JPPIPA 11(1) (2025)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

The Utilization of 18650 Laptop Batteries for Developing Series-Parallel Circuit Practicum Tools

Mohammad Djamil M. Nur[1*], Siti Rabiatul Adawiyah[1], Ummi Khoiriyah[1]

[1] Tadris Natural Sciences, Faculty of Tarbiyah and Teacher Training, State Islamic University Datokarama Palu, Central Sulawesi, Indonesia.

Received: August 10, 2024
Revised: December 08, 2024
Accepted: January 25, 2025
Published: January 31, 2025

Corresponding Author:
Mohammad Djamil M. Nur
djamilnur@uindatokarama.ac.id

DOI: 10.29303/jppipa.v11i1.9918

Abstract: This study aims to first understand the design of the series-parallel of practicum tools by utilizing the used battery of the 18650 Laptop. Second, determine how effectively the series-parallel circuit practicum tools use 18650 laptop batteries. This research is research and development (R&D). The research stages include preliminary studies, product planning and design, product validation and revision, and product tests and revisions. The sample consisted of students from the 2022, 2023, and 2024 batches of the Tadris Science Study Program of FTIK UIN Datokarama Palu. The sampling technique used is purposive sampling. The data was collected through interviews, observations, documentation, and questionnaires. The research results were obtained from a practicum tool product consisting of a series-parallel circuit board, voltmeter ammeter digital-based, and input voltage sourced from a used 18650 battery. The results of product validation tests that material experts have carried out have a percentage of 95% with a very feasible category, and media experts have obtained a rate of 95.83% with a Very suitable category. The revised product was then initially tested to receive an assessment percentage of 94.26% in the Very suitable category. Field tests with a limited scale were conducted using revised products with a 98.57% assessment percentage in the Very suitable category. Products that have been made are suitable for use in series-parallel circuit practicums.

Keywords: Practicum; Series-parallel circuit; 18650 Battery.

Introduction

Developing innovative and sustainable laboratory practices is crucial for improving the quality of technical and science education, particularly in the teaching of Natural Sciences (Li et al., 2022). An educational program is deemed successful when students learn theoretical ideas and gain practical experiences that help them understand the subject matter (Garrido Wainer, 2022).

Laboratory tools are essential for supporting experiments and conceptual understanding. However, with the advancement of technology and the increasing number of electronic devices, new challenges arise regarding sustainability and the environmental impact of our actions (Nur et al., 2023). Laboratory tools must integrate the use of sustainable and eco-friendly energy resources.

This study focuses on developing a laboratory tool for series-parallel circuit experiments using recycled 18650 laptop batteries. This approach aims to combine technical, economic, and environmental elements.

Old laptop batteries, particularly 18650, are frequently found in electronic waste (Nadia Dwi Apriani et al., 2021). These batteries still retain a considerable charge, making them suitable for reuse in practical tools, even though they may no longer be efficient for their original devices. Using used laptop batteries saves money and helps mitigate the environmental impact of electronic waste.

Sustainability in this context involves recycling used batteries, using energy efficiently, and addressing electronic waste (Tan et al., 2020). This research seeks

How to Cite:
Nur, M. D. M., Adawiyah, S. R., & Khoiriyah, U. (2025). The Utilization of 18650 Laptop Batteries for Developing Series-Parallel Circuit Practicum Tools. *Jurnal Penelitian Pendidikan IPA*, *11*(1), 855–866. https://doi.org/10.29303/jppipa.v11i1.9918

not only to provide a technical solution by integrating sustainability into the development of practical tools but also to raise awareness and foster commitment among students and educational stakeholders to adopt sustainable practices.

This research simultaneously addresses two issues: enhancing technical and scientific learning quality while emphasizing sustainability and environmental friendliness. Therefore, developing a series-parallel practical tool using recycled 18650 laptop batteries is both an innovative and sustainable initiative. Other schools or universities can also adopt it to improve educational quality while creating a positive environmental impact.

A battery is a device capable of powering electrical equipment such as flashlights, mobile phones, and EVs (Lemian & Bode, 2022). It contains one or more electrochemical cells connected externally. When the battery generates power, the anode and cathode work together to deliver energy (Mo et al., 2022).

