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# Analysis and design of disaster mitigation robotic stem learning for coastal students

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***ABSTRACT***

One of the reasons scientific literacies in the coastal areas of Indonesia are low is because of a lack of access to contextual and relevant learning materials. This research aims to analyze learning needs in STEM (Science, Technology, Engineering, and Mathematics) in coastal areas and construct contextual, innovative, and applicable robotic learning media. This research employs a Research and Design (R&D) approach with a development model that comprises needs analysis, media design, media development, expert validation, and limited trials. The produced outcome is a Robotic STEM Project Kit that contains three major prototypes: a fire alarm, a flood detector, and a bridge that opens and closes automatically. This media is designed to address problems in coastal environments, enabling students to be directly involved in solving real-world problems. The validation attained from four experts shows that this media has considerably great relevance and practicability. Initial trials show this medium is practical to use, easy to package and install, and that students are able to understand the physics concepts it conveys. Hence, it is shown that robotics-based project media offer a great solution for contextual learning in coastal areas. This research also helps in the adaptation of the STEM-based curriculum to the local geographic and socio-cultural.

**Contribution/Originality:** This research contributes to providing innovative media for the often-overlooked coastal context. The product developed aligns with current Indonesian Curriculum requirements, employing an in-depth learning approach with three principles: enjoyable, attentive, and meaningful learning. Learning science is not just about theory but also about tangible products.

## 1. INTRODUCTION

Engagement with natural sciences at the secondary school level requires pupils to master and integrate concepts (Mabsutsah & Yushardi, 2022). Science as a process of discovery-based learning includes activities of memorization, understanding, and exploration of facts and phenomena occurring within the natural world (Soekarman, 2021). Furthermore, science as a discipline stresses the direct involvement of the student within the learning process (Hutchins et al., 2020), thereby evoking interest and broadening the learner's intellectual scope (Bigozzi, Tarchi, Fiorentini, Falsini, & Stefanelli, 2018).

However, the low positive perception of science as a subject, a challenge that stems from the perception of science as being complex, continues to be prevalent. This includes a disconnection of the subject matter from students' daily experiences in real-world situations (Kervinen, Roth, Juuti, & Uitto, 2020) and particularly in coastal regions which usually have low educational and technological resources, as opposed to urban areas., and particularly in coastal regions which usually have low educational and technological resources as opposed to urban areas.

Indonesia is an archipelago with 17,380 islands, and geographically, accessing educational equity, especially along the coast, is challenging. Contextual and meaningful learning is a steep learning curve along the coast. Learning and thinking skills are low (Madyani, Yamtinah, Utomo, Saputro, & Mahardiani, 2020; Sarwanto, Fajari, & Chumdari, 2021). Scientific literacy is at an even lower level (Zulirfan, Yennita, Maaruf, & Sahal, 2023). Thus, appropriate learning media are needed for students along the coast to improve learning of science concepts.

The contextual learning approach is considered to mitigate this challenge (Santoso, 2019). Learning difficulties are an interplay of internal aspects like motivation, physical condition, and concentration, and external factors like learning methods, family support, and learning environment (Syakur, Purnamasari, & Kurnia, 2021).

The incorporation of STEM (Science, Technology, Engineering, and Mathematics) education responds to technological advancements and the priorities outlined in the National Education policy. The aim of education is not only to learn and master concepts but to use them to address real-life problems. Additionally, STEM education can be used in technology for disaster risk reduction in underserved and disaster-prone coastal communities. Several studies show the integration of robotics in STEM education and that this integration enhances students' abilities in STEM (Jamzuri et al., 2024; Sadik, Johnson, Lee, & Williams, 2024).

Although both studies showed positive results, they were still limited in scope, such as not directly involving students in the process of assembling and using robots, and not yet developing more than one prototype as a learning medium.

Thus, a robotics-based STEM learning project contextualized for coastal students will not only improve scientific literacy but also equip them with 21st-century skills such as critical thinking, problem-solving, and innovation. This research aims to answer four main questions.

1. What are the characteristics of STEM project needs that are appropriate for students in coastal areas?
2. How is a STEM project designed, integrating technology elements relevant to coastal students?
3. How do experts assess the feasibility of the developed STEM project?
4. What are students' opinions about the use of the developed STEM project?

By answering these questions, this research is expected to make a real contribution to developing STEM-based learning media that are adaptive to the needs of coastal students, providing a basis for regional education policy-making.

## 2. LITERATURE REVIEW

### *2.1. STEM Education*

Facing the challenges of the 21st century and the Industrial Revolution 4.0 requires human resources with critical and creative thinking skills, as well as high levels of technological and information literacy. Education is key to developing these competencies. According to Murnawianto, Sutanto, and Yuniar (2017), students' thinking skills in Indonesia are still predominantly at the Low-Order Thinking Skills (LOTS) level, meaning that not many students are familiar with analysis, synthesis, and evaluation as part of Higher-Order Thinking Skills (HOTS).

Integrating real-world experiences has made the cross-disciplinary Science, Technology, Engineering and Mathematics (STEM) approach a proven pedagogy for building students' critical and creative thinking skills. Oschepkov, Bormashov, and Nikolaev (2022) creatively demonstrated the positive transformational impact of the approach on students' understanding and scientific literacy. Additionally, active learning in STEM has empirically been documented as a game-changer in fostering critical thinking skills among elementary school students (Sukmana, Aulia, & Rian, 2023). PBL STEM as a pedagogical framework has also been documented as effective in cultivating critical thinking skills (Utami & Permadi, 2025).

