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Training for Assembly of Appropriate Technology-Based Battery Packs to Improve Vocational School Students' Competence in Supporting Green Energy Programs

Fachry Fathan Irsyad[1], I Gede Putu Oka Indra Wijaya[2,*], Ahmad Fahmi Aldarwis[3], Aminah Indahsari Marsuki[4], Jangkung Raharjo[5]
[1,2,3,5] Energy System Engineering Study Program, School of Electrical Engineering, Telkom University
[4] Telecommunications Engineering Study Program, School of Electrical Engineering, Telkom University
[1,5] Center of Excellence of Sustainable Energy and Climate Change, Telkom University
[1,2,3,4,5] Jl. Terusan Buah Batu Dayeuhkolot Bandung, 40257, Indonesia
*Corresponding Author: igpoindrawijaya@telkomuniversity.ac.id

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ABSTRACT
Background: Human resources skilled in energy storage technology, particularly lithium-ion batteries, are needed to support the increased use of electric vehicles in Indonesia. However, the material at the vocational school level is still far from green industry standards. The objective of this community service program is to improve the practical skills of students at SMKN 4 Bandung by providing training on battery manufacturing based on Appropriate Technology (TTG).
Contribution: This activity truly benefits the school community by providing infrastructure that supports practice and improves project-based curricula. In addition, the program helps students independently produce core components for electric vehicles, supporting national energy independence.
Method: The program implementation method consists of four main stages. First, conducting literature research and surveys on the necessary information; providing theory on battery management systems, also known as BMS; hands-on practice building a 36V 6Ah battery using a spot welder; and finally, conducting a comprehensive evaluation.
Results: The results of the activity showed a significant increase in participants' knowledge; the average competency score increased from 59% in the pre-test to 85% in the post-test, and the satisfaction survey showed that the level of participants' appreciation of the relevance of the training reached 85.32%.

Conclusion: The program successfully achieved its goal of reducing skill disparities among students. The results produced a prototype battery that can be installed on electric bicycles, proving that action-based learning is an effective method for incorporating renewable energy technology into vocational education environments.

INTRODUCTION

The rapid development of energy technology has driven an increase in demand for energy storage systems that are efficient, reliable, and sustainable [1], [2]. Batteries, especially lithium-ion batteries, are one of the main components that play an important role not only in electric vehicles, but also in portable electronic devices and large-scale energy storage systems. With increasing demand, the quality of battery design, assembly, and maintenance has become a crucial factor in ensuring performance and user safety. The Indonesian government, through Presidential Regulation No. 79 of 2023, has amended Presidential Regulation No. 55 of 2019 on the Acceleration of the Battery Electric Vehicle Program as part of the national clean energy transition strategy. This policy requires the availability of human resources (HR) with technical competence in the field of battery technology, from assembly and testing to maintenance.

Comanescu emphasized that the performance and reliability of lithium-ion batteries are greatly influenced by manufacturing quality, assembly control, and occupational safety standards [3]. Minor defects in production, such as particle contamination or cell configuration errors, can trigger rapid degradation, potentially leading to fire and explosion [3]. The tragic case of a battery factory explosion in Seoul in 2024 that killed 22 workers is clear evidence of the urgency of implementing safety protocols and the importance of technical training for workers. In Indonesia, the limited number of skilled workers in the field of battery technology remains a major challenge.

SMKN 4 Bandung, as a vocational education institution with six areas of expertise, has one of its flagship departments, namely Electrical Power Installation Engineering, which is relevant and in line with the needs of national electric vehicle development. However, in reality, there are still many students, university students, and workers who do not have the technical understanding and skills related to battery technology in accordance with industry standards. This competency gap has the potential to hinder the acceleration of Battery Electric Vehicle Program implementation, even though the government is targeting Indonesia to become a center for electric vehicle and energy storage system production in the Southeast Asian region. Therefore, a community service program in the form of lithium-ion battery assembly training is strategic to bridge this gap.

