepts to be more concrete, so that students can understand the material more deeply. A picture shows that AR applications in education can improve students' understanding of STEM

material by making learning more interesting and interactive (Godoy Jr, 2022). In addition, with the existence of learning technology, STEM projects can be implemented well. The following is an example of a STEM project that is carried out virtually.

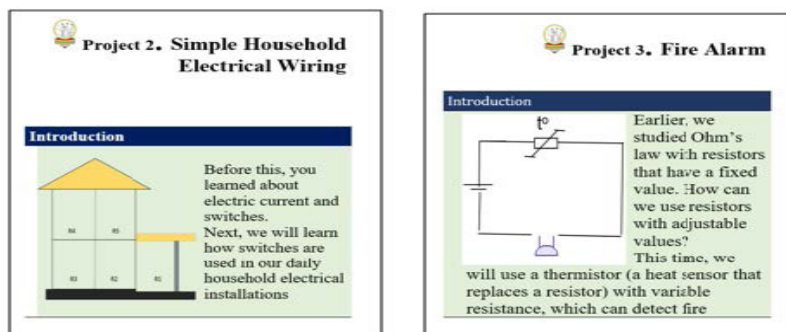


Figure 2. Example of a Virtual STEM Project (Yennita et al., 2022) Design, Develop, Implementation and Evaluation

The use of technology in STEM in addition to being used in virtual experiments, technology can also be used in building STEM projects virtually. The following are STEM projects that are built virtually.

By effectively leveraging technology, educators can create more meaningful and relevant learning experiences, preparing students for future challenges and opportunities. Thus, technology integration in STEM learning is not just an option but a necessity to ensure that education remains relevant and adaptive to the times.

The Importance of Technology Integration in STEM

The integration of technology in STEM (Science, Technology, Engineering, and Mathematics) education plays a crucial role in preparing the younger generation to face the challenges of the digital era. The application of technology in STEM learning not only improves students' conceptual understanding but also develops 21st-century skills such as critical thinking, creativity, collaboration, and digital literacy.

One of the main benefits of integrating technology into STEM education is the enhancement of critical thinking and problem-solving skills. Through the use of digital tools and platforms, students are encouraged to analyze data, identify patterns, and solve complex problems with a systematic

approach. For example, the use of virtual laboratories allows students to conduct scientific experiments without the constraints of space and time, so that students can test hypotheses and see the results directly. This is in line with research showing that the use of technology in STEM learning can improve students' analytical and problem-solving skills (Hafizah Hussin et al., 2019) Technology, Engineering and Mathematics (STEM).

In addition, technology integration encourages creativity and innovation in learning. The use of devices such as microcontrollers and sensors in science projects allows students to design and build prototypes that solve real-world problems. This approach not only makes learning more interesting but also facilitates students to apply theoretical concepts to real-world practice. For example, a technical toy-making project has been implemented in Vietnam to integrate STEM education, where students are directly involved in the design and construction process, thereby enhancing their technical understanding and skills (Quang et al., 2015).

Collaboration is also an important aspect that is strengthened through the integration of technology in STEM education. Digital platforms and communication tools allow students to work together on group projects, even if they are in different locations. This teaches students teamwork skills, effective communication, and project management. Additionally, collaboration with the tech industry can provide students with practical insights and real-world experiences, preparing them for the real world of work. Collaborations between schools and tech companies, such as the provision of IoT devices and hands-on training from industry professionals, have been shown to improve the quality of learning and the relevance of the curriculum to industry needs.

Digital literacy is also an essential component gained through the integration of technology in STEM education. Students not only learn to use devices and applications, but also understand the working principles behind the technology. This understanding is important so that students can adapt quickly to technological developments and become innovators in the future. For example, the introduction of robotics in the STEM curriculum helps students understand the concepts of programming and mechanics, which are the foundation of many modern technologies.