Multidisciplinary integration in STEM learning promotes conceptual connectivity among students, which is the integration of content and skill focus (Marsono, Suryani, & Budi, 2019). This is consistent with the positive perceptions of STEM in learning reported among science teachers (Astutik & Prahani, 2018). There are, however, practical challenges in the implementation of STEM in Indonesia, and they pertain to teacher training, availability of resources, and curriculum integration (Roehrig, Moore, Wang, & Park, 2021).

Aslam, Iqbal, and Khan (2023) investigate how beginning educators struggle with classroom management, integration of STEM curricula, and lack of adequate resources, and the differences for developing countries. Alsalamat (2024) studied Saudi Arabian science teachers and reported positive attitudes toward STEM; however, the teachers experienced competing demands, insufficient resources, and lack of training. In Delahunty, O'Connor, and McLaughlin (2021) study, Irish educators reported the traditional curricular structure as a major source of frustration, as it significantly limited the ability to teach using an interdisciplinary approach. Teachers in China, as highlighted by Dong, Li, and Zhang (2020), also reported very limited time for inter-collaborative activities, assessment, and resources as major barriers to free interdisciplinary teaching.

In Indonesia, the implementation of STEM is important as it helps close the gap between students' competencies and the demands of the 21st century. Students learn more than the concepts of integrated disciplines; they learn to think critically, creatively, and collaborate for the real world. However, the realities that exist in the field are significant challenges that constrain STEM implementation, such as inadequate facilities, insufficient training of teachers, and the pressure of traditional curricula. Therefore, for STEM education to be more meaningful, contextual, and sustainable, there is a need for policy to support the provision of resources and the improvement of teacher training.

### *2.2. Robotic Technology in Learning*

Robotic technology in learning is the use of robots or robot-based systems as media or tools in the educational process to support active, contextual, and interdisciplinary education. Educational robotics not only serves as a technical tool, but is also seen as a practical pedagogical approach for developing 21st-century skills such as critical thinking, creativity, problem-solving, collaboration, and computational thinking (Darmawansah, Hwang, Chen, & Liang, 2023; Ouyang & Xu, 2024; Tselegkaridis & Sapounidis, 2022).

Robotics is a branch of engineering and computer science that studies the design, construction, operation, and programming of robots, mechanical devices that can be programmed to perform specific tasks automatically. In the educational context, this technology has been utilized as an innovative learning medium supporting the Project-Based Learning (PBL) approach, which has proven effective in improving students' collaborative skills, problem-solving, creativity, and computational thinking (Coufal, 2022; Ouyang & Xu, 2024; Tselegkaridis & Sapounidis, 2022).

However, the challenges in implementing robotics technology in education are not limited to device availability, but also include appropriate pedagogical integration to ensure its use remains aligned with curriculum objectives. Therefore, it is crucial to develop a robotics implementation strategy that focuses not only on technical aspects but also on a holistic pedagogical approach oriented towards student needs (Conde, González, & López, 2023; Darmawansah et al., 2023).

Robotic technology in learning refers to robots or automated systems designed and programmed to perform specific tasks automatically. This technology is widely used in STEM and Project-Based Learning (PBL) approaches to provide students with opportunities to design, build, and program robots, thereby encouraging active learning and creating meaningful, integrative learning experiences. Several international studies have shown that the application of robotics in education not only has a positive impact on academic achievement but also supports the development of computational thinking, critical thinking, creativity, problem-solving, and collaboration skills (Alonso-García, Pérez-Sánchez, García-Torres, & Rodríguez, 2024; Darmawansah et al., 2023; Muhterem, 2025; Ouyang & Xu, 2024; Tselegkaridis & Sapounidis, 2022).

Educational robotics relates to educational robots or automated systems designed and programmed to operate and accomplish tasks without human intervention. Within STEM and Project-Based Learning (PBL) methodologies, this technology encourages participation and active learning. Educational robotics technology fosters the design, construction, and programming of robots for educational purposes, providing integrated and meaningful learning experiences. Numerous studies across the globe have proven that educational robotics fosters the achievement of learning outcomes, significantly enhances educational attainment, and develops competencies such as computational and critical thinking, creativity, problem-solving, and collaborative skills (Alonso-García et al., 2024; Darmawansah et al., 2023; Muhterem, 2025; Ouyang & Xu, 2024; Tselegkaridis & Sapounidis, 2022).

Employing modern robotics technologies is a unique way to improve educational quality and engage 21st-century learners. Practical, hands-on robotics applications improve students' learning experiences acquired through meaningful integration of the STEAM disciplines. Students learn the value and necessity of collaboration, communication, and creativity through the construction and programming of robots. The application of robotics increases their fundamental motivation to learn by providing meaningful, relevant, and problem-solving pedagogical engagements. While the integration of robotics is very positive, it is also complicated by a lack of facilities and training. Additional partnerships on pedagogy are urgently needed so that the integration of robotics is not limited to basic skills but also enriches students' understanding, digital fluency, and critical consciousness on issues such as disaster risk and environmental sustainability.

## 3. METHODOLOGY

Enhancing students' creative thinking skills through disaster mitigation robotics-based STEM projects adds to the education R&D STEM field. Using the ADDIE design framework involves analyzing, designing, developing, implementing, and evaluating the process. However, this study will limit the scope to the Developmental stage, while the Implementation and Evaluation stages will be conducted in future research.

Descriptive, qualitative, and quantitative methods were used to capture the process and results without bias. These methods were most efficient in developing educational STEM learning resources targeted at coastal area students. The research process will be demonstrated in this diagram to the reader.