The electronic resource to be used reaches the positive terminal through a circuit and is discharged through what is known as the negative terminal (Lysov et al., 2021). A redox reaction occurs when the battery is connected to an external electrical load, producing low-energy products from high-energy reactants. The free energy differentiation is then delivered to the external circuit as electrical energy (Large et al., 2021).

Lithium-ion batteries, known as 18650 cylindrical lithium batteries, derive their name from their dimensions: 18 mm in diameter and 65 mm in length (Bezsonov et al., 2022). High-capacity batteries like these are commonly used in electric bicycles, power tools, portable electronics, and other applications (C. Wang et al., 2022). Lithium-ion batteries operate almost universally at a voltage of 3.8 volts. The typical capacity rating of 18650 lithium-ion batteries ranges from 2,300 to 3,600 mAh (Y. Wang et al., 2022).

Many electronic devices use 18650 batteries to store power. The extensive use of recycled laptop 18650 batteries indirectly contributes to environmental pollution. Batteries that are no longer used become electronic waste and hazardous B3 waste (Sommerville et al., 2021). If used laptop 18650 batteries are repurposed for DC power sources, lighting energy, laboratory practical components, and other uses, electronic waste can be reduced. The composition of the 18650 lithium-ion battery is shown in Figure 1.

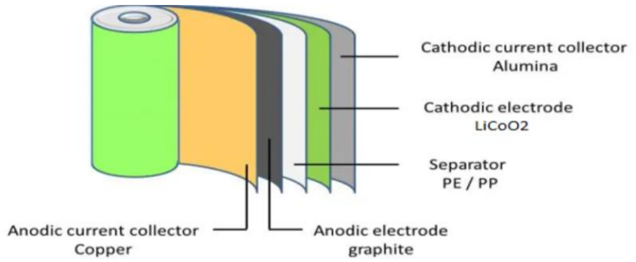

Figure 1. Composition of 18650 Lithium-ion Battery

If the positive terminal of one cell is connected to the negative terminal of the next cell, a group of batteries is said to be connected in series, as shown in Figure 2 below.

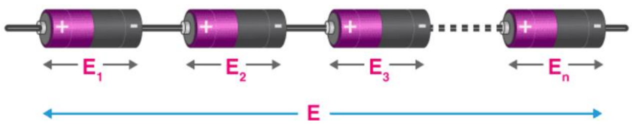

Figure 2. Battery Series Lineup

If E is the total electromotive force (EMF) of the battery combined with n being the number of cells, then: (Setiyono et al., 2023)

$$E = E_1 + E_2 + E_3 + ... + E_n \quad (1)$$

Suppose the positive terminals of a group of batteries are connected, and the negative terminals of each battery are also connected. In that case, it is called a parallel battery configuration.

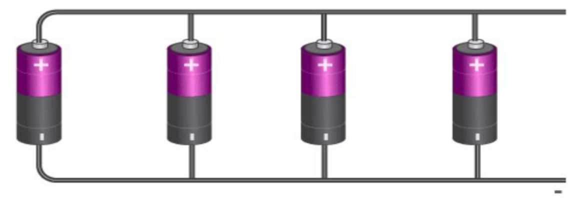

Figure 3. Battery Parallel Arrangement

Suppose the electromotive force (EMF) of each cell is the same. In that case, the EMF of a battery combined with n cells connected in parallel is equal to the EMF of each cell, and the internal resistance resulting from this combination is: (Surya Wardhana et al., 2021).

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n} \quad (2)$$

The Dictionary of Indonesia states that practicum is a component of learning intended to provide students with opportunities to try and apply what they have learned in conceptual understanding to the real world (Kemdikbud, 2021). Practical activities offer numerous benefits for students. They can enhance motivation to learn science, provide fundamental skills for conducting experiments, transform practical activities into educational settings that apply a scientific approach, and, most importantly, help students understand theoretical concepts (Rohimat, 2023).

Practical tools are essential for science education as they enable students to develop observational, problem-solving, and practical skills through direct experiences with scientific concepts (Andris et al., 2022).

