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Low-Cost Online Science Lab on Energy Conversion with a STEM Approach

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Abstract
The limited laboratory facilities in many schools are a challenge in science learning, especially in understanding the physics concept of energy changes. This study aims to describe the description and feasibility of the Low-Cost Online Science Lab with a STEM approach through bold experimental activities and analyze student responses to the learning. This study uses the Mix Method with 29 prospective teacher students and 3 experts as research subjects. The results of the analysis show that a valid and feasible Low-Cost Online Science Lab experimental device has been produced on the concept of changing the potential energy of air into electricity in learning. Based on the results of the initial trial and questionnaire analysis, student responses were on average above 85%, indicating that the acceptance of this learning innovation was in the very good category. In its design, the STEM approach is implemented through the design of learning tools and activities that include the concepts of STEM in an integrated manner. The prototype developed is affordable, easy to use, which is expected to be an effective learning alternative, not only for the concept of Conservation of Energy but also for other science materials. Low-Cost Online Science Labs can provide a solution for schools with limited laboratory facilities, while strengthening the implementation of the STEM approach in education.

Keywords: Conservation of Energy, Learning Aids, Low-Cost Online Science Lab, STEM Approach

Introduction

Understanding the concept of conservation of energy in science education is very important. Currently, there are still many students who have misconceptions related to the conservation of energy. There are still many students who do not understand the concept of energy change. This is because most science learning is only theoretical and lacks observation activities in the laboratory (Swandi et al., 2020). Learning is not made conceptual, not connecting everyday phenomena into learning. On the other hand, a science concept is taught more partially which actually results in misconceptions (Martawijaya, Rahmadhanningsih, et al., 2023).

In addition, there are mistakes in teaching about energy changes. Although the law of conservation of energy states that "Energy cannot be created or destroyed, but energy can be changed from one form to another", teachers are wrong in explaining this concept. They teach as if all the energy from an energy source is completely converted to another system. For example, when teachers teach about the energy produced by hydroelectric power plants, they teach that the potential energy produced by water is the same as the electrical energy produced by the generator. In fact, there is energy lost, which the teacher does not explain at all. Therefore, learning must be done through experiments to prove a physics concept. On the other hand, learning about energy changes is more dominated by theoretical learning in the classroom without providing more contextual explanations based on active learning.

Students' understanding of changes and sources of energy is quite important because this concept plays a very important role in everyday life and the development of science and technology. Understanding how energy can change form, such as from water energy to electrical energy, helps students develop critical thinking and problem-solving skills, especially in facing global challenges related to the energy crisis. This knowledge can also encourage students to be more creative and innovative in creating environmentally friendly renewable energy-based solutions, so that they can contribute to the development of a more sustainable future. Therefore, this concept needs to be taught through various experimental activities.

Review of Related Literature

Laboratory experiments and activities play a vital role in helping students develop a deeper understanding of scientific concepts, acquire practical skills, and engage in the process of scientific inquiry ((Díaz, 2016; Raja et al., 2016). Through direct interaction with physical phenomena, students can better understand the underlying principles, make connections between theory and practice, and foster critical thinking and problem-solving skills (Soh & Meerah, 2013; Szőke, 2022). However, many schools, especially those in areas with limited resources, face the challenge of limited or inadequate physics laboratory facilities (Palloan & Swandi, 2019; Swandi et al., 2020). Although some educational institutions already have some laboratory equipment, it is still very lacking when compared to the number of students. This lack of resources hinders students' ability to engage in direct exploration and deepen their understanding of this basic principle (Kunitsky et al., 2024; Permanasari et al., 2021). In addition, to complete various equipment in the science laboratory, costs are needed, where schools often experience financial limitations (Swandi et al., 2020).

The main objective of this study is to introduce a low-cost online science laboratory as an alternative to the traditional laboratory environment and to integrate the STEM approach into the design of this innovative learning environment (Yaneva, 2022). This approach aims to provide an efficient and cost-effective solution for schools with limited resources, allowing students to continue their scientific exploration and experimentation (Kandil, 2021). An integrated STEM approach has been shown to increase student motivation and make learning science easier (Erickson et al., 2022; Martawijaya, Swandi, et al., 2023; Nedic et al., 2003) and has been shown to improve thinking skills and reduce misconceptions (Martawijaya, Rahmadhanningsih, et al., 2023).