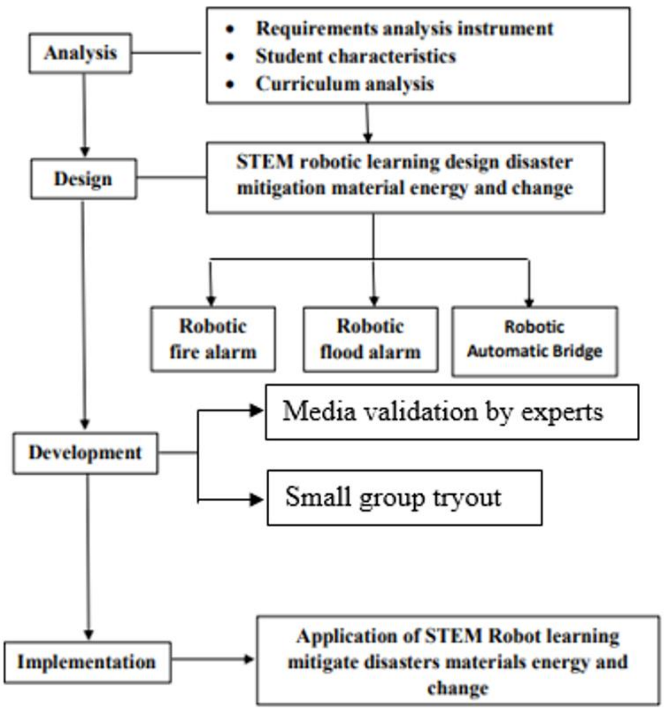


**Figure 1.** Research procedures.

Figure 1 shows the development stages of STEM robotics learning for disaster mitigation. The process begins with the analysis stage, which includes needs analysis, student characteristics, and curriculum analysis. The next stage is the design stage, which involves developing a STEM robotics learning design related to energy and change. Development continues with the creation of prototypes for a fire alarm robot, a flood alarm robot, and an automatic opening and closing bridge, which are then operated by experts and tested on small groups.

The research stages are described as follows:

a. Analysis Stage

This stage involved carrying out a needs analysis via a survey in which a questionnaire was the main tool used for data collection. The survey included 47 science teachers and 552 students across four coastal districts in the Riau Province of Siak (State Vocational School 1 Kerinci Right), Dumai (Dumai City Fisheries Vocational School), Kampar (Global Cendikia Vocational School), and Pelalawan (Pelalawan 5th Junior High School). The students who participated in this study were high school students. The questionnaire consisted of 15 items designed to elicit information regarding:

1. The need for STEM-based media in science learning.
2. Respondents' level of understanding of the STEM approach.
3. The implementation of STEM project learning in the Indonesian curriculum.

The questionnaire was distributed online via Google Forms, and the data were analyzed descriptively and quantitatively, expressed as percentages, and presented in pie and bar charts.

b. Design Stage

The learning media design was developed based on the findings of the analysis stage. The media was designed in the form of a STEM Robotic Disaster Mitigation Kit that can be assembled into three types of projects:

1. Automatic fire alarm.
2. Flood detector.
3. Automatic opening closing bridge.

The design took into account the feasibility of tools and materials, aesthetic aspects, safety of use, and usability for junior high school students in coastal areas. The media were designed to be reassembled by students to support project-based learning activities.

c. Development Stage

This stage is the realization of the media design into a physical prototype. This stage involves several essential processes.

1. Media Validation by Experts

Validation was conducted by four science education and educational technology experts using a Likert scale questionnaire (1–4) to assess content, visual design, ease of use, and curriculum alignment. Validity criteria were defined as each assessment item receiving a score of at least three from each validator. If the criteria were not met, the media was revised based on expert input.

2. Small Group Tryout

The practicality test was conducted with 30 students and four physics teachers from the same region. The instrument used was a practicality questionnaire with a four-level scale: not practical (1), not very practical (2), helpful (3), and very practical (4). The assessment aimed to evaluate the media's feasibility, ease of use, and flexibility from the perspectives of various users.

Data from these three testing stages were analyzed descriptively to evaluate the extent to which the developed robotic STEM media were feasible and practical for use in science learning in coastal areas.

## 4. RESULTS AND DISCUSSION

### *4.1. Analysis Phase*

*RQ1: What are the STEM project needs that are appropriate for coastal students?*

The needs analysis was conducted by distributing questionnaires to 47 science teachers and 552 junior high school students from four coastal districts in Riau Province. The collected data showed that 42.60% of teachers implemented STEM project learning to help students understand science concepts directly through product creation or problem-solving activities. 83% of teachers agreed that project-based learning in the Independent Curriculum primarily aims to develop students' critical and creative thinking skills in the context of science learning.

These findings are supported by the literature, which shows that project-based learning is efficacious in improving 21st-century skills (AlAli, 2024; Tuong et al., 2023; Zayyinah, Erman, Supardi, Hariyono, & Prahani, 2022). Several studies also indicate that project-based science learning can improve students' critical and creative thinking skills (Chen & Yang, 2019; Hasibuan, Sari, Syahputra, & Nahadi, 2022; Jawad, Majeed, & ALRikabi, 2021; Sumarni & Kadarwati, 2020).