Practical tools in science learning are effective because they demonstrate scientific concepts and engage students. Engaging and interactive practical tools can encourage students to participate more actively in learning (Gallach et al., 2020). Previous studies have shown that appealing and relevant practical tools can boost students' interest and understanding of the subject matter.

Learners can broaden their understanding of abstract scientific ideas using practical tools correctly. These tools can not only be more interactive and engaging but also more accessible (Santhyami, 2021). Learners can connect theories to physical phenomena through hands-on experiences. Well-designed experimental tools can help students gain a firm grasp of scientific principles (Schlatter et al., 2021).

Education is vital in transforming how individuals think and act toward sustainability. Education that instills sustainability principles can produce a more environmentally conscious generation capable of applying sustainability concepts in daily life (Gutierrez-Bucheli et al., 2022).

The use of recycled batteries as a power source for science lab experiments demonstrates a response to the issue of electronic waste. Used laptop batteries, often considered electronic waste, can provide a sustainable solution by reducing the harmful environmental impact of electronic waste (Ghulam & Abushammala, 2023).

Scientific concepts and engaging learners are closely connected. Attractive and interactive practical tools can encourage students to participate more actively in learning. Previous studies have shown that using appealing and relevant practical tools can enhance learners' interest and understanding of lesson materials.

Method

One helpful method studied was development studies, also known as research and development (R&D). The product to be achieved requires two phases of research: a survey to assess needs and experimental research to determine whether the product functions and is effective in society (Belenos et al., 2023).

Books, modules, software, hardware, packages, programs, and educational tools are examples of products developed through research and development (Nasser & Saldriani, 2019).

This research employs a development model based on Borg and Gall, which is structured into five stages: preliminary study by analyzing the product; planning and initial product development; expert validation and product revision; small-scale field testing and product revision; and final small-scale field testing resulting in the final product.

The research subjects for developing this tool include Tadris Science students from the 2022 cohort, focusing on the pre-practice study of series and parallel circuits using traditional methods. The following subjects are Tadris Science students from the 2023 cohort participating in the initial trial. The final field test involves a limited field trial with subjects selected from Tadris Science students enrolled in the 2024 cohort.

This study employs a purposive sampling method, chosen due to specific considerations (Sugiono 2016 dalam Fakhri, 2021). The development procedure is illustrated in Figure 4.

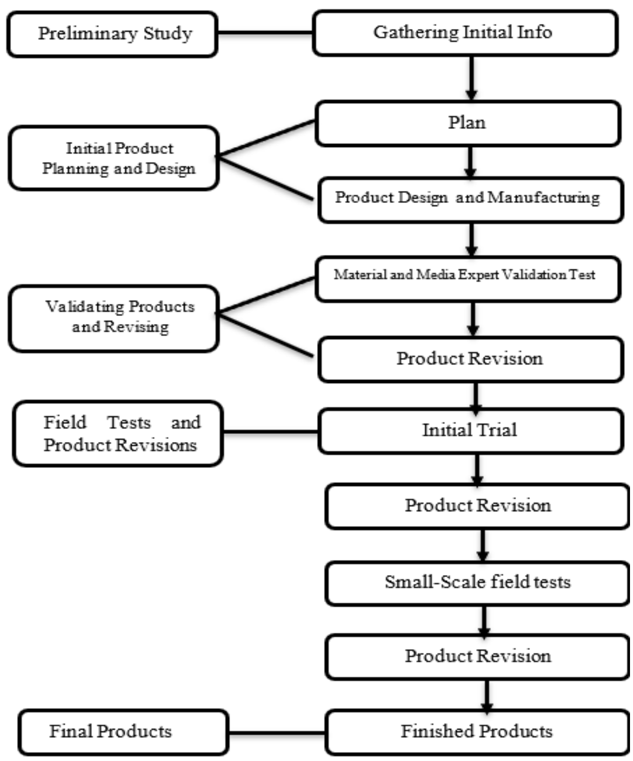

Figure 4. Development Procedure Chart

In this development research, the following data collection techniques were applied:

Interview Technique: During the preliminary study, respondents included laboratory assistants, especially those involved in series-parallel circuit practicums, and student practitioners from the class of 2023.