So far, online science learning has been widely carried out using virtual laboratories and has been accessible online. However, not all science concepts have virtual laboratories.

On the other hand, although virtual laboratories can be a solution to overcome the limitations of lab equipment in the laboratory, this learning certainly does not provide a real experience (Nedic et al., 2003). Therefore, it is important to provide real laboratories but can be accessed online by students (Byagathvalli et al., 2019; Erickson et al., 2022). By developing a low-cost online science laboratory that combines STEM approaches, this study seeks to empower teachers and students in resource-constrained settings to engage in meaningful scientific exploration and experimentation (Leineweber, 2020; Szőke, 2022; Yordanov et al., 2023).

This approach not only addresses the problem of limited laboratory facilities but also promotes an integrated understanding of science, technology, engineering, and mathematics (Arumugam et al., 2021; Thatcher et al., 2022). Using a combination of affordable materials, open-source software, and innovative design, these labs aim to be cost-effective solutions that can be replicated and implemented in a variety of educational settings (Afriana et al., 2016; Hofstein & Lunetta, 1982; Permanasari et al., 2021). An integrated STEM approach into the design of a low-cost online science lab will emphasize the interconnectedness of multiple disciplines, encouraging students to develop critical thinking, problem-solving, and interdisciplinary skills (Baudin et al., 2022).

Objectives

By introducing a low-cost online science laboratory and integrating STEM approaches, this study aims to address the challenges faced by schools with limited resources, particularly in the context of physics education. The proposed solution has the potential to increase student engagement, improve learning outcomes, and foster a deeper understanding of scientific principles, which of course can be explored in future research. By addressing the limitations of laboratory learning implementation, this study is expected to contribute to the advancement of science education and empower teachers and students to explore and understand the basic principles of physics in innovative, meaningful and engaging ways. Therefore, the formulation of the problem in this research is:

1. How is the description of the Low-Cost Online Science Lab on Energy Conversion experimental device?
2. How is the feasibility of the Low-Cost Online Science Lab and the STEM approach used in the learning stages?
3. How do students respond to science learning using the Low-Cost Online Science Lab on Energy Conversion?

Methodology

This study uses a Mix Method which is divided into two approaches, namely qualitative and quantitative. The qualitative approach is used to answer the first problem formulation through literature studies from various sources such as physics textbooks, journals on physics experimental tools, and the internet that provides experimental tool components. This study aims to examine concepts related to energy changes and how to develop simple and inexpensive experimental tools. Based on the results of the literature study, the concept and experimental tools that can be developed are determined in the form of Potential Energy Changes into Electrical Energy.

Furthermore, to determine how the feasibility of the Low-Cost Online Science Lab and the STEM approach are applied in learning, it is obtained through a qualitative approach through discussions with 2 science education lecturers (practitioners) and 1 STEM expert through expert validation and Focus Group Discussion. The feasibility aspects include the design and construction (DC), suitability with STEM (S-STEM), effectiveness in learning (EL), innovation and efficiency (IE). Based on the results of discussions with experts, it is recommended to use project-based learning stages.

While the quantitative approach is used to find out how students respond to the implementation of the Low-Cost Online Science Lab on Energy Conversion through a limited trial. There are 29 prospective elementary school teachers involved in this activity who are divided into 2 groups. 3 students did face-to-face learning and 26 students took online learning. After the learning was completed, they were asked to fill out a questionnaire about the Technology Acceptance Model. The following are the characteristics of student respondents.

Table 1. Characteristics of Student Respondents

Characteritics	Information
Department	Primary Teacher Education
Gender	7 Male, 22 Female
Semester	IV
Average Age	± 20 tahun

Qualitative data is analyzed using content analysis techniques. Content analysis is a technique in qualitative data analysis that is used to systematically understand and interpret the meaning of text data. Qualitative data in the form of text, photos or images, videos, and so on are categorized and given special codes. Previously random data is arranged to be more organized to help researchers understand the data patterns. This makes it easier for the analysis process to obtain clearer information and can be presented in a simpler form. While quantitative data is analyzed by calculating the percentage of respondents' assessments for each item and aspect and then presented in the form of tables or graphs or charts.