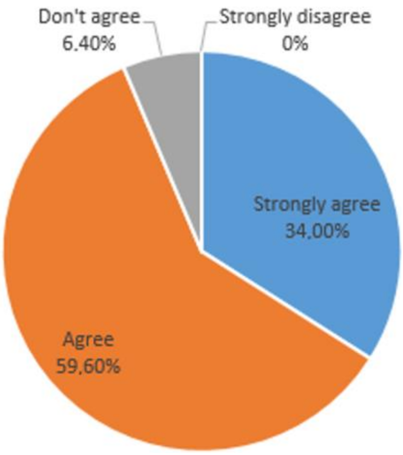


**Figure 2.** The importance of learning STEM Robotics projects.

Figure 2 shows the distribution of student responses to the implementation of STEM robotics learning. The majority of students responded positively, with 59.60% agreeing and 34.00% strongly agreeing. Only 6.40% disagreed, and none strongly disagreed. These results indicate that STEM robotics learning was well received by students.

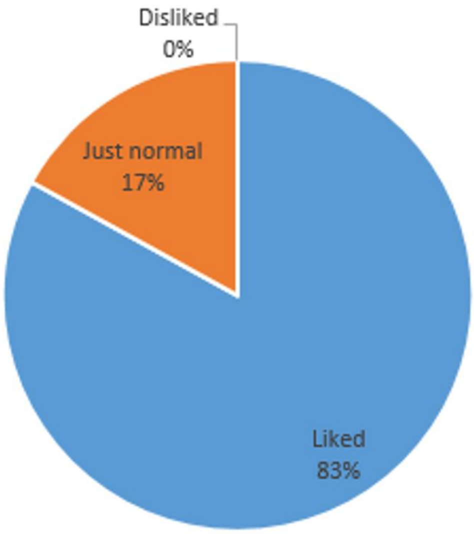


**Figure 3.** Students enjoy STEM Robotics

Figure 3 shows the level of student satisfaction with the STEM robotics project. Eighty-three percent of students stated they enjoyed the learning, 17% stated they were indifferent, and none stated they disliked it. These results indicate that the STEM robotics project provided a positive and enjoyable learning experience for students. Although the majority of teachers recognize the importance of this approach, several barriers remain. In relation to the aforementioned concepts, 66% of educators indicated challenges in creating relevant ideas (STEM), and 59.4% highlighted the importance of learning materials related to STEM projects. In addition, the considerable challenges teachers mentioned included time limitations, lack of support from administration, and inadequate access to technology (Asghar, Ellington, Rice, Johnson, & Prime, 2012; Herro & Quigley, 2017; Wang, Moore, Roehrig, & Park, 2011). Furthermore, the perception that students are incapable of or uninterested in STEM activities is also a common obstacle (Al Salami, Makela, & De Miranda, 2017; Goodpaster, Adedokun, & Weaver, 2012; Le, Tran, & Tran, 2021).

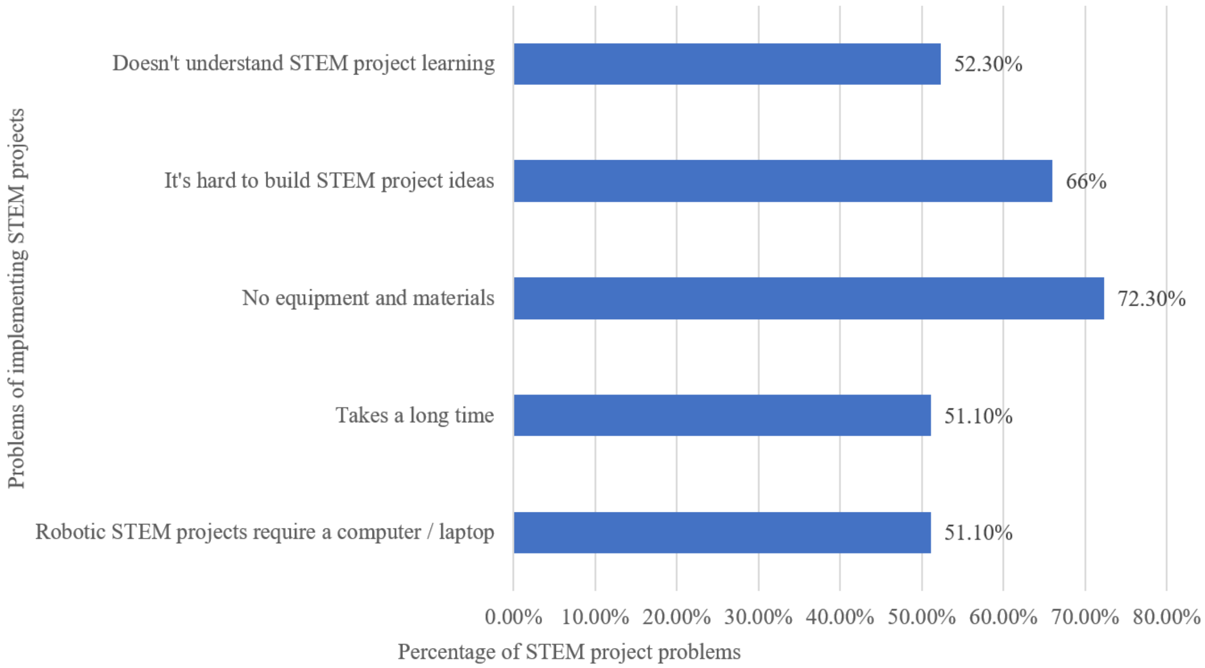

**Figure 4.** Problems in STEM project learning.

Figure 4 shows various challenges in implementing STEM project learning. The main challenges encountered were limited equipment and materials (72.30%), followed by difficulties in designing STEM projects (66%), and a lack of understanding of STEM project learning (52.30%). Furthermore, STEM project learning was also perceived as time-consuming and requiring a computer or laptop (51.10%), respectively. These findings indicate that facilities, understanding, and time are the main challenges in implementing STEM projects.