The implementation of technology integration in STEM education is not without challenges. Limited resources, such as lack of technological devices and internet access, as well as the need for adequate teacher training, are

obstacles that need to be overcome. Therefore, support is needed from various parties including the government, educational institutions, and the private sector, to provide the necessary facilities and conduct training programs for educators. In addition, the development of a flexible and adaptive curriculum to technological developments is also the key to success in this integration (Davidi et al., 2021). Overall, the integration of technology in STEM education is a strategic step to prepare a competent and adaptive young generation in the digital era. By utilizing technology as a learning tool, students not only gain theoretical knowledge, but also practical skills that are relevant to the needs of the times. This is in line with the goal of education to produce individuals who are able to contribute positively to society and are ready to face the dynamics of technological developments in the future.

Technological Developments in the World of Education

Technology has experienced rapid development in the world of education, giving a significant impact on learning methods and interactions between educators and students. Along with the emergence of the industrial revolution 4.0, various technological innovations have begun to be applied in education, such as the use of artificial intelligence (AI), big data, the Internet of Things (IoT), and augmented reality (AR) and virtual reality (VR). These technologies not only help in increasing the effectiveness of learning but also enrich students' learning experiences with a more interactive and innovative approach (Pratama & Setiawan, 2022).

In the digital era, information and communication technology (ICT) has become an integral part of the world of education. Since the introduction of computers in the education system in the late 20th century, technological developments have continued with the emergence of the internet which has changed the way information is accessed. The internet today allows students to obtain wider learning resources ranging from electronic books, scientific journals, online courses, and students can conduct virtual experiments. In addition, Learning Management Systems (LMS) such as Moodle, Google Classroom, and Edmodo are also important tools in online learning that allow for more flexible interaction between teachers and students (Einggi Gusti Pratama & Andhyka Kusuma, 2021).

Other technologies that have had a major impact on education are virtual reality (VR) and augmented reality (AR). Using VR and AR, students can experience deeper and more immersive learning, especially in the fields of science, technology, engineering, and mathematics (STEM). For example, in

biology learning, VR allows students to explore human anatomy interactively without having to use real specimens (Khuzeir Tarmizi et al., 2021).

Although technological developments in education bring many benefits, challenges still remain. One of the main challenges is the gap in access to technology, especially in remote areas or developing countries that still have limited internet infrastructure and digital devices. In addition, teacher readiness in adopting technology is also a determining factor in the success of implementing technology in education. Therefore, training and improving digital literacy for educators is essential to ensure optimal use of technology in learning.

Overall, technological developments in education have brought about a major transformation in the way teaching and learning take place. From the use of the internet to artificial intelligence and virtual reality, technology continues to evolve and provide various solutions to improve the quality of education. However, the success of implementing technology in education still depends on the readiness of infrastructure, teacher training, and education policies that support digital innovation in learning.

Challenges and Opportunities in STEM Implementation

The implementation of STEM (Science, Technology, Engineering, and Mathematics) education in Indonesia faces various challenges that require serious attention. One of the main challenges is the limited facilities and infrastructure in many schools, especially in remote areas. Many schools in Indonesia do not have adequate science laboratories, technological equipment, or stable internet access. These limitations hinder effective learning processes and limit students' opportunities to engage in practical activities that are essential in STEM education. In addition, the readiness and competence of teachers in teaching with a STEM approach is also a significant challenge. Many educators have not received adequate training to integrate science, technology, engineering, and mathematics in learning. This has an impact on the lack of confidence and effectiveness in delivering STEM material holistically and interdisciplinary.

Lack of resources and appropriate learning materials is also a barrier. Schools often lack relevant and up-to-date teaching materials and teaching aids that can support STEM learning optimally. These limitations make the learning process less interesting and less able to facilitate the understanding of complex concepts in STEM. On the other hand, the implementation of STEM education in Indonesia also opens up various opportunities that can

be utilized to improve the quality of education. One of them is the increasing government support for the development of STEM-based education. This initiative includes the integration of the STEM curriculum into the national education system and the provision of training programs for teachers to improve student competency in teaching with a STEM approach. Overall, although there are various challenges in the implementation of STEM education in Indonesia, the opportunities that exist provide hope for further improvement and development. With a joint commitment between the government, educational institutions, industry, and society, STEM education can be an important pillar in preparing a competent young generation of Indonesia who are ready to compete in the era of globalization.