Analysis

Description of the Innovation "Low-Cost Online Science Lab"

Based on the results of literature studies from various sources, it was concluded that the concepts and teaching aids developed were related to the change in potential energy of water into electricity that help students understand the basic principles of physics related to changes in energy forms. This tool is designed to show how the potential energy of water at a certain height can be converted into kinetic energy when the water falls and then converted into electrical energy by a generator. The design of laboratory equipment based on simple technology (low-cost) on the concept of energy conversion using easily available materials. In addition to being able to buy energy conversion equipment components directly on the market place, equipment can also be easily obtained using simple materials that are around us. After the teaching aids are assembled, the next step is to combine the use of the tool with digital devices. The accelerometer on the cellphone can be used to determine the rotation speed or simulation application to visualize energy data. The image below is a demonstration tool after assembly:

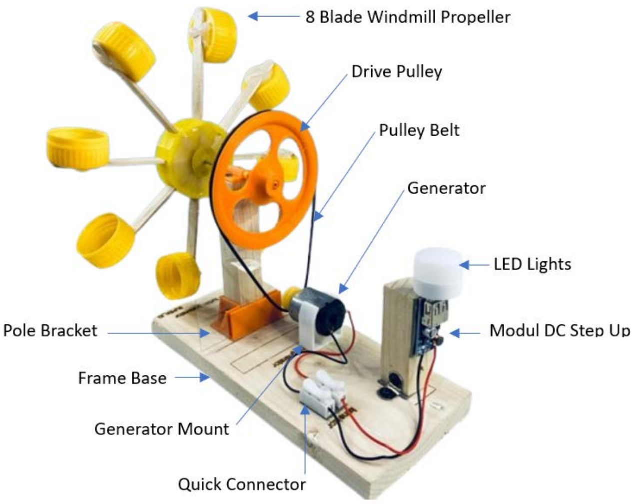

Figure 1. Examples of learning aids that have been assembled

Water is stored in a container placed at a certain height. In this position, water has potential energy that depends on the mass of the water and the height of the water. The higher the position of the water, the greater the potential energy it has. When the valve or water channel is opened, the water begins to fall and flows towards the propeller or turbine. During the journey of the water falling, the potential energy possessed by the water will be converted into kinetic energy due to the acceleration of gravity that affects the water when it falls.

The speed of the falling water depends on the height of the water and the acceleration of gravity. The kinetic energy of the falling water will be used to rotate the propeller or turbine attached to the tool. When water flows and hits the propeller, the thrust from the water flow will rotate the propeller. The kinetic energy obtained from the movement of this water is then transferred to the turbine shaft. This rotating turbine is connected to a generator. When the turbine rotates, the kinetic energy provided by the water flow will move the rotor in the generator. This process utilizes electromagnetic induction, where the movement of the rotor in a magnetic field produces an electric current. The generator converts mechanical energy (rotational motion) into electrical energy.

The electrical energy produced by the generator can be channeled to an energy measuring device, such as a voltmeter or ammeter, to show the amount of power produced. In addition, the electrical energy can also be channeled to run other devices, such as small LED lights, to demonstrate the practical application of the energy produced. This teaching aid allows students to see firsthand the basic principles of the law of conservation of energy and energy conversion. They can observe how the potential energy stored in water can be converted into kinetic energy when the water moves and then converted into electrical energy. Thus, this tool not only teaches theory but also provides practical experience that makes it easier for students to understand physics concepts related to changes in energy forms. This teaching aid can also be adapted to explain various other concepts in science learning, such as energy efficiency, the impact of changes in height on potential energy, and the relationship between mechanical energy and electrical energy. In this way, the teaching aid becomes a very useful medium for teaching STEM concepts in a practical and interesting way.

Feasibility and STEM Components in Learning
The feasibility of Low-Cost Online Science Lab on Energy Conversion is based on the assessment of 3 experts. Expert assessment is divided into two, namely quantitative assessment by scoring each item in the validation sheet and qualitative assessment through suggestions and product improvements. Based on the results of the analysis of the percentage of expert assessments for each aspect is shown in the Figure 2 below