According to students, 86.4% believed that STEM robotics projects could encourage their creativity, and the majority (72.1%) preferred scientific instruction that included hands-on practice in creating basic technical equipment. Nonetheless, 58.8% of students thought their earlier work was less interesting. This suggests a critical need for more creative, relevant STEM project materials suited to the needs of pupils living along the shore.

### *4.2. Design Phase*

*RQ2: How to design a STEM project incorporating technology elements for coastal students?*

Based on the needs analysis, the design for the Robotic STEM Project Kit was developed. This kit contains removable components in a single box and can be used for three types of projects: a Robotic Fire Alarm, a Robotic Flood Alarm, and an Automatic Bridge.

a. The Robotic Fire Alarm is designed using an Arduino Uno, a fire sensor, an LED, a buzzer, and a mini water pump that activates when it detects fire. This project simulates a simple fire extinguishing system. The Robotic Fire Alarm design is shown in Figure 5.

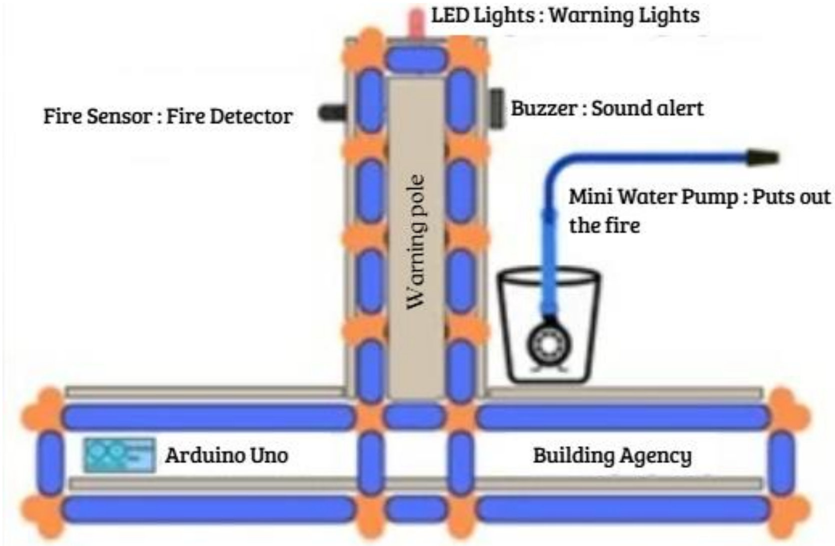


**Figure 5.** Robotic Fire Alarm

Figure 5 illustrates the system configuration of the robotic fire alarm, showing the integration of fire detection, warning indicators, and a water-based response mechanism.

b. The Robotic Flood Alarm uses an ultrasonic sensor to measure water levels, which then activates a buzzer and a mini pump to release water if dangerous water levels are detected. This system represents a simple technology-based flood mitigation application. The Flood Alarm design is shown in Figure 6.

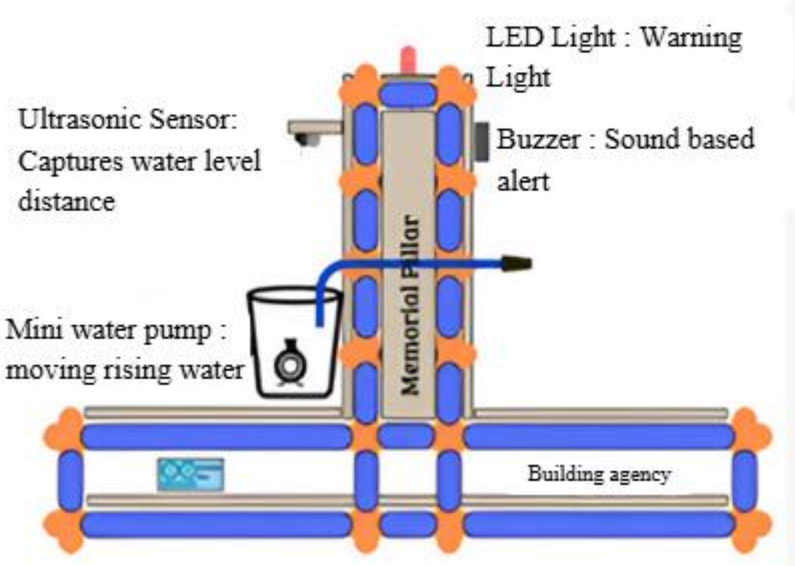


**Figure 6. Robotic Flood Alarm**

Figure 6 shows how the robotic flood alarm system is set up. It uses an ultrasonic sensor to check the water level and gives warnings with both sound and light signals.

c. The Automatic Opening and Closing Bridge uses infrared sensors and servo motors to open the bridge when a ship approaches automatically. This project demonstrates how automated systems can be applied to coastal infrastructure. The design of the automatic opening and closing bridge can be seen in Figure 7.

