# Evaluating Student-Built Earthquake Alarm Prototypes: Integrating Engineering Practices Through Real-World Projects in Junior High School

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**Received**: 4th July 2025; **Accepted**: 5th August 2025; **Published**: 15th August 2025
DOI: https://dx.doi.org/10.29303/jpft.v11i1a.9306

***Abstract*** *- Preparing students for 21st-century challenges requires learning experiences that connect scientific knowledge with real-world applications. This study investigates the integration of engineering practices in junior high school physics education through a project in which ninth-grade students designed and built simple earthquake alarm prototypes. The project adopted the PGBU (Pikir, Gambar, Buat, Uji)—a structured design process widely used in Indonesia—to guide students through iterative phases of thinking, sketching, building, and testing. Data from 24 student groups were analyzed using a rubric assessing functionality, application of physics concepts, creativity, construction neatness, and use of recycled materials. Most groups performed at moderate to high levels, with relatively higher performance observed in creativity and functionality. Results also indicated evidence of collaboration and the ability to apply physics concepts in real-world contexts. The project-based implementation of PGBU effectively fostered essential 21st-century competencies such as creative problem-solving, critical thinking, and teamwork. These findings highlight the potential of culturally grounded, design-based learning to support meaningful STEM education in junior high schools.*

***Keywords***: *PGBU; earthquake alarm; engineering practices; creativity; collaboration*

## INTRODUCTION

The demands of the 21st century require a transformation in education that equips students with the ability to solve real-world problems through critical thinking, collaboration, and creativity. As technological advancements accelerate and new challenges emerge, students must not only understand scientific concepts but also be able to apply them in practical, meaningful ways (Oliveira et al., 2019). In response, engineering education and Project-based Learning (PjBL) have become essential components of 21st-century curricula (Diana et al., 2021; Sukackė et al., 2022). Following the increasing importance of critical thinking, collaboration, and creativity, the integration of engineering practices into educational frameworks offers students the opportunity to engage with real-world problems through hands-on, design-based learning. By incorporating Project-based Learning (PjBL), students not only gain deeper insights into theoretical concepts but also develop practical skills, preparing them to navigate the complexities of the modern world. As such, embracing these pedagogical approaches ensures that students are not merely consumers of knowledge but active contributors and problem-solvers in a rapidly evolving global landscape.

Engineering offers a rich context for applying knowledge from science, mathematics, and technology to design innovative solutions (Pepin et al., 2021). Through project-based approaches, students experience learning that is inquiry-driven, interdisciplinary, and grounded in real-world relevance. Interdisciplinary STEM PjBL enables students to build conceptual understanding by making connections across disciplines while engaging in collaborative problem-solving (Belbase et al., 2022;

Capraro et al., 2013). The emphasis on interdisciplinary learning within STEM education is crucial. As students are tasked with solving problems that draw upon knowledge from various fields, they develop a holistic understanding of how these disciplines interconnect and inform each other. This approach not only deepens conceptual knowledge but also cultivates a mindset of problem-solving and innovation. The collaborative nature of STEM PjBL further enhances the learning experience as students work together to tackle complex problems, reflect on diverse perspectives, and refine their solutions (Lin et al., 2021). Ultimately, this model equips students with the skills necessary to thrive in a world that demands both technical proficiency and creative, interdisciplinary thinking.

Technology further supports PjBL by providing tools for exploration, design, and communication (Belbase et al., 2022; Capraro et al., 2013). However, it is essential to note that authentic engineering experiences can also be implemented even with minimal technology, such as using mechanical sensors and recycled materials—demonstrating that quality STEM education is accessible in a wide range of learning environments.

In the context of secondary school physics, integrating engineering practices through the engineering design process offers a particularly powerful opportunity to bridge theoretical concepts with practical application. The engineering design process, which involves identifying problems, brainstorming solutions, designing prototypes, testing, and revising, is at the heart of creating functional and innovative solutions (Capraro et al., 2013). When students engage in this process, they not only gain a deeper understanding of the scientific concepts they study but also develop the skills and mindset of engineers—skills such as problem-solving, iteration, and critical thinking.