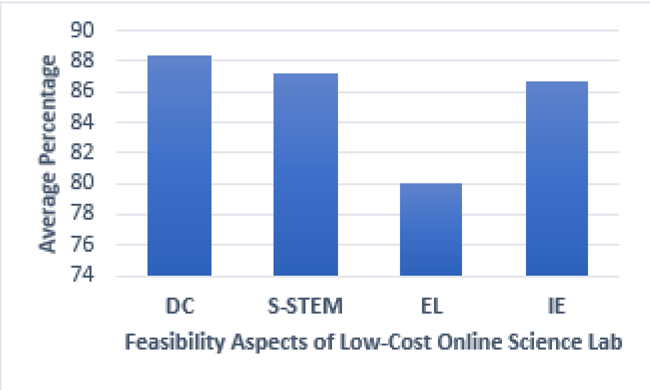

Figure 2. Percentage Score based on Feasibility Aspects of Low-Cost Online Science Lab

Based on the analysis results, the average feasibility score of the Low-Cost Online Science Lab on Energy Conversion was 85.57, which is in the very feasible category. This shows that based on expert assessments, this product is very feasible to be applied in learning. The design and construction (DC) aspects have the highest assessment with an average score of 88.33 (very feasible) and the aspect with the lowest value is effectiveness in learning (EL) with an average score of 80 (feasible).

Findings and Discussion

All experts agree that this experimental tool has strength and durability so that it can be used repeatedly. In addition, the experimental tool is safe to use, easy to assemble and has an attractive appearance. However, some aspects of design and construction, namely the need for protection of the dynamo and electric switch from water splashes. While in terms of suitability with STEM, all experts agree that the experimental tool can be used by integrating STEM interdisciplinary learning. In addition, all STEM components can emerge from the learning process using teaching aids. Then the experts also strongly agree that this teaching aid provides innovation in overcoming the limitations of laboratory equipment and is efficient in terms of using learning time.

However, all experts provide several improvements, especially related to the aspect of effectiveness in learning. This aspect can only be measured after the learning process takes place by providing various measurements before and after the application of online-based experimental tools such as measuring conceptual understanding, misconceptions or various other skills. However, in theory, by looking at the suitability of the experimental tool with the concept of energy change, all experts agree that there will be an increase in student understanding or skills after using this tool in learning. Next, a discussion was held to find out how STEM is integrated into learning. Based on the results of the literature study and discussions with experts, the following are the STEM components in learning taken from several sources.

Table 1. Independent Sample Size Effects.

STEM Components	Definition
Science	Provides a foundation of scientific knowledge about natural phenomena
Technology	Uses technological tools to facilitate learning
Engineering	Focuses on designing and building solutions to real-world problems
Mathematics	Used for data analysis and calculations

Based on the definition of STEM components in the table 1, the following image shows how STEM components appear in learning using the teaching aid

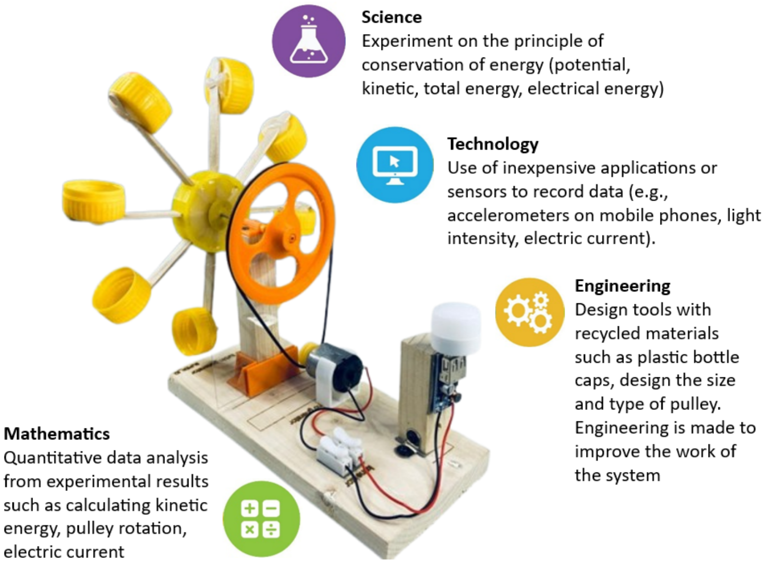

Figure 3. STEM Components in the Experiment Converting Potential Energy to Electrical Energy.