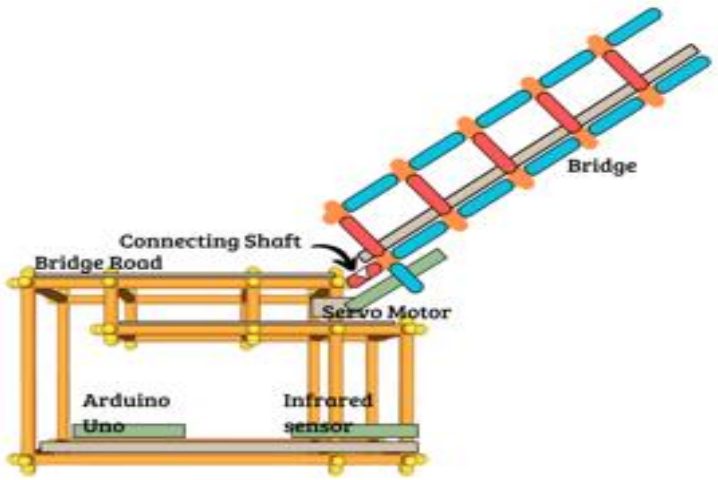


**Figure 7.** Automated Bridge Robotic

Figure 7 shows an automatic bridge robot system where infrared sensors sense when a ship is coming and send signals to an Arduino Uno. The Arduino then uses a servo motor attached to the bridge to open and close it automatically, as part of a smart coastal infrastructure setup.

### *4.3. Development Phase*

#### *4.3.1. Validation*

*RQ3: What are the experts' opinions about the developed STEM project?*

The development phase of the R&D process is perhaps the most critical of all the phases. Upon reaching this phase, the learning media are materialized with the initial designs transformed into a working physical product. This begins with the choosing of appropriate media, the construction of which is made, then the cutting of the materials according to the design framework followed by the electronic components which are to be arranged and placed within the STEM kit's building structure. Each piece of the media is assembled with consideration with regards to the integration of the pieces, the stability of the structure, and efficient use of space so that the overall product is aesthetically pleasing. This is a process that requires a lot of precision because field-research conditions could differ from the initial design plan and for researchers to obtain the best results, the plan has to be altered numerous times with the prototype made to undergo an iterative process. The media that was developed is shown in Figure 8.

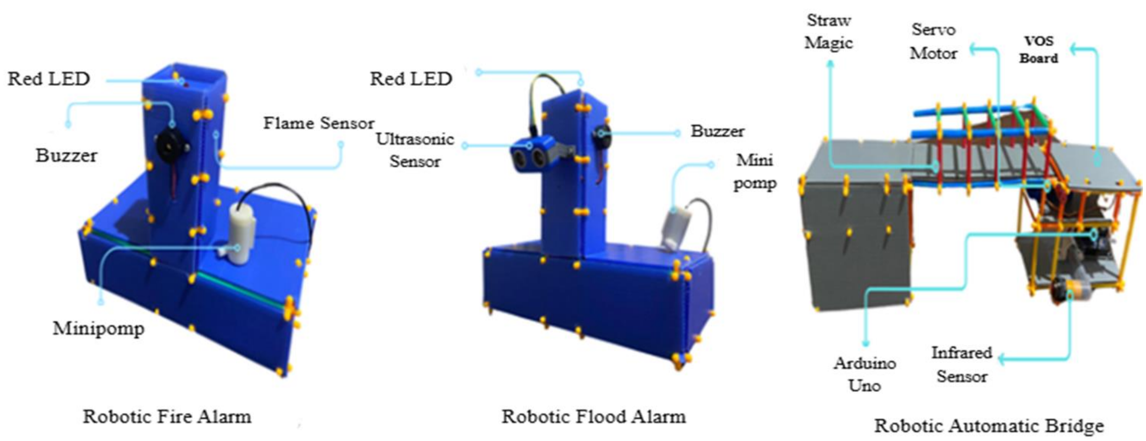


**Figure 8.** STEM Robotic Media.

Figure 8 depicts the final results of STEM-based robotic design, including a robotic fire alarm, robotic flood alarm, and robotic automatic bridge as real implementations of STEM design. Once the three media forms were constructed and verified to work properly, including microcontroller programming, the next step was to have experts assess the media. Four experts from the robotics educational field were involved, including specialists in educational media, pedagogy, and scientific content. The purpose of this validation was to evaluate the media from multisectoral perspectives to support the contribution of the media in project-based science learning.

The results of the validation of the robotic media were obtained and depicted in the form of a radar chart in Figure 9, showing the five primary indicators of the assessment, namely, the functions of the tools, instructional components, user-friendliness, the aesthetics and structure, and the overall mean score (average of the validation results) of each of the devices. The three media that were validated include the robotic automatic bridge, robotic fire alarm, and robotic flood alarm.