Artificial Intelligence (AI) and Machine Learning in STEM Education

The development of Artificial Intelligence (AI) technology has had a significant impact on the world of education, especially in the fields of Science, Technology, Engineering, and Mathematics (STEM). AI helps improve the learning experience by providing an adaptive learning system that can adjust materials according to student needs. AI in education can optimize data-based learning to provide more personalized recommendations for students. On the other hand, AI contributes to project-based learning and experiments in STEM, where AI-based systems can help students design, test, and analyze experiments more efficiently. However, the main challenge in implementing AI in STEM education is the readiness of the infrastructure and skills of educators in utilizing this technology. The application of AI in education requires intensive training for teachers so that students can effectively integrate this technology into learning. In addition, there are also ethical challenges related to the use of student data that require strict regulations to protect the privacy and security of student information (Selwyn, 2019). With the continued advancement of AI and ML, STEM education can become more inclusive, efficient, and responsive to student needs. Therefore, the integration of this technology must continue to be encouraged with supportive policies and the development of teacher and student competencies in operating AI-based systems in the classroom.

Robotics as a STEM Learning Medium

Robotics plays a vital role in STEM (Science, Technology, Engineering, and Mathematics) education by providing interactive, innovative, and hands-on learning experiences. The use of robotics in learning enables students to understand abstract concepts in STEM through hands-on experiments, which

ultimately enhances students' understanding of science and technology (Jung & Won, 2018). Thus, the integration of robotics in education not only helps students in developing technical skills, but also critical thinking, problem solving, and collaboration skills.

In science, robotics helps students understand the principles of physics, biology, and chemistry through robot-based experiments. For example, sensors on a robot can be used to measure temperature, light, or gas levels in an environment, allowing students to conduct hands-on scientific experiments (Sapounidis & Alimisis, 2020). In the field of technology and engineering, robotics allows students to design, build, and program robots that strengthen students' understanding of mechanical systems and programming (Eguchi, 2016). With these skills, students not only learn technical concepts but also understand how to apply them in real life.

In addition, robotics also enhances computational thinking and programming skills which are an integral part of the STEM curriculum. Robotics-based learning allows students to understand programming concepts practically through simple coding and algorithms implemented in robots (Jung & Won, 2018). By learning programming through robotics, students not only gain technical skills, but also improve their ability to think logically and systematically.

Robotics also plays an important role in increasing student engagement in STEM learning. Several studies have shown that the use of robotics in education can increase student motivation to learn and make students more active in understanding STEM concepts (Nugraha et al., 2020). The project-based learning approach applied in robotics allows students to work in teams, develop innovative solutions, and solve real-world problems. Thus, robotics contributes to fostering collaboration and communication skills that are essential in the future workforce. However, the implementation of robotics in STEM education also faces several challenges, such as limited resources, high costs, and the need for adequate teacher training. Therefore, support is needed from various parties, including the government, educational institutions, and the technology industry to ensure that robotics can be effectively integrated into the STEM curriculum (Benitti, 2018). With adequate investment in robotics technology, it is hoped that students can gain maximum benefits from this innovative learning approach. Overall, robotics has a significant role in STEM education by providing a more engaging and meaningful learning experience for students. With the right application, robotics can help develop 21st-century skills needed to face

future challenges, while increasing students' competitiveness in the digital era.