Through this program, participants not only gain a conceptual understanding of battery working principles and energy storage technology, but also hands-on experience in battery pack assembly, series-parallel cell configuration, and Battery Management System (BMS) installation [4], to performance testing and the implementation of occupational safety standards. With this approach, training not only provides knowledge transfer, but also practical, applicable skills that meet industry needs. Based on national policy, research findings, and real needs in vocational education, this training is expected to produce excellent, competitive human resources who are adaptable to developments in energy technology. This program also supports the government's agenda in accelerating the national energy transition, while encouraging the creation of local energy independence. Thus, this community service has a strategic contribution in building a technology-based vocational education ecosystem that can strengthen the nation's competitiveness in the era of electric vehicles and renewable energy [5], [6].

METHOD

The stages of implementing this community service activity are designed systematically so that the goal of improving student competence can be achieved optimally. Based on Figure 1, there are three main stages, namely initial preparation, implementation of activities, and evaluation and reporting.

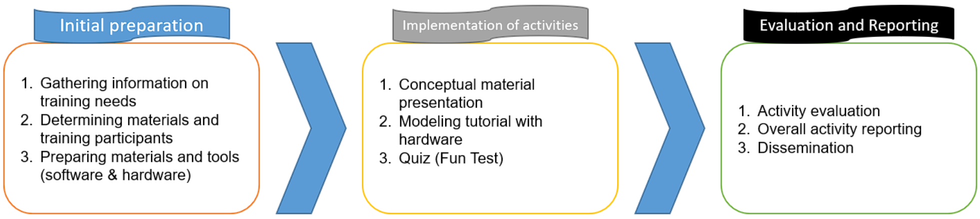

Figure 1. Methods and stages of activity implementation

1. Initial Preparation

At this stage, the implementation team coordinated intensively with SMKN 4 Bandung to gather information related to the actual needs of the battery pack assembly program. The process of identifying these needs included mapping the basic skills that students already possessed and determining the most suitable participants for the Electrical Installation Engineering competency. After that, the training material was compiled in stages, adjusting to the students' level of understanding so that the material could be absorbed effectively [7]. In addition to developing the modules, the team also prepared all the necessary equipment and supporting components, both software (battery configuration simulation and design) and hardware (battery cells, BMS, measuring instruments, and safety devices), to ensure that the training ran smoothly.

2. Implementation of Activities

The implementation stage begins with a presentation of the theory that provides a conceptual foundation regarding the working principles of lithium-ion batteries and the functions of the Battery Management System (BMS) [4], how to connect batteries using spot welding [8], [9], as well as safety standards in assembly [10], [11]. Students are introduced to the concept of series-parallel cell configuration through the example of assembling a 36V 6Ah battery pack as a basic exercise. This exercise serves as an important foundation before students are directed to design. In this process, students learn to calculate the number of cells needed, arrange the appropriate configuration, and understand the power balance between cells. To reinforce their understanding, the activity is supplemented with a hardware modeling tutorial and an interactive quiz (fun test) that encourages active student participation [12], [13].

3. Evaluation and Reporting

The evaluation stage was conducted in layers, with testing of the 36V 6Ah battery pack as an initial trial that had been assembled by the students. The testing included measuring voltage, capacity, current stability, and safety tests when integrated with electric bicycles [14], [15], [16], [17], [18]. Test results were systematically recorded as a basis for analyzing the success of the assembly process and assessing the level of mastery of the material. In addition, discussion sessions were held with students to reflect on the effectiveness of the activities, identify technical obstacles encountered, and formulate improvement strategies for future training [19], [20].

Activity reports are compiled in comprehensive documents that contain results, achievements, and recommendations for further development. Training results are also disseminated through internal school publications, social media, and academic forums, so that the benefits of the activities can reach a wider audience. With this approach, the program not only improves students' technical skills in a tangible way, but also supports innovation in the development of environmentally friendly energy resources and strengthens the role of vocational education in the clean energy transition [21], [22].