Despite growing interest in STEM education and PjBL, there is a lack of research focusing on how students at the junior high school level engage in engineering practices through hands-on design processes (Al-Kamzari & Alias, 2025; Probowati et al., 2020; Chang et al., 2022; Wulandari et al., 2024; Yanti et al., 2023). Most existing studies focus on high school or tertiary levels, often assuming students have prior content knowledge and technical skills. In contrast, middle school students—especially those in early adolescence—represent a developmental stage rich with potential for cultivating creativity and curiosity yet are underrepresented in engineering education research. Furthermore, much of the literature concentrates on learning outcomes rather than the actual design process, leaving a gap in understanding how students approach problem definition, ideation, prototyping, testing, and revision (Al-Kamzari & Alias, 2025; Sukackė et al., 2022). These hands-on, iterative processes are essential for fostering authentic engineering habits of mind, such as resilience, systems thinking, and creative problem-solving.

In the Indonesian context, where curriculum reforms encourage contextualized and student-centered learning, there is limited evidence of the effectiveness of localized engineering design frameworks such as PGBU *(Pikir, Gambar, Buat, Uji)*. As a relevant design process, PGBU not only requires the development of hands-on skills but also combines them with minds-on skills, encouraging students to become independent problem-solvers, creative and reflective, as well as critical and expressive (Chandra, 2013, 2022; Chandra et al., 2010).

To address this gap, this study explores how ninth-grade students engage in engineering practices through a PjBL activity involving the construction of simple earthquake alarm prototypes. The students follow the PGBU design process, a structured, iterative model that guides learners through the phases of thinking, sketching, building, and testing solutions. Student products are evaluated using a rubric that assesses functionality, application of physics concepts, creativity, construction quality, and material use. This research contributes to the understanding of how design-based STEM learning, supported by a localized engineering design process, can enhance students' critical thinking, creativity, and collaboration—skills essential for the 21st century.

## RESEARCH METHODS

This study employed a qualitative descriptive research design, which is appropriate for gathering deep insights and understanding complex phenomena (Lin et al., 2021; Thorne, 2017). This approach is particularly effective in exploring the nuances of student engagement with the engineering design process through the PGBU (*Pikir, Gambar, Buat, Uji*). By focusing on students' experiences, interactions, and reflections during each phase of the PGBU process—Think (*Pikir*), Sketch (*Gambar*), Build (*Buat*), and Test (*Uji*)—the study seeks to capture the complexity of their learning journey. The research was conducted at a private junior high school in Indonesia, involving one class of ninth-grade students. A total of 24 student groups participated in the study, each consisting of approximately nine students. The teacher determined grouping to ensure balanced participation and collaboration. All participants took part in the project as a mandatory component of their final term assessment. The project was integrated into the school's final assessment period as a project-based examination, implemented outside regular classroom hours to provide a more flexible and focused learning environment.

Data was collected through documentation of students' final products, along with assessments conducted during their presentations. These presentations provided an opportunity to evaluate students' ability to explain their design process, demonstrate their understanding of physics concepts, and reflect on the functionality of their earthquake alarm prototypes. This combination of product documentation and presentation-based assessment allowed for a comprehensive evaluation of both the tangible outcomes and the student's ability to communicate their learning.

The primary instrument for assessment was a rubric-based product evaluation sheet constructed to evaluate five key dimensions of student work. These included the functionality of the alarm in detecting mechanical vibrations, the accuracy of physics concepts applied, the creativity displayed in the overall design, the neatness of construction, and the effectiveness of utilizing recycled materials. Each criterion was assessed using a 4-point scale, ranging from 1 (poor) to 4 (excellent), thus enabling a standardized yet holistic appraisal of each group's performance. The rubric was designed to balance both technical and creative aspects of engineering design, as appropriate for junior high school learners, as shown in Table 1.