Questionnaire Technique: This data collection technique utilized written questions provided to respondents for their answers. The questions were closed-ended, requiring respondents to select one of the given answer options. The researcher employed the questionnaire method to determine the quality of the tested product. The instruments were distributed to students from the class of 2022, subject matter experts, and media experts.

Observation Technique: The researcher used observation techniques during the practicum on the concept of series-parallel electrical circuits. This practicum aimed to observe the conditions and how practitioners conducted the series-parallel circuit practicum.

Documentation Technique: All actions taken by the researcher are documented as attached, and they may include photos or questionnaire response sheets provided to the respondents. The data collection techniques encompass various methods, from observation, questionnaire distribution, and product development to collecting experimental information from practitioners conducting practical activities.

The two types of data used in this study are qualitative and quantitative. Qualitative data are obtained through observation and documentation methods, while quantitative data are collected through questionnaire distribution, enabling conclusions to be drawn regarding the quality of the resulting tools.

To evaluate a product through expert verification, the following steps can be used:

After distributing the questionnaire, an analysis was conducted to determine the average score of each evaluated component. To do this, the following equation was used:

$$\bar{X}\frac{\sum X}{n} \tag{3}$$

Information:

$\sum X$ = The total score obtained

$\bar{X}$ = The average score of the questionnaire assessment

n = The amount of data

The average value of each component is determined and used to translate this average value into qualitative data.

$$\text{Interval Distance (i)} = \frac{\text{Highest Score} - \text{Lowest score}}{\text{Number of Interval Classes}} = \frac{4-1}{4} = 0.75 \tag{4}$$

Next, determine the feasibility category of the practical tool for validity testing, as shown in Table 1; then, calculate the product feasibility percentage.

$$\text{Eligibility Percentage} = \frac{\text{Research Score}}{\text{Eligible maximum score}} \text{x } 100\% \tag{5}$$

Table 1. Eligibility categories for validity tests

Average Score ($\bar{X}$)	Category
$3.25 < \bar{X} \leq 4.00$	Very suitable
$2.50 < \bar{X} \leq 3.25$	Suitable
$1.75 < \bar{X} \leq 2.50$	Less suitable
$1.00 < \bar{X} \leq 1.75$	Not suitable

The following steps can be used to analyze field test product data:

After distributing the survey, the data is analyzed by calculating the average score for all components to be evaluated. The average value of each evaluated component is calculated and converted into qualitative data using the following equation:

$$\text{Interval Distance (i)} = \frac{\text{Highest Score} - \text{Lowest score}}{\text{Number of Interval Classes}} = \frac{2-1}{2} = 0{,}25 \tag{6}$$

Next, determining the feasibility category for the field test, as shown in Table 2; then, calculating the product's feasibility percentage.

Table 1. Feasibility categories for validity testing

Average Score ($\bar{X}$)	Category
$1.75 < \bar{X} \leq 2.00$	Very suitable
$1.50 < \bar{X} \leq 1.75$	Suitable
$1,.25 < \bar{X} \leq 1.50$	Less suitable
$1.00 < \bar{X} \leq 1.25$	Not suitable

$$\text{Eligibility Percentage} = \frac{\text{Research Score}}{\text{Eligible maximum score}} \text{x } 100\% \tag{7}$$

Moreover, evaluating media and material experts can ensure the product's suitability. If the expert team concludes that the product falls into the 'Suitable' or Very suitable' category, it can be used for research or additional studies. The product must be modified until it meets the 'Suitable' or 'Very suitable' category; however, if the expert team determines it falls into the 'Not suitable' or 'Unqualified' group, further modifications are necessary.

Result and Discussion

This research is a Research and Development study that produces a practical tool for the Basic Science Concepts course, specifically for the series-parallel circuit material. The product consists of a voltmeter, ammeter, 18650 battery, input voltage sourced from the 18650 battery, battery holder, cables, and a switch.