Using Video Tracker for Motion Analysis

The use of Tracker software in motion analysis has become an important innovation in physics learning. Tracker is an open source software specifically designed to analyze videos and model the motion of objects. By utilizing recorded videos, users can track the position, velocity, and acceleration of an object accurately, making it easier to understand the concepts of kinematics and dynamics in physics. In the context of education, Tracker has been used as a tool to improve students' understanding of the concept of motion. For example, research by Fitriyanto & Sucahyo (2016) shows that the application of Tracker software in kinematics motion practicum can improve students' science process skills. Students become more active in observing, measuring, designing experiments, interpreting data, and communicating. This is in line with the findings of Habibbulloh & Madlazim, (2014) who stated that the use of video analysis methods with Tracker software can improve students' science process skills in the concept of free fall motion. Research that has been conducted, learning using trackers can help students understand the concept of physics learning. The following is a picture of the results of learning analysis using video trackers.



Figure 3. Uniform Linear Motion Experiment

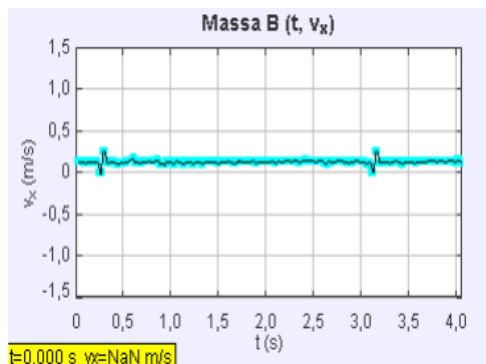


Figure 4. Graph of Uniform Linear Motion Experiment Results

Video Tracker is a digital-based software used to analyze motion in videos. This tool is widely used in physics learning to help students understand the concepts of kinematics and dynamics more concretely. With Video Tracker, students can record or take videos of an object's movement, then analyze its position, velocity, and acceleration frame by frame. The use of Video Tracker allows students to connect theory with real phenomena, thereby improving conceptual understanding and higher-order thinking skills. In addition, this application also trains multi-presentation skills, such as presenting data in the form of graphs, tables, and visual simulations. In technology-based learning, Video Tracker is an innovative tool that encourages scientific exploration and investigation. Through real-data-based analysis, students can develop analytical and problem-solving skills, which are important in STEM-based science learning.

Robotics Projects in STEM Learning

Implementation of robotic projects in STEM learning has been proven effective in improving students' understanding of science, technology, engineering, and mathematics concepts. Case studies in various educational institutions show that the integration of robotics in the curriculum not only enriches the learning experience but also develops 21st-century skills such as problem solving, critical thinking, creativity, and collaboration. One example of the application of robotics in STEM learning is at Joy Kids National Plus Tasikmalaya Kindergarten. There, STEAM extracurricular activities involving robotic coding games have been implemented to train problem-solving skills in early childhood. This approach involves children in unplugged coding activities that help students understand commands in a series, including direction and sequence. The results showed that children were able to develop observation, information gathering, analysis, and communication skills through this activity (Sopiah et al., 2023).

At the junior high school level, the introduction of robotics has also had a positive impact. Lego robot training for students at Bani Hasyim Junior High School (SMP) in Malang Regency, for example, has increased students' interest and understanding of technology and robotics. This activity involves exposure to materials and hands-on practice, where students assemble and program Lego robots to complete certain missions. After the training, 80% of participants expressed interest in studying robotics further, demonstrating the effectiveness of this approach in motivating students (Gumilang et al., 2023). Many studies have been conducted in the application of technology in STEM, research conducted by Yennita et al., (2020) developed a prototype electrical installation as a STEM project for junior high school students and in this study the research team succeeded in developing it. Furthermore, research conducted by Yoeliana et al., (2022) stated that the application of STEM project-based learning can improve students' creative abilities.

In addition, STEM-based robotics training has been conducted in one of the high schools in Bandung City. This training aims to teach physics concepts through robotics, which can foster STEM education and improve logical, creative, innovative thinking skills, and teamwork skills. The results showed that 90% of students understood the introduction to Arduino, analog signals, and programming languages; 98% of students were able to assemble robots; and 95% of students were able to connect programming languages to robots via Bluetooth. In addition, 85% of students understood how to analyze data through graphs and verify them with data from robots (Asri, 2018).

