

Initial Steps for Strengthening 21st Century Education: Training on Developing STEM Modules Based on an Interdisciplinary Approach

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Abstract: The STEMNESIA workshop serves as a strategic initial step in strengthening 21st-century education in Garut Regency through training on developing STEM (Science, Technology, Engineering, and Mathematics) learning modules with an interdisciplinary approach. Amid the dominance of conventional teaching methods that remain theoretical and separated by subjects, this workshop emerged as an innovation to introduce a contextual approach that integrates science, technology, engineering, and mathematics to solve local problems. The event was attended by 60 participants, including lecturers, teachers, and students from the science and physics programs, who worked collaboratively to design modules and create prototypes based on regional potential, such as water filters, irrigation systems, and soil moisture measurement tools. Through a step-by-step workshop method that included concept introduction, module design, and product development, participants understood the principles of STEM theoretically and experienced it firsthand through the engineering design process. As a result, eight contextual and applicable STEM module designs were created, and a paradigm shift in learning occurred, from a one-way model to a participatory and collaborative learning process between teachers and students. This activity demonstrates that 21st-century education can be implemented in regional areas with intensive training and continuous mentoring support. The STEMNESIA workshop has become a critical foundation for the transformation of innovative, relevant, and problem-solving-oriented science/physics education.

Keywords: 21st-century education, Engineering Design Process, interdisciplinary learning, learning modules, local issues, STEM.

Introduction

In the 21st century, educational challenges are becoming increasingly complex with the rapid development of science and technology (Erstad et al., 2021; Hernandi et al., 2024; Iksal et al., 2024; Wachid et al., 2024). This requires students not only to master academic content but also to develop critical thinking, creativity, collaboration, and problem-solving skills (the 4Cs). These changes also demand a transformation in teaching approaches, from conventional methods to more contextual, innovative, and problem-solving-based learning (Alturki & Aldraiweesh, 2023; Cheruiyot & Molnár, 2025; Irvani et al., 2023; Irvani & Hanifah, 2024). The STEM (Science, Technology, Engineering, and Mathematics) approach emerges as a solution to meet these demands by integrating various disciplines

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into a meaningful learning experience. Through this interdisciplinary approach, students are trained to think systematically, collaborate in teams, and develop creative solutions to problems relevant to everyday life and local potential.

Science education, particularly Physics, needs to be updated with contextual and interdisciplinary approaches, such as STEM (Science, Technology, Engineering, and Mathematics), so that students not only understand concepts theoretically but also apply them in solving real-world problems in their surroundings (Dare et al., 2021; Johnson & Czerniak, 2023; Paling et al., 2024; Roehrig et al., 2021). The STEM approach provides space for students to actively engage in inquiry, experimentation, and solution design through the integrated application of science, technology, engineering, and mathematics. As a result, learning becomes more meaningful because it is oriented towards real-world phenomena and encourages interdisciplinary collaboration. Additionally, STEM fosters 21st-century skills such as critical thinking, creativity, communication, and teamwork, which are essential in addressing global challenges. In Indonesia, particularly in areas like Garut Regency, the implementation of this approach is still relatively new, making intensive training and mentorship necessary for both teachers and students to effectively and sustainably adopt this learning model.

Many teachers and students in Garut Regency are still unfamiliar with the application of the STEM approach, particularly in the form of structured and contextual learning modules. Until now, science and physics education in most schools have still focused on conventional methods that are theoretical and separated by subjects, thus lacking practical skills, problem-solving, and interdisciplinary integration (Amarulloh et al., 2023; Ding, 2024; Dyachenko et al., 2024). The limited training and examples of STEM modules relevant to local potential have become one of the main obstacles in adopting this approach. As revealed in the STEMNESIA PKM activity, many teachers admitted that it was their first time hearing the term STEM comprehensively, let alone designing modules based on an interdisciplinary approach. Students, too, are generally not accustomed to learning activities that require creativity, experimentation, and collaboration in creating real solutions. This situation shows a gap between the need for 21st-century education and the practical readiness on the ground, making training, such as STEM module development workshops, crucial as an initial breakthrough to introduce, inform, and equip teachers and students with innovative learning approaches relevant to today's challenges.