This practicum tool is packaged outside a box made of transparent Aklyric, which measures 29 cm in length, 21 cm in width, and 13.5 cm in height. The product made by the researcher is the development of a series of parallel practicum tools that are commonly used by students for practicum in the form of KIT. To use the product, users or practitioners can see it in the practicum instruction module of the series-parallel circuit. The research and development steps are as follows:

The first step in research and development is a preliminary study conducted on Monday, May 27, 2024. This preliminary study was carried out on students of the 2023 Science Study Program by distributing a questionnaire regarding the implementation of a series-parallel circuit practicum in the basic science concept course. The questionnaire contains 6 questions, each question has an answer option with a different score. If students choose option A, they will get a score of 1 which means they do not understand. If students choose option B, they will get a score of 2 which means they understand. And if students choose option C, they will get a score of 3 which means they understand very well. The achievement of the series-parallel series Practicum using conventional tools got a percentage of 56.83%. Based on the preliminary study results, the researcher finally found the problems experienced by the practitioners, namely the voltmeter and ammeter measuring instruments, which are still analog (not digital), which can result in misreadings and take time to read the scale from the practitioners. In addition, the observation results showed that the practitioners had difficulties in connecting the series-parallel to the circuit board. It will certainly increase the time needed to do the Practicum. Furthermore, in the event of a PLN power outage, the Practicum cannot be carried out because it relies only on a power supply whose voltage source comes from PLN.

The next stage is to plan the product based on the problems obtained through the preliminary study results. Researchers collected and measured 18650 batteries using a Lii 500 lithokala charger, as shown in Figure 5.

Figure 5. 18650 Battery Charging Process

Next, design a product outside of which there are two main measuring instruments: voltmeter, ammeter. Nowadays, there are Aklyrik Boxes as a series circuit board, parallel circuit, and series-parallel circuit. The product is then equipped with a switch and voltage source from the 18650 battery. Product planning can be seen in figure 6, figure 7, and figure 8.

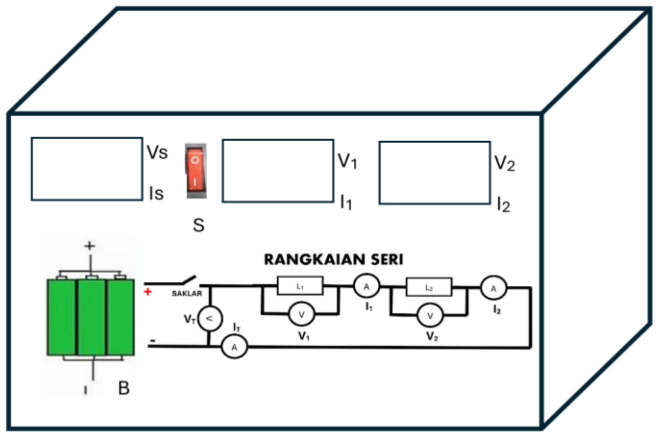

Figure 6. Initial Design of Series circuit Products

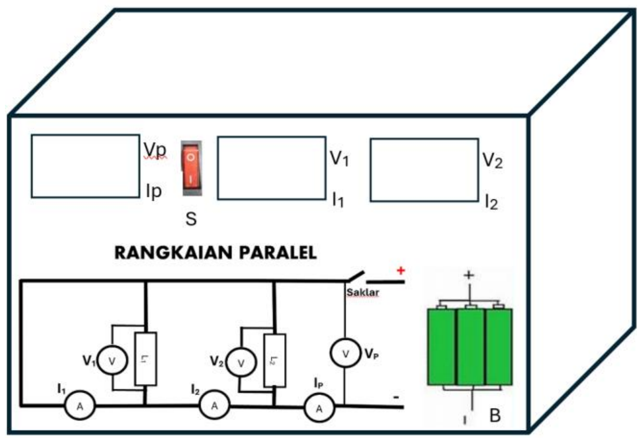

Figure 7. Parallel circuit Product Initial Design

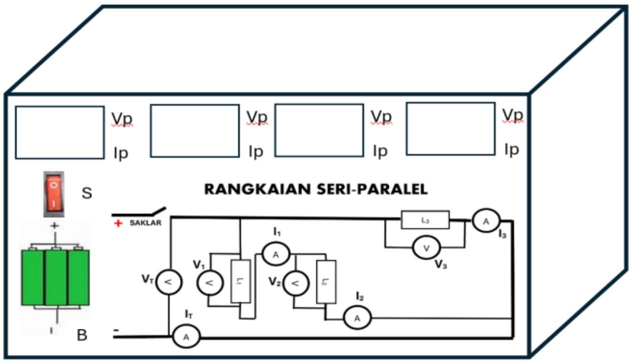

Figure 8. Initial Product Design of Series-Parallel Combined circuit

The products that have been designed are then made into practicum tool products. To make a product, several parts must be made or modified, including:

The tools and materials needed to make this measuring instrument are 18650 batteries, 18650 battery holders, DC ammeter voltmeters, USB LED lights, switches, connecting cables, and network boxes. The USB LED lamps used are two for series circuit, two for parallel circuit, and three for series-parallel circuit, with a value of 5V/1A each. The working principle of manufacturing this measuring instrument refers to series, parallel, and parallel-series circuit. The working principle is that when the 18650 battery is connected to the circuit through a connected switch, the LED light turns on, accompanied by the voltage reading and current values displayed on the LCD from the DC ammeter voltmeter.

To calibrate the DC voltmeter-ammeter, connect the DC voltmeter-ammeter and the load (DC LED) to the power source. The DC voltmeter-ammeter is calibrated using the DT-830B digital multimeter, as shown in Figure 8. Suppose the values displayed on the DC voltmeter-ammeter differ from those on the DT-830B digital multimeter. In that case, the screw on the back of the DC voltmeter-ammeter must be adjusted, as shown in Figure 9.

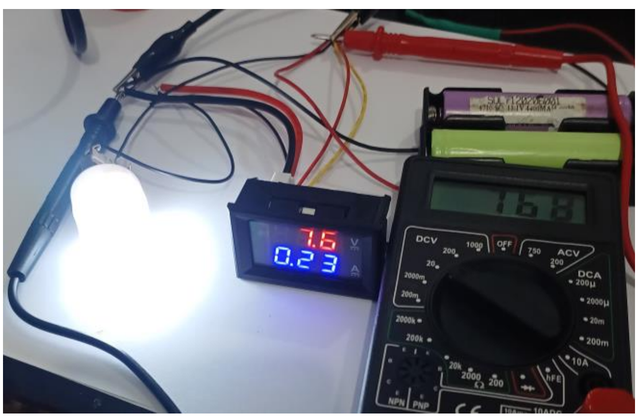

Figure 9. Calibrating the Measuring Instrument

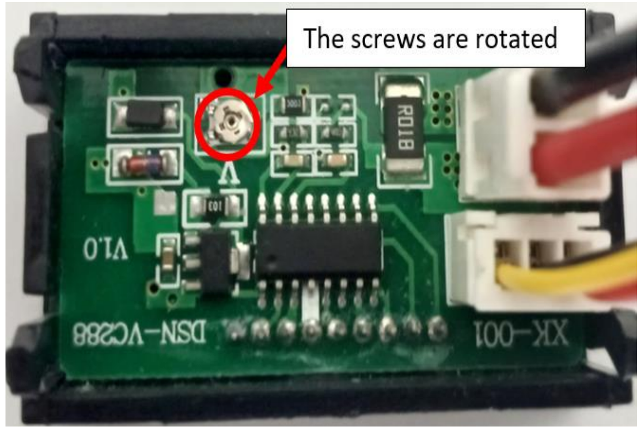

Figure 10. How to calibrate a DC ammeter voltmeter

The input voltage will be connected to the circuit board. The material used for the input voltage is from used 18650 batteries salvaged from laptops that are still functional and have been tested for their capacity with a Litokala Lii 500 charger. The researcher designed the voltage sourced from the 18650 battery as a solution to ensure that the series circuit, parallel circuit, and series-parallel combined circuit practicums can still be conducted during PLN power outages while also providing a simple, affordable, and environmentally friendly practicum.

The design of the voltage source circuit for the series circuit can be seen in Figure 9. The design of the voltage source circuit for the parallel circuit can be seen in Figure 10. The design of the voltage source circuit for the combined series-parallel circuit can be seen in Figure 11.