**Table 1.** Rubric-Based Product Evaluation

| Criterion | Description | High (4) | Moderate (3) | Fair (2) | Poor (1) |
|---|---|---|---|---|---|
| **Functionality** | Effectiveness of the prototype in detecting vibrations or simulating earthquake response. | Device operates reliably and consistently as intended. | Device functions with minor issues or inconsistencies. | Device functions inconsistently or only in part. | Device fails to function or does not respond to vibrations. |
| **Physics Concepts** | Accuracy and relevance of physics principles applied in the design and explanation. | Physics concepts are clearly and accurately applied and explained. | Concepts are applied correctly but with limited explanation or depth. | Physics concepts are partially applied or not well explained. | Physics concepts are largely incorrect or absent. |
| **Creativity** | Originality, inventiveness, and imaginative use of materials in the design. | Design is highly original with creative use of materials and features. | Design includes some creative elements but lacks full originality. | Design shows limited originality and minimal creative detail. | Design lacks creativity or is copied without modification. |
| **Neatness** | Craftsmanship, structural integrity, and overall presentation quality. | Prototype is well-built, stable, and visually clean and organized. | Build is mostly clean with minor construction flaws. | Prototype is unevenly built or has noticeable flaws. | Prototype is unstable, messy, or carelessly assembled. |
| **Recycled Materials** | Extent and effectiveness of using recycled or sustainable materials in the prototype. | Recycled materials are used thoughtfully and effectively throughout. | Some recycled materials are used but not fully integrated. | Use of recycled materials is present but poorly integrated. | No recycled materials are used or usage is irrelevant. |

The data analysis employed a descriptive qualitative approach, which allowed for the identification of patterns and variations in student performance across groups. Rubric scores were compiled, tabulated, and summarized to reveal overall trends. The results were presented using tables and visual diagrams to facilitate a clear and accessible interpretation of the findings.

To support a more structured interpretation of the results, average scores for each rubric criterion were further categorized into qualitative performance levels. This categorization provided a clearer picture of student achievement in each area and helped identify specific strengths and areas for improvement. The performance levels of each criterion were defined as follows in Table 2.

**Table 2.** Rubric for Performance Levels of Each Criterion

| Average Score (out of 4) | Level Performance |
|---|---|
| 3.60-4.00 | High |
| 3.00-3.40 | Moderate |
| Below 3.40 | Developing |

To interpret the total scores representing each group's overall performance, a similar three-level classification system was applied. Since each group could earn a maximum of 20 points across five criteria (each rated on a 4-point scale), the following thresholds were established in Table 3.

**Table 3.** Rubric for Interpreting Group Performance Levels by Total Score

| Total Score | Overall Level Performance |
|---|---|
| 18–20 | High |
| 15–17 | Moderate |
| Below 15 | Developing |

The engineering project was implemented as a project-based final examination conducted outside regular classroom hours. Students were introduced to the challenge of designing and building a simple earthquake alarm system. The project was carried out over several sessions under the supervision of a science teacher who acted as a mentor throughout the process.

Students were guided through the project using the PGBU *(Pikir, Gambar, Buat, Uji)* model—a structured design framework rooted in Indonesian educational practice. The procedure followed six phases, as shown in Figure 1.

**Figure 1.** Procedure of Project Implementation

Guidance and formative feedback were provided through scheduled consultations with the teacher. Students engaged in group work guided by the PGBU (*Pikir, Gambar, Buat, Uji*) design process, which encouraged them to think critically, visualize ideas, construct prototypes, and iteratively test their designs. Teacher support was delivered through structured mentoring sessions, in which students could seek clarification, receive feedback, and refine their work at each stage of the design process. This scaffolding approach allowed students to maintain autonomy over their designs while ensuring that learning remained aligned with the intended scientific and engineering outcomes.