At the junior high school level, the implementation of STEM learning through Lego robot training has also been carried out. This activity involves the presentation of materials and direct practice, where students assemble and program Lego robots to complete certain missions. The results showed an increase in students' understanding of technology and robotics, as well as a high interest in studying the field further (Gumilang et al., 2023).

At the vocational high school level, robotics training and workshops have been provided to teachers and students of SMK Kesehatan Binatama Yogyakarta. This activity aims to improve understanding and skills in the field of robotics, especially in applications in the medical field. The results showed that the training participants gained basic knowledge of robotics and were able to design and program simple robots (Nur'aidha & Sugianto, 2022).

Overall, the above case studies show that the integration of robotic projects in STEM learning has a significant positive impact on the development of students' skills and understanding. This approach not only makes learning more interesting and interactive, but also prepares students to face the challenges of the modern technological era.

Project Based Learning Concept in STEM

Project-based learning in STEM (Science, Technology, Engineering, and Mathematics) education is an innovative approach that puts students at the center of learning. This method encourages students to learn through active exploration, solving real-world problems, and applying concepts across disciplines. In STEM, PBL allows students to develop critical thinking, creativity, communication, and collaboration skills that are essential to facing real-world challenges.

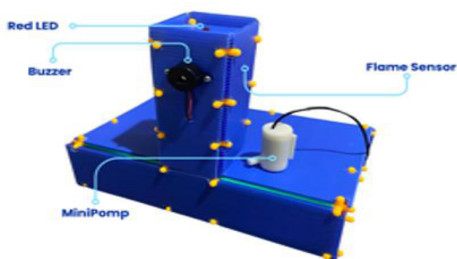


Figure 5. Fire Alarm

One of the key strengths of PjBL in STEM is its ability to connect theory to practice. Students not only learn abstract science and math concepts but also use them to design real-world solutions to complex problems. For example, a disaster mitigation project might incorporate physics principles into programming early warning systems such as fire alarms and flood alarms. This approach makes learning more meaningful and relevant to students. Here are some examples of STEM projects that leverage technology in the context of disaster mitigation.

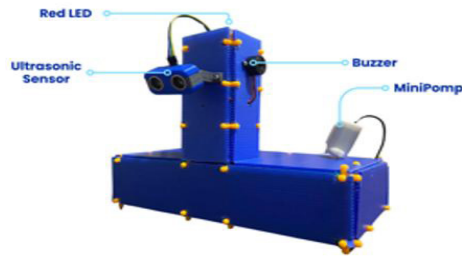


Figure 6. Flood Alarm

In the implementation of PjBL in STEM, teachers act as facilitators who guide students through various stages of the project. This process usually begins with identifying a problem or challenge that must be solved. After that, students conduct research, design solutions, conduct experiments, and evaluate the results obtained. With a structured project, students are encouraged to work independently or in groups which ultimately improves students' collaboration and responsibility skills.

Project-based learning in STEM also provides a more in-depth learning experience compared to conventional learning methods. In projects involving design and experimentation, students can develop complex problem-solving skills and systematic thinking. In addition, collaborative projects strengthen communication and coordination skills that are very important in the professional world. However, the implementation of PBL in STEM also has its own challenges. One of them is the need for careful planning and the availability of adequate resources. Teachers must have the skills to design projects that are in accordance with the curriculum and are able to provide effective direction to students. In addition, limited facilities and time are often obstacles in implementing projects, especially in schools with limited resources. Therefore, support from schools, government, and the community is very important in ensuring the success of project-based learning in STEM. Overall, PjBL in STEM is an effective approach in increasing student engagement and enriching the learning experience. By providing real challenges and encouraging active exploration, this approach helps students develop 21st-century skills that are much needed in the workplace and everyday life. Despite the challenges in its implementation, the benefits gained are far greater, making PBL a viable strategy to be applied in STEM education at various levels.