First, students deepen their understanding of concepts (SCIENCE) related to potential energy, kinetic energy and energy changes. The law of conservation of mechanical energy states that in a closed system without the influence of external forces (such as friction or air resistance), the total mechanical energy, which is the sum of kinetic energy and potential energy, will remain constant. The ENGINEERING component appears when students assemble experimental props. To convert the potential energy of water received by the propeller into electrical energy maximally, engineering can be done in several ways. One of them is by optimizing the design of the turbine or propeller that receives the water flow. After the assembly process is complete, TECHNOLOGY components can be operated through the use of technology such as cellphone applications. This application can be used to measure energy by utilizing built-in sensors such as accelerometers and gyroscopes to record movement data, which is then analyzed to calculate energy. The data generated from the experimental process is analyzed using MATHEMATICS components. The potential energy Ep produced by water is converted into electrical energy. By performing mathematical analysis we obtain an equation, we obtain.

In order for learning to be more in-depth, experiments can be conducted several times by varying the control variables and independent variables. In addition to providing quite diverse efficiency values, learning will also be more in-depth where changes in variables may change the efficiency value which of course can be a step for students to explore and conduct in-depth analysis.

Student Perception of the Learning Process

The innovation in this study is to introduce innovation in science learning using teaching aids integrated with STEM and presented in a online manner in learning. In order for this learning innovation to be carried out, hardware is needed in the form of an action camera connected to a PC, microphone and software in the form of a zoom application. The components of the teaching aids can be obtained through the market place but can also be obtained with easily obtained materials. The installation of teaching aids is not easy. For students who are accustomed to using various work equipment or making crafts, they may find it easier to complete. However, not all students' abilities are the same so teachers need to make clear guidelines on how to install them into a complete teaching aid package.

Figure 4. Students are conducting online testing of experimental props.

In Figure 3, there are 3 students testing the experimental equipment used. They carry out the learning process starting from deepening the concept, design and assembly, experiments, and data analysis. One student uses an action camera attached to his head. The visuals produced by the camera are then transmitted to a laptop connected to the zoom application. So that other students can follow the learning online.

Figure 5. View of the experimental process witnessed by distance students using the Zoom application.

The image above is a display of the experimental process carried out by students. With the help of an action camera, students who are outside the classroom or laboratory can follow all stages of experiment-based learning. In addition to being able to observe all experimental activities, students at a distance can also participate directly by communicating with teachers or other students who are carrying out experimental activities. This makes learning more interactive and provides real experiences for students.

The introduction of the Low-Cost Online Science Lab on Energy Conversion was conducted in a limited classroom where 26 students tried the experimental props without collecting data. After they tried it, they filled out the Technology Acceptance Model questionnaire adopted by the Theory of Reasoned Action (TRA) which is widely used to predict the acceptance and usefulness of technology. This questionnaire contains 17 questions with 5 indicators, namely Perceived Usefulness (PU), Perceived Ease of Use (PEU), Attitude (ATT), Subjective Norm (SN), Behavioral Intention (BI). The results of the student response analysis are presented in the graph below.

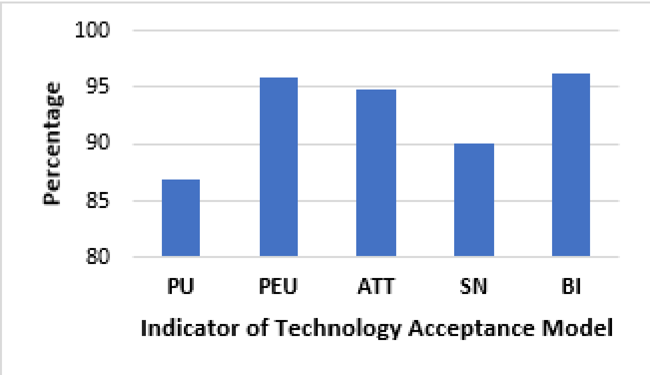

Figure 6. Student responses after limited use of the Low-Cost Science Lab

The results of the Technology Acceptance Model (TAM) analysis of the low-cost online science lab show that the indicators perceived usefulness (PU) and perceived ease of use (PEU) play an important role in shaping users' attitudes (ATT) and their intention to use this technology (BI). The graph shows that PEU and BI have high percentage values, indicating that users find this lab tool easy to use and intend to use it in further learning. Meanwhile, PU has a lower value than other indicators, which may indicate that although this technology is considered useful, there are other factors that may influence the perception of its usefulness, such as limited features or additional needs in supporting complex science experiments. In addition, social norms (SN) also have an influence on the acceptance of this technology, indicating that support from the social environment, such as lecturers and peers, can increase the adoption of the low-cost online science lab. With a high level of acceptance based on the results of this TAM, further development can be focused on improving features and functionality to better suit user needs.