## RESULTS AND DISCUSSION

### Results

This study evaluated the performance of 24 student groups in designing earthquake alarm prototypes based on five criteria: functionality, application of physics concepts, creativity, construction neatness, and the use of recycled materials. Each criterion was scored on a four-point scale, with a maximum total score of 20. To begin with, students' total scores were used to classify their overall performance across the project. The overall performance of student groups is summarized in the following Figure 2, which illustrates the distribution across high, moderate, and developing performance categories.

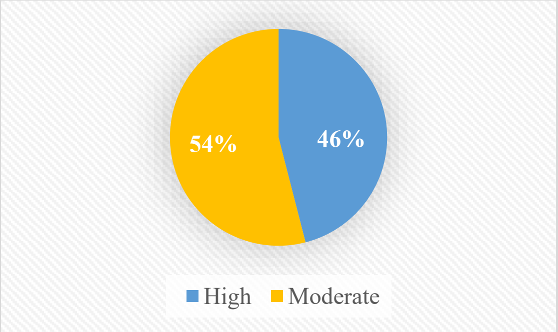


**Figure 2.** The overall performance of student groups

The pie chart above illustrates the distribution of performance categories among the 24 student groups involved in the earthquake alarm prototype project. This indicates that majority of students successfully met the expectations of the project and demonstrated essential competencies in science, engineering, and design. Their ability to conceptualize and construct functional prototypes, apply relevant physics principles, and engage in creative problem-solving reflects a well-developed understanding of the engineering design process. These outcomes were primarily supported by the structured application of the PGBU (*Pikir, Gambar, Buat, Uji*) model, which guided students through sequential phases of thinking, sketching, building, and testing. The PGBU framework not only scaffolded their learning process but also encouraged critical reflection, iterative improvement, and hands-on exploration—hallmarks of effective STEM learning in the 21st century. While overall scores provide a general view of group achievement, a closer examination of each assessment criterion reveals specific patterns in student strengths and areas needing improvement. The average scores across all groups for each criterion were as follows in Table 4.

**Table 4.** Average Scores Across All Groups for Each Criterion

| Criterion | Average Score (out of 4) | Level Performance |
|---|---|---|
| Functionality | 3.63 | High |
| Physics Concepts | 3.46 | Moderate |
| Creativity | 3.58 | High |
| Neatness | 3.33 | Moderate |
| Recycled Materials | 3.08 | Moderate |

The analysis revealed that students demonstrated strong performance in certain areas while showing moderate proficiency in others. Functionality and Creativity were both categorized as High, suggesting that most student groups were able to build working prototypes and express original, innovative ideas in their designs. In contrast, Physics Concepts, Neatness, and Use of Recycled Materials were categorized as Moderate, indicating that while students generally met expectations in applying scientific knowledge, maintaining construction quality, and incorporating sustainable materials, there was more variability in these areas. These distinctions highlight where students excelled and where instructional reinforcement could further enhance learning outcomes.

Creativity was one of the most prominent strengths demonstrated across student prototypes. Based on rubric scores and qualitative observations, more than half of the groups achieved a high level of creative performance. The creativity rubric emphasized originality, inventiveness in the mechanism or structure, and the aesthetic integration of design features.

Many groups developed earthquake alarms embedded within miniature buildings or urban layouts, demonstrating contextual imagination and visual storytelling. Some employed symbolic decorations, thematic elements, or unconventional materials that reflected unique interpretations of the project. These high-scoring groups often presented designs that went beyond the basic functional requirement, reflecting a deeper engagement with the design task. In contrast, moderate-scoring groups displayed creative effort but tended to follow more conventional forms or presented ideas with limited elaboration.