RESULTS AND DISCUSSION

1. Literature Exploration and Partner Needs Analysis

The initial step of this program began with conducting an in-depth study of various recent literature on renewable energy technology. The team also coordinated directly with SMKN 4 Bandung to align the program's objectives as can be seen in Figure 2. The main focus was to map the level of understanding of students, especially those majoring in Electrical Power Installation Engineering. Through intensive discussions, the team successfully identified the skill gaps that still existed among the students. These findings were then used to develop training materials that were truly relevant to the school's curriculum needs. As a result, this program was able to respond to the demands of the rapidly growing electric vehicle industry.

Figure 2. Direct coordination session with the Principal of SMKN 4 Bandung to synchronize the training curriculum

2. Theoretical Briefing and Practical Equipment Preparation

Before entering the technical session, twenty students were provided with a thorough theoretical foundation on the characteristics of lithium-ion battery cells as shown in Figure 3. This understanding is essential for them to recognize the chemical properties and operational limitations of each battery component. In addition, the material also emphasized the crucial role of the Battery Management System (BMS) as the main protector of device safety. Preparation for this activity is not only focused on the material, but also includes the development of comprehensive learning modules. Supporting infrastructure such as spot welders and performance testing equipment has been provided to facilitate practical needs in the field. With the availability of complete tools, the entire learning process is expected to run smoothly without technical obstacles.

Figure 3. Theoretical training and practical equipment preparation

3. Practice Implementation and Competency Transformation

At the core stage in Figure 4, students are directly involved in the step-by-step battery manufacturing process. This practical activity begins with the assembly of small-scale batteries with specifications of 36V 6Ah. Students are taught how to use spot welders by paying attention to the duration of short circuits and how to assemble them in parallel first before connecting them in series. In addition, for safety reasons, students are also taught at the beginning how to use safety gloves and how to use spot welders safely, as well as tips on how to assemble batteries safely, given the sensitivity of lithium-ion batteries.

The effectiveness of this learning method is clearly evident in the participants' increased technical understanding. Based on evaluation data, the students' pre-test results initially showed an average score of only 59%. However, after receiving intensive guidance and hands-on practical experience, their scores improved significantly. Their post-test scores jumped dramatically, reaching an average of 85% at the end of the training session. This proves that the learning by doing approach is very effective in transferring complex technical skills to students.

Figure 4. Competency Practices and Transformation

4. Collaborative Project Initiative

This activity promotes a strong synergy between theory and practical application in the field. The batteries assembled by the students did not end up as mere displays in the school laboratory. Instead, they were immediately integrated into the electric bicycle project of SMKN 4 Bandung [23]. This strategic collaboration provides students with a very real experience in understanding modern automotive systems. They can see firsthand how battery components work in a complete electric vehicle system. In addition, this initiative is a concrete step in supporting the green energy movement in education. Through this integration, the school has also succeeded in creating an environmentally friendly and sustainable technology ecosystem.

5. Internal Audit and Impact Assessment

In order to ensure the quality of the final results, the team conducted a comprehensive evaluation of the entire series of activities. This evaluation included technical stability tests on the battery packs assembled by the students. In addition to technical aspects, the team also distributed satisfaction surveys to gauge the response of the training participants as illustrated in Figure 5. The questionnaire results showed a very positive response to the material and methods provided. The level of student appreciation, which includes the categories Strongly Agree, Agree, and Neutral, reached 85.32%. This statistical data is a strong indicator that the training program provides real benefits for their personal development. Overall, this program was very well received as it provided new insights that are relevant to the students' future.