After the trial, students gave some of their opinions regarding the implementation of the low-cost online science lab. Here is a summary of student opinions:

- We were given direct experience in assembling experimental equipment, I think this learning is more interesting and meaningful

• I really enjoy testing the equipment we made directly, we can prove Law of Conservation of Energy that we have studied in theory, without any real activities based on evidence
• The action camera allows us to see the experimental process remotely, but the position of the camera and the unstable movement of the camera make the display on the laptop unstable.
• It is necessary to experiment in a place with good lighting, so that the captured view is clearer.

Implication and Further Research

Through direct interaction with physical phenomena, students can better understand fundamental principles, make connections between theory and practice, and develop critical thinking and problem-solving skills (Šlekienė & Ragulienė, 2013). However, many schools, especially in low-resource areas, face the challenge of limited or inadequate physics laboratory facilities (Evains et al., 2024; Swandi et al., 2020). Lack of access to hands-on learning experiences can hinder the development of essential skills and the overall quality of science education (Corter et al., 2011; Hofstein & Lunetta, 1982). This study introduces the innovation of Low-Cost online Science Lab as an alternative solution to overcome the limited laboratory facilities in schools. By integrating STEM approaches, this online laboratory aims to provide an efficient, affordable, and accessible learning environment for students from various backgrounds (Banky & Blicblau, 2015).

The use of low-cost online science labs in science learning can be based on constructivist theory and Ausubel's meaningful learning theory. Constructivist theory argues that students construct their own understanding through direct experience and interaction with the environment, which in this case is facilitated by online laboratories as a means of independent exploration. By conducting virtual experiments, observing phenomena, and testing hypotheses, students engage in inquiry-based learning that helps deepen their understanding. Meanwhile, Ausubel's meaningful learning theory emphasizes the importance of prior knowledge in understanding new concepts, where online laboratories allow students to relate the material being studied to previous experiences. Thus, the use of low-cost online science labs is not only a solution to the limitations of physical laboratory facilities but can also increase student engagement in the learning process and strengthen their conceptual understanding through exploratory and contextual experiences.

The implications of this study are to provide opportunities for schools with limited resources to implement experiment-based learning and motivate teachers to adopt creative and innovative STEM approaches (Banky & Blicblau, 2015; Doucette et al., 2020). By providing an affordable and accessible laboratory solution, this research has the potential to increase student engagement, improve learning outcomes, and foster a deeper understanding of scientific principles, particularly the conservation of energy concept (Šlekienė & Ragulienė, 2013).

Overall, this research developed a Low-Cost online Science Lab that integrates STEM approaches to provide an engaging and affordable learning experience for students, especially in resource-limited settings. By addressing the limitations of traditional laboratories, this research is expected to contribute to the advancement of science education and empower both teachers and students to explore and understand fundamental principles of physics, such as the conservation of energy concept.

The implementation of the learning stages of online science learning can be done in subsequent research. This aims to determine whether the syntax is appropriate and what improvements can be made. The development of similar tools also needs to be done for other physics concepts so that it has a wider impact on science learning. Then the provision of practical guidance for teachers in assembling and using this tool in the classroom as well as supporting learning devices such as student work and various measuring instruments to determine the effectiveness of this innovation is also interesting to study further. In addition, this innovation can also be developed into a science learning model that can later be widely replicated in science learning at various levels of education. Experimental research can also be conducted to determine how effective the implementation of Low Cost Online Science Lab is in influencing students' understanding of concepts, misconceptions, and various thinking skills.

Conclusion

Based on the results of this study, it can be concluded that the Low-Cost online Science Lab can be an innovative alternative for learning the concept of conservation of energy and become a reference for learning science in other concepts. This is a solution in presenting inexpensive experimental-based learning equipment that can be used by many students. In addition, this innovation has succeeded in integrating the STEM approach in the design of cost-effective, relevant, and easy-to-implement tools through research-based learning that is carried out in a online manner. Although this study is still limited to the introduction of ideas and initial testing of the equipment used, further research is needed to see how this innovation affects the mastery of concepts and various 21st century skills more broadly.

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