Based on the needs assessment conducted through surveys and interviews with curriculum vice principals and science teachers in Garut Regency, data shows that most teachers have no experience in designing or implementing STEM-based learning, particularly in the form of structured modules. Furthermore, the lack of learning examples rooted in local context becomes an obstacle in creating relevant and meaningful materials for students (Gadaza et al., 2025; Henukh et al., 2024; Moslimany et al., 2024; Shih, 2022). Therefore, direct training is needed that not only introduces the concept of STEM but also provides practical guidance to teachers and students in developing STEM modules based on local potential and issues. The STEMNESIA workshop was designed as a direct response to these needs.

The main goal of the STEMNESIA community service activity is to provide comprehensive knowledge and skills to science and physics teachers in developing innovative and contextual STEM-based learning modules. Through intensive training guided by international expert Dr. Do-Young Park, teachers are not only introduced to the concepts and principles of the STEM approach but also equipped with practical guidelines for designing modules that integrate science, technology, engineering, and mathematics in a cohesive manner. The workshop is designed to help teachers identify local issues in the school environment and transform them into engaging and meaningful teaching materials for students. As a result, the developed modules not only meet curriculum requirements but are also relevant to real-life situations and encourage students to think critically, creatively, and collaboratively. It is hoped that, after participating in this activity, teachers will be able to implement STEM modules in their classrooms, making science and physics education more active, engaging, and impactful in shaping a generation ready to face the challenges of the 21st century.

Method

This activity was held on Friday, June 23, 2023, at the Faculty of Islamic Education and Teacher Training, University of Garut, and was attended by 60 participants, including lecturers, teachers, and

students from the science and physics education programs in Garut Regency. The activity used a workshop method, which was divided into three main sessions: (1) Introduction to STEM Modules and Products, (2) STEM Module Development Workshop, and (3) Development of STEM Module Products. The session on the introduction to STEM modules and products was directly guided by Do-Young Park, Ph.D., a STEM education expert from the United States. In this session, participants gained a deep understanding of the definition of STEM modules as integrated teaching tools that combine science, technology, engineering, and mathematics to address real-world problems. The speaker also emphasized the fundamental differences between conventional teacher-centered learning and the STEM approach, which focuses on inquiry, problem-solving, and student collaboration. Examples of STEM modules relevant to Indonesia's local potential, such as renewable energy, irrigation systems, and waste management, were presented to provide concrete illustrations and inspire creative ideas among the participants.

After the presentation session, the activity continued with a participatory STEM module development workshop. Participants were divided into mixed groups consisting of teachers and students to encourage intergenerational collaboration and perspective exchange. Each group was tasked with identifying contextual issues in their surroundings, such as flooding, waste, or limited access to energy, and then designing a STEM-based learning module that included learning objectives, integration of all four STEM components, hands-on activities, and an end product in the form of a prototype or teaching media. The design process was guided by the Engineering Design Process (EDP), which includes problem identification, research, solution design, creation, testing, and evaluation. Intensive mentoring was provided by Dr. Do-Young Park and the Physics Education faculty team from the University of Garut to ensure that each group was able to produce relevant and applicable designs.

In the third session, participants transitioned from module design to the actual creation of STEM products. With the designs they had developed, each group began building simple prototypes using readily available materials. Some groups created water filters from natural materials, small wind turbine models for demonstrating renewable energy, and soil moisture measurement tools for use in science experiments. This process emphasized creativity, functionality, and active student involvement as the center of learning. The entire activity was designed to demonstrate that the STEM approach does not require expensive equipment but focuses more on integrated thinking and problem-solving methods for real-world issues.

This workshop method was designed in stages so that participants not only understood STEM theoretically but also experienced it firsthand. The combination of expert presentations by international specialists, group work, and academic mentoring made this method effective in building participants' awareness and capacity for applying STEM in schools. The final outcome of this session was not only physical products but also module designs that are ready to be further developed as innovative teaching materials in the classroom.

Result and Discussion

Many participants, both teachers and students, stated that the first day of the STEMNESIA workshop was their first experience in developing STEM-based learning modules, highlighting the limited understanding and application of the STEM approach in science/physics education in secondary schools in Garut Regency. This finding aligns with research that indicates teachers' low understanding of the integrative STEM concept as one of the main barriers to its implementation in Indonesia. This situation emphasizes the need for initiatives like STEMNESIA as a strategic platform to directly and contextually introduce 21st-century education (Henukh et al., 2024; Lestari & Muhajir, 2021). The STEM approach aims not only to enhance mastery of science and mathematics content but also to develop critical thinking, creativity, collaboration, and problem-solving skills through real-world contexts. These core competencies are difficult to achieve through conventional teaching methods. This approach provides students the opportunity to examine contextual issues in an interdisciplinary manner, integrating science, technology, engineering, and mathematics in the problem-solving process (Masripah et al., 2024; Sari et al., 2025; Ye et al., 2023).