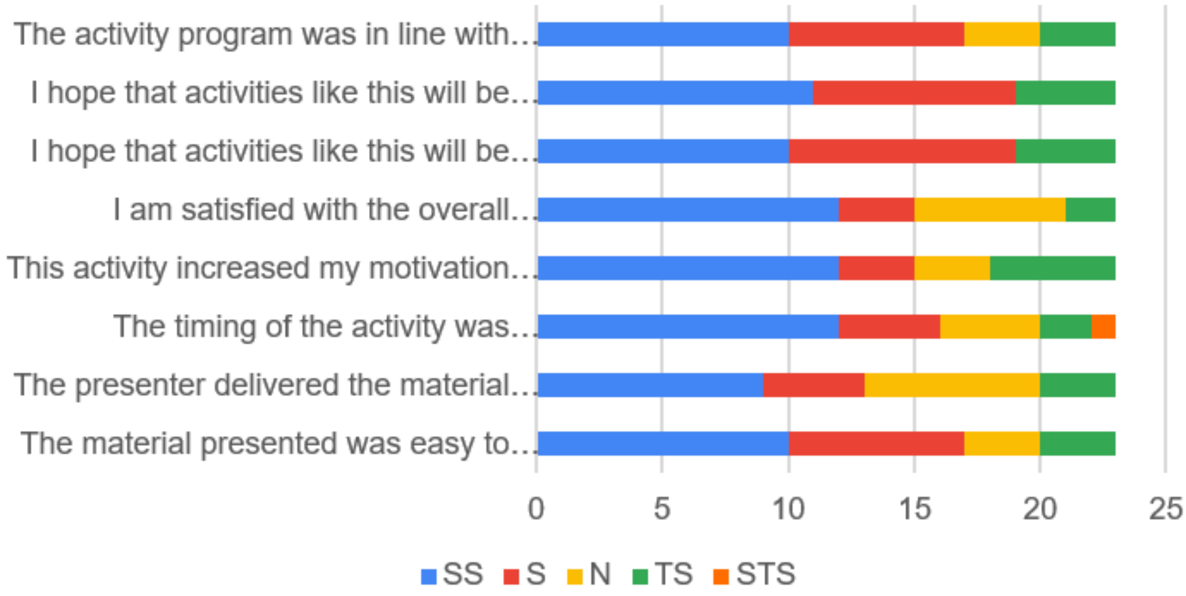

Figure 5. Percentage of Student Questionnaire Results

6. Dissemination and Publication of Outputs

As a closing step, the entire series and success of this activity were widely disseminated to the general public. Information about this community service program was officially published through various mass media channels. The team also utilized digital platforms such as YouTube to upload documentation of the activity in the form of educational videos. In addition, a complete report was published on the official website of the Energy Systems Engineering Undergraduate Program as a digital archive. This publication was not merely a formality, but rather a form of transparency regarding the implementation of the activities that had been carried out. This step also aimed to inspire other educational institutions to implement similar programs in the future. Ultimately, this effort became clear evidence of the contribution of academics in advancing the quality of vocational education in Indonesia.

CONCLUSION

Overall, this community service program has successfully achieved its goal of equipping SMKN 4 Bandung students with technical skills in lithium-ion battery assembly that meet green industry standards. This success is clearly reflected in the surge in participants' competence, where technical understanding, which was only at 59% in the pre-test, increased dramatically to 85% in the final evaluation results. In addition to increased knowledge, this program also produced a physical prototype in the form of a 36V 6Ah battery pack that functions stably and safely. The high participant satisfaction rate of 85.32% confirms that the Appropriate Technology (TTG)-based training method and collaborative project not only attracted students' interest but also provided highly relevant educational solutions for the development of electric vehicles in the school environment.

Furthermore, to ensure the sustainability of this program's impact, it is recommended that SMKN 4 Bandung begin integrating battery assembly material into the permanent curriculum of the Electrical Installation Engineering department so that the regeneration of expertise can continue. Strengthening the school workshop facilities with supporting equipment such as load testing tools and more sophisticated battery safety systems is also essential so that students can conduct technical explorations more independently. For the development of future community service programs, the implementation team is advised to expand the scope of the material to include aspects of battery waste management and cell recycling processes, so that students are not only proficient in assembly but also have a full understanding of the entire lifecycle of environmentally friendly products.

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