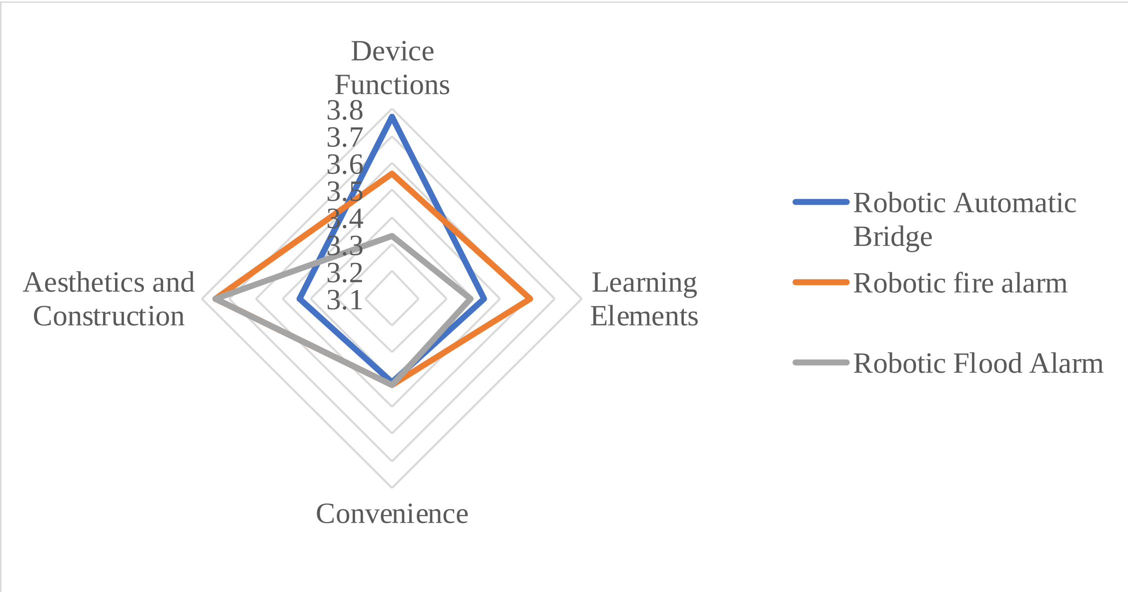


**Figure 9.** STEM Project Validity Test Results.

Figure 9 depicts the results of the STEM project validity test by comparing the Robotic Automatic Bridge, Robotic Fire Alarm, and Robotic Flood Alarm based on aspects of device function, learning elements, ease of use, and aesthetics and construction.

The validators rated the Robotic Fire Alarm as the most technically and operationally excellent, earning a total score of 3.87. With a 3.58 score, the Robotic Fire Alarm also topped the learning aspect. This score suggests that the learning resource has the potential to enhance project-based, contextual learning designed for the Indonesian curriculum. In this area, Robotic Automatic Bridge and Robotic Flood Alarm received the same score of 3.41, indicating that both of them even infused learning elements on a more complex level.

In the usability category, Robotic Fire Alarm also rated best with a score of 3.68, followed closely by the Robotic Automatic Bridge with 3.56. Robotic Flood Alarm, however, received the lowest score of 3.25. This suggests that this learning resource requires improvements primarily in the user interface and operational processes to be more user-friendly for students with diverse skill sets.

The aesthetic and construction aspects had fairly uniform results. Both the Robotic Fire Alarm and Robotic Flood Alarm received the highest scores of 3.68, while the Robotic Automatic Bridge followed closely behind with 3.56. This suggests that visually and architecturally, the three devices meet the aesthetic and ergonomic standards threshold for media of project-based learning.

Based on the average score, the first place went to Robotic Fire Alarm, which received a score of 3.63. It was followed by Robotic Automatic Bridge with a score of 3.60, and then the last place was Robotic Flood Alarm with a score of 3.41. These results show that the Robotic Fire Alarm media is the most balanced of the devices across all criteria and is therefore the most suitable device for bringing contextual science learning to the coastal area. The Robotic Automatic Bridge has other functionalities and can be utilized with a few more modifications. The Robotic Flood Alarm, on the other hand, still leaves a lot to be desired, especially in usability, learning activities integration, and classroom lesson relevancy.

The results of the validation of the designed robotics media reflect the results of the assessment of five aspects, which are the function of the device, learning activities, usability, design, and construction. The overall average indicates that the robotic automatic bridge, robotic fire alarm, and robotic flood alarm obtained validation scores within the practical range. This finding is consistent with a meta-analysis (Ouyang & Xu, 2024) that found educational robotics has a moderate positive effect on student learning outcomes and attitudes, and with a meta-analysis (Wang, Sang, Huang, Li, & Guo, 2023) that confirmed that educational robots with medium to high validation scores are suitable for classroom use. This is also in line with Darmawansah et al. (2023), which emphasizes the importance of holistic evaluation encompassing function, ease of use, and aesthetics in contextualizing STEM-based robotics media for learning.

### *4.3.2. Small-Scale Trials*

*RQ4: What are students' opinions on the use of the developed STEM projects?*

A small-scale trial was conducted with 30 students in a coastal high school. The trial aimed to evaluate the media's practicality, including ease of use, ease of understanding its application, security, and packaging.