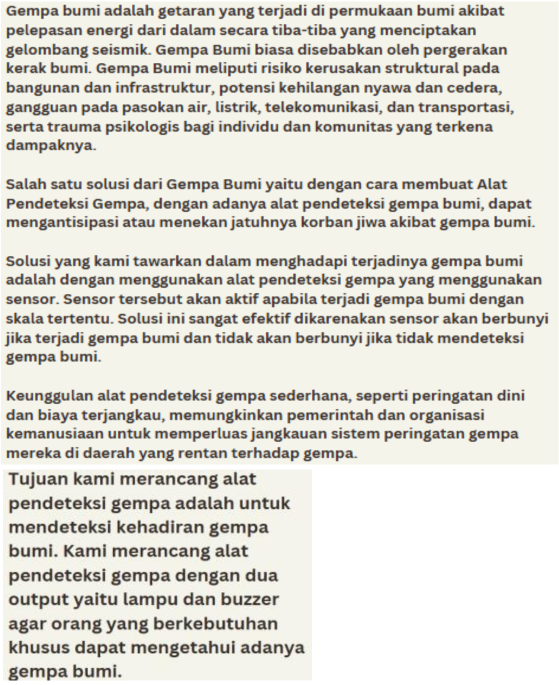
The strong performance in this area suggests that the project provided an adequate space for students to express creative thinking, encouraging divergent ideas and personalized design solutions within the engineering design process (PGBU).

To further illustrate how students engaged with the engineering design process, this section presents examples of student work aligned with the four phases of the PGBU model—Pikir (Think), Gambar (Sketch), Buat (Build), and Uji (Test). These artifacts not only demonstrate the iterative nature of student learning but also provide qualitative evidence supporting their development of creativity, collaboration, and practical problem-solving skills.

### 1. Think (*Pikir*)

In this initial phase, students demonstrated their conceptual understanding of earthquakes and the social impact they can cause. Sample student explanation during "Pikir" (Think) phase is shown in Figure 3. They framed their design task as a response to a real-world problem and proposed a solution involving a vibration-sensitive sensor that activates a buzzer in the event of seismic activity. The explanation emphasized both the technical logic and the societal value of the device, revealing students' ability to engage in problem identification and purpose-driven design.

A particularly thoughtful design consideration appeared in one group's explanation, as shown Figure 2, where they incorporated dual outputs—light and sound—so that the device would be accessible to individuals with hearing or visual impairments. This early-stage thinking highlights students' attention to inclusivity and real-world applicability, demonstrating how the PGBU process fosters not only technical problem-solving but also empathetic and user-centered design. This phase encouraged students to define the problem in their terms, laying the foundation for authentic, student-centered design.



Gempa bumi adalah getaran yang terjadi di permukaan bumi akibat pelepasan energi dari dalam secara tiba-tiba yang menciptakan gelombang seismik. Gempa Bumi biasa disebabkan oleh pergerakan kerak bumi. Gempa Bumi meliputi risiko kerusakan struktural pada bangunan dan infrastruktur, potensi kehilangan nyawa dan cedera, gangguan pada pasokan air, listrik, telekomunikasi, dan transportasi, serta trauma psikologis bagi individu dan komunitas yang terkena dampaknya.

Salah satu solusi dari Gempa Bumi yaitu dengan cara membuat Alat Pendeteksi Gempa, dengan adanya alat pendeteksi gempa bumi, dapat mengantisipasi atau menekan jatuhnya korban jiwa akibat gempa bumi.

Solusi yang kami tawarkan dalam menghadapi terjadinya gempa bumi adalah dengan menggunakan alat pendeteksi gempa yang menggunakan sensor. Sensor tersebut akan aktif apabila terjadi gempa bumi dengan skala tertentu. Solusi ini sangat efektif dikarenakan sensor akan berbunyi jika terjadi gempa bumi dan tidak akan berbunyi jika tidak mendeteksi gempa bumi.

Keunggulan alat pendeteksi gempa sederhana, seperti peringatan dini dan biaya terjangkau, memungkinkan pemerintah dan organisasi kemanusiaan untuk memperluas jangkauan sistem peringatan gempa mereka di daerah yang rentan terhadap gempa.

Tujuan kami merancang alat pendeteksi gempa adalah untuk mendeteksi kehadiran gempa bumi. Kami merancang alat pendeteksi gempa dengan dua output yaitu lampu dan buzzer agar orang yang berkebutuhan khusus dapat mengetahui adanya gempa bumi.