Technologies to Support PjBL in STEM

Project-based learning in STEM (Science, Technology, Engineering, and Mathematics) education is increasingly developing with the support of technology. Technology allows the learning process to be more interactive, efficient, and relevant to the real world. By utilizing technology, students can explore STEM concepts in more depth and apply them in complex, data-driven projects. One of the technologies that supports PjBL in STEM is modeling and simulation software. Applications such as PhET Interactive Simulations, Tinkercad, and GeoGebra allow students to conduct virtual experiments before applying them in real projects. For example, in an earthquake-resistant building engineering project, students can use structural modeling software to test their designs before building them in physical form. These simulations not only save costs and time but also provide deeper insights into the underlying scientific principles.

In addition, robotics and programming technologies play a significant role in STEM-based PjBL. Using platforms such as Arduino, Raspberry Pi, or LEGO Mindstorms, students can design and build automation solutions for real-world challenges. For example, in a disaster mitigation project, students can create a sensor-based early warning system that detects environmental changes such as rising water levels.

Augmented Reality (AR) and Virtual Reality (VR) technologies also offer a more immersive learning experience in PjBL. With AR and VR, students can explore 3D models of atomic structures, human anatomy, or even explore outer space environments without having to leave the classroom. Applications such as Merge Cube and Google Expeditions allow students to interact directly with virtual objects in projects, increasing conceptual understanding and engagement in learning.

Although technology offers many benefits in supporting PjBL in STEM, challenges in its use remain. Not all schools have equal access to sophisticated technological devices and training is needed for teachers to be able to utilize technology optimally in learning. Therefore, support from the government and educational institutions is needed to ensure that technology can be well integrated into PjBL STEM at various levels of education. Technology plays a very important role in increasing the effectiveness of PjBL in STEM. By utilizing simulation software, robotics, AI, AR/VR, and online learning platforms, students can develop 21st-century skills such as problem solving, critical thinking, and collaboration. Therefore, the integration of technology in PjBL must continue to be improved so that STEM learning is increasingly

relevant to the development of the times and the needs of future industries.

Evaluation and Assessment in Technology-Based STEM Learning

Evaluation and assessment in technology-based STEM (Science, Technology, Engineering, and Mathematics) learning have an important role in measuring student achievement and the effectiveness of the learning process. In STEM learning that emphasizes the application of science in solving real problems, evaluation does not only focus on the final results, but also on students' thinking processes, creativity, and collaboration skills. With the support of technology, assessments can be carried out more interactively, objectively, and data-based to provide more accurate feedback to students and teachers.

One form of assessment commonly used in technology-based STEM learning is project-based assessment. In this method, students are assessed based on their ability to design and complete projects that combine STEM concepts such as robotic modeling, programming-based application development, or data-based scientific experiments. Teachers can use digital assessment rubrics that cover various aspects such as problem solving, innovation, application of theory, and teamwork. By using online learning platforms such as Google Classroom, teachers can collect and evaluate student projects more systematically.

In addition to project-based assessments, technology also enables real-time formative assessments. Tools like Kahoot!, Quizizz, and Socrative allow teachers to give interactive quizzes that provide immediate feedback to students. With the data analytics features available on these platforms, teachers can see patterns in student understanding, identify where students are struggling, and adjust learning strategies to be more effective. With immediate feedback, students can immediately correct mistakes and improve their understanding of the STEM concepts they are learning.

Technology also enables the implementation of simulation-based assessments and virtual experiments. With software such as PhET Interactive Simulations, Tinkercad, or Labster, students can conduct experiments and explore STEM concepts without having to be in a physical laboratory. These simulations not only increase the accessibility of learning but also allow teachers to assess student understanding through the analysis of experimental data that students conduct. For example, in physics learning, students can use simulation applications to test Newton's laws under various

conditions and report the results in the form of data-based analysis.