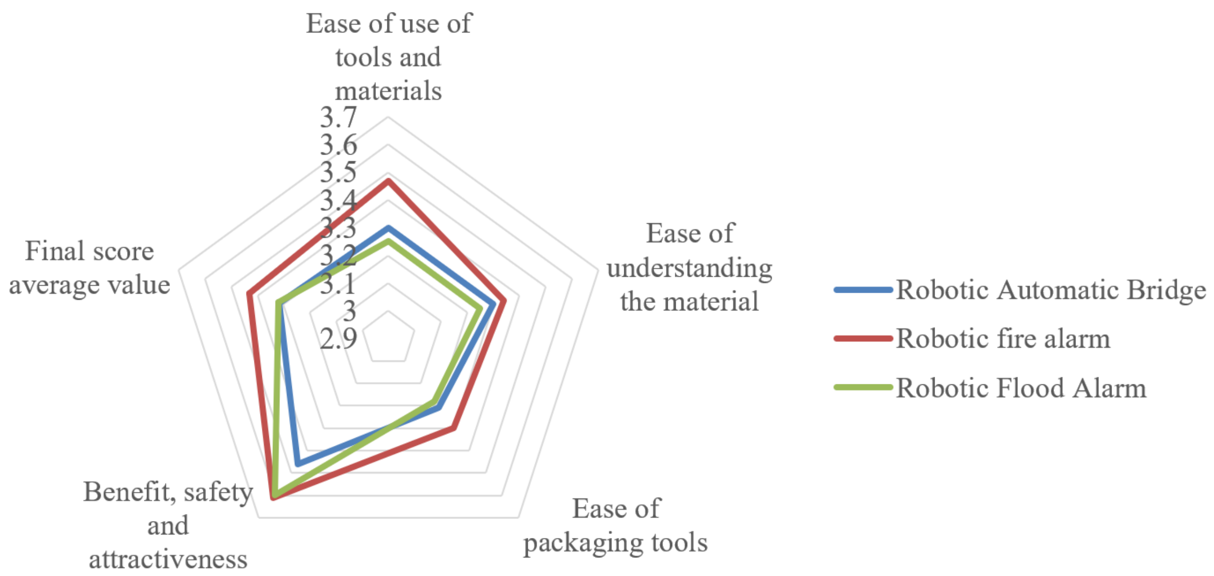


**Figure 10.** Student practicality test results.

Figure 10 illustrates the results of the practicality test by students on the Robotic Automatic Bridge, Robotic Fire Alarm, and Robotic Flood Alarm based on the ease of use of tools and materials, ease of understanding the material, ease of packaging the tools, benefits, safety and attractiveness, and the final average value.

The evaluation of practicality, including ease of use, understandability, and security, is also supported by a study on assessment optimization in STEM project-based learning, which emphasizes the importance of systematic evaluation tools to measure process and outcome aspects in a balanced manner.

The average practicality values of the Robotic Fire Alarm (3.43), Robotic Flood Alarm (3.32), and Robotic Automatic Bridge (3.31) indicate that these media are practical and suitable for students to use. When reviewed for each indicator of media practicality according to students, it was found that 1) Ease of use of tools and materials had a score of 3.34. 2) Ease of understanding the material with a score of 3.30. 3) Ease of packaging tools with a score of 3.23. 4) Benefit, safety, and attractiveness with a score of 3.56. These results have been declared suitable for use as a STEM learning medium for coastal areas.

In accordance with the findings (Ouyang & Xu, 2024), which stated that the use of educational robotics has a moderate positive effect on student learning achievement and attitudes in STEM. These results are also in line with other meta-analyses that confirm educational robots increase student motivation and engagement in the classroom. This robotic STEM project has been designed to develop the creative thinking skills of coastal students, based on several sources on STEM, namely (Komalasari, Nugraha, Danim, & Razak, 2024), which demonstrate that STEM learning based on a scientific approach improves critical and creative thinking skills and student learning outcomes at the secondary level. In addition, these results align with the analysis by Retno, Purnomo, Hidayat, Mashfufah, and Umah (2025), which found that STEM project-based learning (PjBL STEM) significantly enhances students' creative thinking skills.

Integrating STEM into the science education curriculum is more than just a pedagogical advancement; it is also a vital approach to solving 21st-century educational problems. Worldwide studies indicate that the social, cultural, and economic environment influences STEM adaptation. For example, studies in Vietnam indicate that the lack of teachers and the overloading of the curriculum often cause the implementation of STEM to ignore its cross-disciplinary depth and focus on the integration of simple project work (Tuong et al., 2023). Other developing countries, such as Nigeria and the Philippines face the same challenges, where it is common for teachers to consider STEM projects as ancillary activities and ignore their integration as the major focus of teaching (Ayeni, Chisom, Al Hamad, Osawaru, & Adewusi, 2024). This shows that the most fundamental challenge of implementing STEM goes beyond teachers' willingness to use it, to the existence of a conducive educational environment that comprises facilities, training, and structured regulatory frameworks.

Robotics involves the components of mechanics, electronics, and programming, making it fascinating as a STEM learning medium. There is potential to enhance further the computational skills, collaboration, and problem-solving skills through robotics (Darmawansah et al., 2023). The greatest challenge, however, is how teachers can connect the use of robotics to students' local context. The coastal local context in Indonesia presents excellent opportunities, as there are many natural phenomena and daily life challenges (floods, fire, infrastructure damage) that can serve as materials for STEM projects. This means that the incorporation of robotics not only improves students' skills but is also relevant to local wisdom-based scientific literacy and disaster preparedness.

## 5. CONCLUSIONS

Overall perceptions of STEM-based project-based learning by science teachers in coastal localities tend to be positive. However, STEM projects in schools tend to be poorly implemented. The prevailing science learning process in coastal sites is predominantly content-oriented, knowledge transmission is defied, and it is not sufficiently aimed at project-based solutions. Teachers build a consensus that STEM project-based learning, indeed, ought to culminate in the production of a design, model, or prototype that addresses contextual, authentic problems suited to the students' local setting.

From the students' side, learning through robotics is creative, engaging, and fun. There is a desire for STEM with robotics projects that are contextualized to the needs and problems of the coastal area. They also see learning STEM robotics as a necessity not only to solve present learning problems but also as a vital requirement for the future.

This research is the first to develop a STEM robotic learning design aimed at coastal areas, which comprises three distinct prototypes: a robotic fire alarm, robotic flood alarm, and robotic open-close bridge. The three products were all validated by learning professionals and tested for practicality with students. The findings showed that the learning media were content-valid and practical for implementation.

Consequently, the STEM Robotics project aimed at disaster mitigation represents a valuable approach to incorporating science education, technology, creativity, and problem-solving skills into the coastal environment. More of these initiatives should be developed and implemented in the future to make education more responsive to local and global changes.

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**Transparency:** The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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