**Figure 3.** Sample student explanation during the Think (*Pikir*) phase

### 2. Sketch (*Gambar*)

This hand-drawn sketch illustrates an innovative yet straightforward earthquake alarm mechanism, as shown in Figure 4. The circuit uses a buzzer, wires, and conductive materials such as paper clips and metal weights to detect vibration. When shaking occurs, a suspended wire touches a paper clip connected to a metal component, completing the circuit and activating the buzzer. The annotations show how the student conceptualized the working logic of the design, emphasizing how physical contact under motion leads to current flow. This example demonstrates a practical understanding of circuitry, as well as the creative adaptation of familiar materials for sensor function.

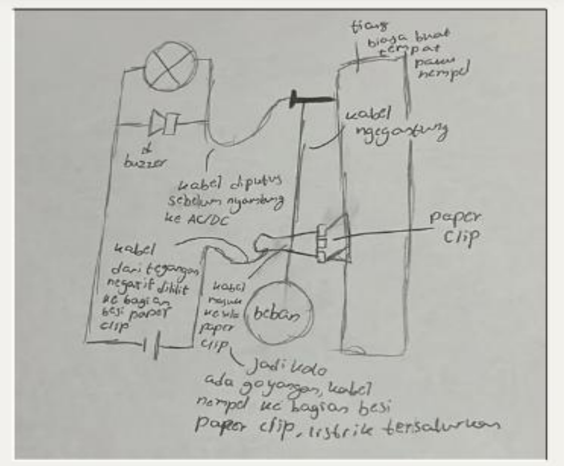


**Figure 4.** Sample Student sketch during the Sketch (Gambar) Phase

### 3. Build (*Buat*)

In the building phase, students transformed their sketches into physical prototypes using a combination of electronic components and recycled materials. Figure 5 and Figure 6 show document both the construction process and completed prototypes. Figure 5 captures the collaborative nature of the building process, with team members actively working together to wire and assemble the circuit. This hands-on activity enabled students to test hypotheses, troubleshoot connectivity issues, and revise their designs in real-time. Figure 6 shows that students were built earthquake alarm and structural bases—some embedded into miniature houses to simulate real earthquake-prone environments.

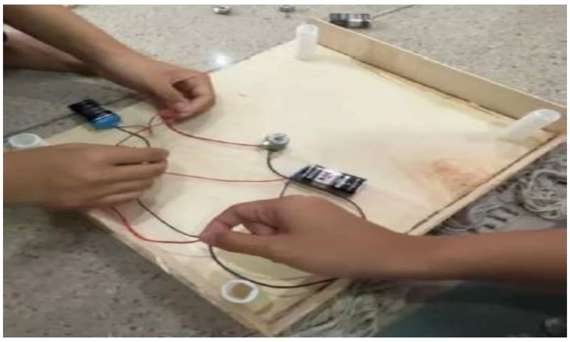


**Figure 5.** Students engaging in the building process, wiring components on a wooden platform.

Components were attached to wooden boards or housed within cardboard models. This reflects students' attention to both functional circuitry and environmental context.

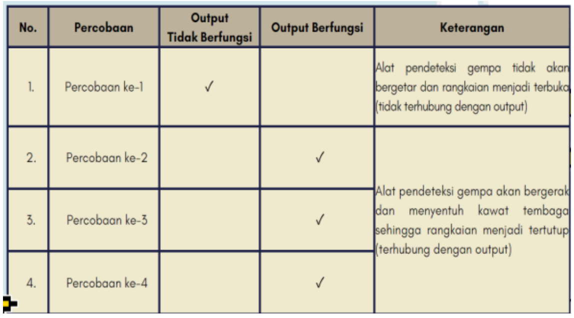
**Figure 6.** Students engaging in the building process, wiring components on a wooden platform

### 4. Test (Uji)

The final phase involved testing the earthquake alarm prototypes under simulated vibration conditions. Students conducted multiple trials to verify whether the sensor mechanism would activate the output system—usually a buzzer, LED, or both. As shown in the sample testing log, as shown in Figure 7, the prototype was tested in four trials, with results indicating a functional alarm in three out of four attempts. These outcomes suggest a reliable sensor response once vibrations reach a certain threshold.