Digital portfolio-based assessment is also an effective approach in technology-based STEM learning. Using platforms such as Google Sites, Seesaw, or Padlet, students can collect and document their work in the form of digital reports, programming codes, or video presentations. These portfolios allow teachers to assess student progress more comprehensively and provide more detailed feedback. In addition, students can also reflect on their learning and develop communication skills by compiling digital reports or presentations.

Although technology provides various advantages in STEM evaluation and assessment, there are several challenges that need to be overcome. One of them is limited access to technological devices in some schools which can cause gaps in the implementation of technology-based assessments. In addition, teachers need to have skills in using various digital tools in order to design assessments that are effective and in accordance with learning objectives. Therefore, training for educators and the provision of adequate technological infrastructure are very important to ensure that evaluation in STEM learning can run optimally. Evaluation and assessment in technology-based STEM learning provide many benefits in increasing the effectiveness of learning and developing student skills. By combining various methods such as project-based assessments, interactive quizzes, digital simulations, and electronic portfolios, educators can assess students' understanding more accurately and deeply. With the support of the right technology, STEM learning can be more adaptive, innovative, and relevant to the needs of the industrial world and future challenges.

Examples of Implementation of PjBL in STEM

Project-Based Learning (PjBL) in STEM (Science, Technology, Engineering, and Mathematics) education provides a more meaningful learning experience by connecting theory and practice in real-world contexts. This method not only improves students' understanding of STEM concepts, but also develops critical thinking skills, problem solving, creativity, and teamwork. The implementation of PjBL in STEM can be done through various projects that are relevant to everyday life and global challenges.

One example of the implementation of PjBL in STEM is the project of designing and building an eco-friendly house model. In this project, students are invited to identify problems related to energy efficiency and environmental sustainability. Students then design a house using

the principles of physics in natural lighting, air ventilation, and the use of solar panels as an alternative energy source. In the technology and engineering stage, students can use modeling software such as Tinkercad or SketchUp to create a 3D design of the house. In addition, students can conduct experiments using temperature and light sensors to test the effectiveness of the design created. This project integrates various disciplines in STEM, from science in understanding the concept of energy, technology in the use of modeling software, engineering in model construction, to mathematics in calculating energy efficiency.

Another project that is often implemented in STEM PjBL is the creation of a simple water filtration system. In this project, students are given the challenge of designing and building a water filter that can remove impurities from contaminated water. Students need to understand the science concepts of the physical and chemical properties of water, the technology in selecting effective filter materials, and the engineering in designing an optimal filtration system. Students can also measure the effectiveness of the system they create using water quality sensors or conducting simple laboratory tests. With this project, students not only understand the importance of sanitation and clean water access, but also learn how to apply STEM concepts to solve real-world problems.

Implementation of PjBL in STEM can also be done in the field of robotics and programming. For example, students can be given the challenge of creating a simple robot that can help with household chores or support disaster mitigation. Using platforms such as Arduino or LEGO Mindstorms, students learn to design and program robots so that they can run automatically. This project allows students to understand the principles of electronics, logic-based programming, and mechanical design in one integrated project. In addition, students can conduct tests to improve the performance of the robots they create so that students can develop deeper analytical and problem-solving skills.

In addition to these projects, PjBL in STEM can also be applied in the environmental field using technology such as air quality monitoring using IoT (Internet of Things) sensors. In this project, students can develop a simple tool that can detect air pollution levels and send data in real time to a digital platform. By understanding how sensors, IoT networks, and data analysis work, students can gain further insight into the impacts of air pollution and find technology-based solutions to overcome them. Although PjBL in STEM provides many benefits, its implementation still requires

careful planning. Teachers must design projects that are in line with the curriculum and ensure that students have access to the necessary resources. In addition, collaboration with industry or communities can increase the relevance of the project and provide students with broader insights. With the right approach, PjBL in STEM can be an effective learning strategy in equipping students with 21st-century skills and preparing students to face future challenges.

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