Figure 1. Presentation of material by resource persons

One significant impact observed during the first day of the workshop was the emergence of a learning dynamic that was different from the usual. Active and intense discussions took place between teachers and students in each group session, creating a participatory and inclusive learning environment. The traditional one-way, hierarchical learning model was replaced by a new collaborative interaction pattern. Teachers and students sat side by side in one team, exchanging ideas, engaging in constructive debates, and collectively designing solutions to local issues through the STEM approach. This phenomenon indicates a paradigm shift in the teaching-learning process, where the authority of knowledge is shared equally, and learning becomes a joint exploration space. Many teachers admitted that they rarely experienced such deep student engagement, while students felt more valued and motivated because their opinions were heard and appreciated. This cross-level collaboration serves as concrete evidence that the STEM approach not only develops technical skills but also strengthens social relationships and fosters a democratic learning culture within schools (Gross et al., 2014; Irvani et al., 2020).

The STEMNESIA workshop resulted in eight STEM module designs, developed collaboratively by participants, including science/physics teachers and high school students from various schools in Garut Regency. These modules were designed with an interdisciplinary approach and based on contextual problems relevant to the surrounding environment. Some groups focused on Garut's local potential, such as issues in the agricultural and plantation sectors, organic waste management, and disaster mitigation for natural hazards like landslides and floods. This approach demonstrated the participants' understanding of the importance of linking science to real-world conditions in society, ensuring that STEM learning is not only theoretical but also practical and meaningful.

Not only did the participants produce written designs, but they also created physical products as concrete manifestations of the modules they developed. Prototypes such as simple water filters, irrigation system models, and soil moisture measurement tools were made using affordable and easily accessible materials. This demonstrates that the STEM approach can be implemented even with limited resources, as long as there is creativity and a solid understanding of the concepts. The success of developing both the modules and the products serves as a strong initial indicator that 21st-century education can be effectively applied in schools, particularly in regions like Garut, with continuous mentoring and training.



Figure 2. Group Discussion on the Development of STEM Modules

The workshop activity had a significant educational impact on both teachers and students. Teachers began to understand that the STEM approach is not just an additional material or side project in teaching, but a new paradigm that changes the way they design and deliver lessons. With this interdisciplinary approach, teachers were encouraged to design contextual, problem-based learning that involves inquiry processes and engineering design. On the other hand, students showed increased motivation to learn because they were directly involved in solving real-world problems relevant to their environment and daily lives. Active participation in designing solutions and creating STEM products provided a meaningful learning experience, making the learning process more engaging, applicable, and having a long-term impact on the development of 21st-century skills.

Conclusion

The STEMNESIA workshop successfully served as a strategic initial step in strengthening 21st-century education in Garut Regency through the introduction and training on developing STEM-based learning modules with an interdisciplinary approach. By integrating science, technology, engineering, and mathematics into the context of local issues, this workshop not only introduced the STEM concept to teachers and students but also provided hands-on experience in designing modules and collaboratively creating innovative products. The results of this activity show an increased understanding among participants of contextual learning approaches, inquiry-based methods, and problem-solving oriented towards real-world challenges.

The eight STEM module designs produced by the collaborative groups of teachers and students reflect the significant potential of locally-based education to be developed interdisciplinarily. The creation of simple prototypes such as water filters, wind turbine models, and soil moisture measurement tools demonstrates that the STEM approach can be effectively implemented even with limited resources, as long as it is supported by creativity, proper mentorship, and a collaborative spirit. Furthermore, the participatory and inclusive learning dynamics between teachers and students signify a paradigm shift from conventional learning towards a more democratic and student-centered education.

The STEMNESIA workshop not only had an immediate impact in the form of learning modules and products but also instilled an awareness of the importance of transforming education towards approaches that are relevant to the demands of the 21st century. This success serves as an important foundation for the sustainable development of STEM education at the school level, particularly in regional areas, and emphasizes the need for continued support in the form of advanced training, provision of learning resources, and collaborative networks between schools and universities.

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article. All research and activities related to this study were conducted with full transparency and integrity, ensuring that the findings and conclusions are unbiased and solely based on the data collected.

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