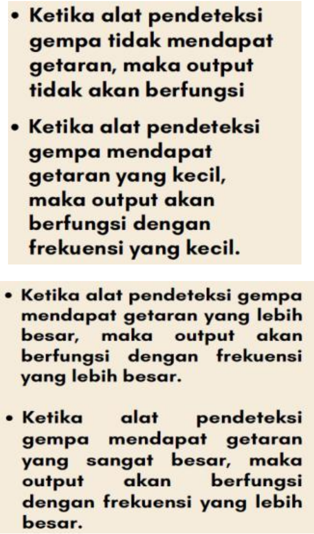
Students also described a correlation between the strength of the vibration and the frequency of the output response. Weaker vibrations triggered slower or less frequent responses, while more vigorous shaking led to faster activation. This understanding was reflected in their written descriptions, as shown Figure 8, which show increasing levels of sensor sensitivity.

This phase illustrates not only the functionality of the student-built devices but also their ability to evaluate, interpret, and refine their designs based on real-world-like testing scenarios.



| No. | Percobaan | Output Tidak Berfungsi | Output Berfungsi | Keterangan |
|---|---|---|---|---|
| 1. | Percobaan ke-1 | ✓ | | Alat pendeteksi gempa tidak akan bergetar dan rangkaian menjadi terbuka (tidak terhubung dengan output) |
| 2. | Percobaan ke-2 | | ✓ | Alat pendeteksi gempa akan bergerak dan menyentuh kawat tembaga sehingga rangkaian menjadi tertutup (terhubung dengan output) |
| 3. | Percobaan ke-3 | | ✓ | |
| 4. | Percobaan ke-4 | | ✓ | |

**Figure 7.** Student trial log showing output functionality across multiple tests.



- **Ketika alat pendeteksi gempa tidak mendapat getaran, maka output tidak akan berfungsi**
- **Ketika alat pendeteksi gempa mendapat getaran yang kecil, maka output akan berfungsi dengan frekuensi yang kecil.**

- **Ketika alat pendeteksi gempa mendapat getaran yang lebih besar, maka output akan berfungsi dengan frekuensi yang lebih besar.**
- **Ketika alat pendeteksi gempa mendapat getaran yang sangat besar, maka output akan berfungsi dengan frekuensi yang lebih besar.**

**Figure 8.** Student trial log showing output functionality across multiple tests

The analysis of student work across all phases of the PGBU demonstrated meaningful engagement with both scientific content and engineering practices. Quantitative assessment showed that most student groups achieved moderate to high levels of performance, especially in functionality and creativity. The qualitative artifacts—including sketches, construction processes, and testing logs—revealed students' ability to apply physics principles in context, innovate with available materials, and collaborate effectively within their teams.

Notably, the implementation of the PGBU model not only structured students' thinking but also supported their transition from conceptual ideas to tested real-world solutions. The combination of structured processes and open-ended design tasks provided students with opportunities to develop 21st-century competencies in authentic ways.

## Discussion

This study demonstrates how integrating engineering practices into junior high school physics education can enhance students' understanding of science concepts and design thinking. The use of the PGBU provided a structured yet flexible framework that mirrors the authentic engineering design process. Each phase of PGBU encouraged students to ideate, visualize, construct, and refine their prototypes, aligning well with the iterative nature of real-world engineering (Chandra, 2013, 2022; Chandra et al., 2010). The majority of student groups achieved high or moderate overall performance, with particularly strong results in the functionality and creativity criteria. These outcomes suggest that students not only engaged with the physics content meaningfully but also developed the capacity to solve practical problems through design. The project created opportunities for critical thinking, decision-making, and troubleshooting—core competencies in engineering education. Similar findings were reported by Safitri et al. (2024), who demonstrated that the STEM-based Engineering Design Process significantly enhanced students' creative and critical thinking skills through structured, student-centered design activities.

The high levels of creativity demonstrated in many student products reflect the effectiveness of project-based learning (PjBL) in nurturing innovative thinking. Students generated original solutions, personalized their designs, and used imaginative approaches to integrate technical and aesthetic elements. These results are consistent with prior studies

(Probowati et al., 2020; Sucilestari et al., 2023) that highlight how PjBL environments support divergent thinking and creative problem-solving. In addition, collaboration was generally well-executed, as inferred from the consistency and structure of group outputs. Although direct observation of teamwork was limited, the alignment of documentation, construction, and presentation suggested effective group coordination. These findings support the argument that PjBL not only promotes content mastery but also fosters interpersonal skills critical for 21st-century learners (Adeoye & Jimoh, 2023; Jannah et al., 2025; Khan et al., 2025; Wulandari et al., 2024; Yanti et al., 2023).

The integration of the PGBU model as an engineering design process in this study provided more than just a scaffold for classroom activity—it offered a transformative learning experience (Vale et al., 2022). Students were not merely building alarms; they were engaging in a structured cycle of ideation, visualization, prototyping, and testing that closely mirrors the way real engineers approach problems. The tangible artifacts from each PGBU phase—student writing, sketches, circuits, and trial logs—demonstrate that this model effectively supports both cognitive and practical learning goals. This is consistent with findings by Khoirunnissa et al. (2024) and Ayida et al. (2025), who reported that embedding engineering design within STEM-PBL and STEM-EDP frameworks significantly fosters critical thinking and creative problem-solving. In such contexts, student-generated outputs—ranging from prototypes to visual reports—serve as evidence of deep engagement with both conceptual understanding and applied engineering reasoning. Similarly, Rachmayati et al. (2020) and Purnama et al. (2023) underscored that STEM projects rooted in engineering practices—such as iterative construction, testing, and reflective redesign— immerse students in structured, authentic experiences that closely mirror professional engineering workflows and strengthen their scientific understanding.

Moreover, the project revealed how engineering practices can be accessible and meaningful even for junior high school students. The PGBU model's simplicity and cultural relevance made it an ideal framework for promoting inquiry, iteration, and creativity. It helped students move from abstract concepts to working systems that they could physically build, test, and improve. The results reinforce the argument that engineering design integration—primarily through frameworks like PGBU—can enhance science education by aligning content knowledge with real-world relevance while also cultivating essential 21st-century skills.

## CONCLUSION

This study explored the integration of engineering practices in junior high school physics education through the PGBU *(Pikir, Gambar, Buat, Uji)*, focusing on the design and construction of earthquake alarm prototypes. The findings revealed that students were able to effectively apply physics principles while demonstrating creativity, problem-solving, and collaboration throughout the project. The majority of groups performed at moderate to high levels, particularly in terms of functionality and creativity, underscoring the effectiveness of the PGBU model in facilitating hands-on learning.

By engaging students in each phase of the engineering design process, the project enabled them to move beyond theoretical knowledge, fostering deeper understanding and skill development in real-world contexts. The combination of structured guidance and opportunities for student-driven design allowed for meaningful exploration of physics concepts while also supporting the development of essential 21st-century skills such as critical thinking, teamwork, and innovation.

The success of this project suggests that integrating engineering practices into science curricula can be a powerful approach to enhancing STEM education. It also highlights the potential of design-based learning to engage students actively, foster creativity, and prepare them for future challenges. Moving forward, further research can explore how such models can be implemented across different educational contexts and examined longitudinally to assess long-term impacts on student learning and engagement.

## ACKNOWLEDGMENT

I want to express my sincere gratitude to the students who participated in this project, as well as to the school leadership and fellow educators at SMP Taruna Bakti, for their unwavering cooperation and support. Their openness to project-based and design-oriented learning was crucial in enabling the successful implementation and documentation of this instructional innovation during my tenure as a science teacher at the school.

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