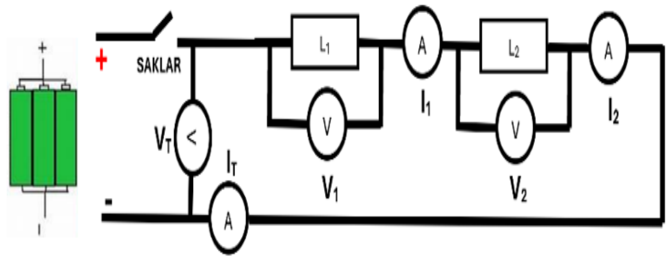

Figure 9. Voltage source circuit design for a series circuit.

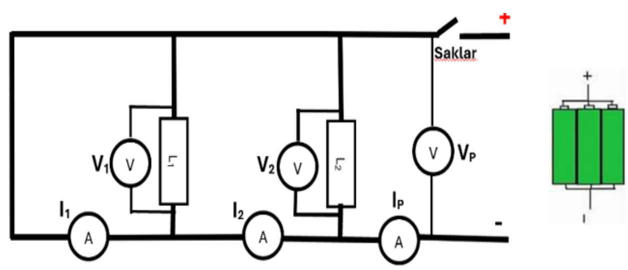

Figure 10. Design of the voltage source circuit for the parallel circuit

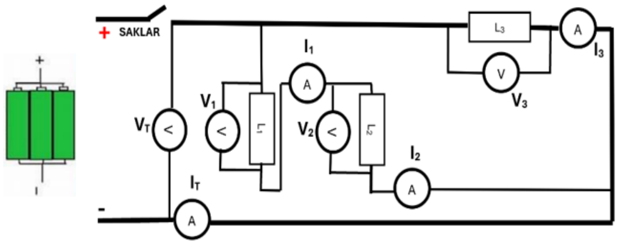

Figure 11. Voltage source circuit design for series-parallel circuit.

The primary circuit on this circuit board consists of an 18650 battery connected to series, parallel, and series-parallel circuits of DC USB LED lights with a rating of 5V/1A. The researcher created a circuit board that is connected to the input voltage of the 18650 battery, which is linked to a switch for each circuit, functioning as a breaker for the current flowing from the input voltage. The researcher used female USB connectors to simplify the installation of the DC USB LED lights in each circuit. The series circuit board can be seen in Figure 12, the parallel circuit board in Figure 13, and the series-parallel circuit board in Figure 14.

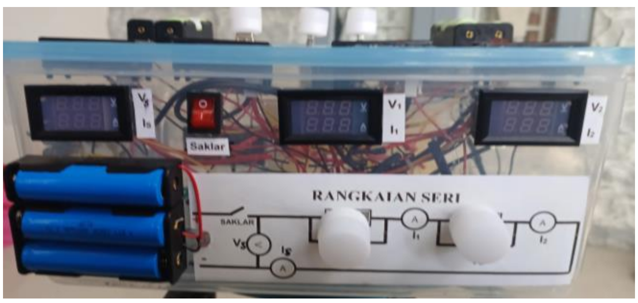

Figure 12. Series network board

Figure 13. Parallel network board

Figure 14. Series-parallel network boards

The process of parts that have been made and modified are then assembled into one box. The entire assembly can be seen in Figure 15.

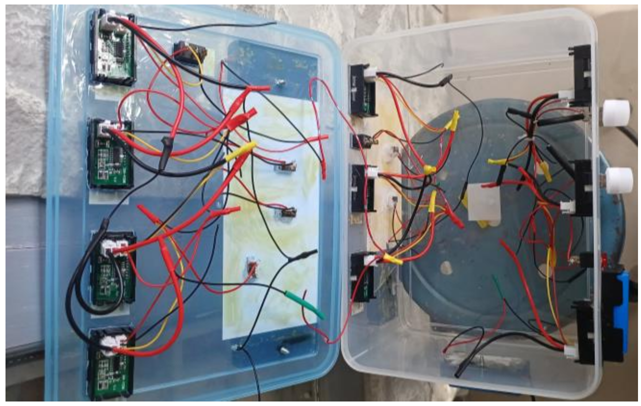

Figure 15. The circuit becomes one in the box

The made and modified parts are then assembled into one unit in the box. Once all circuits have been assembled, the next step is to apply informative labels to the parts of the product, as shown in Figure 16.

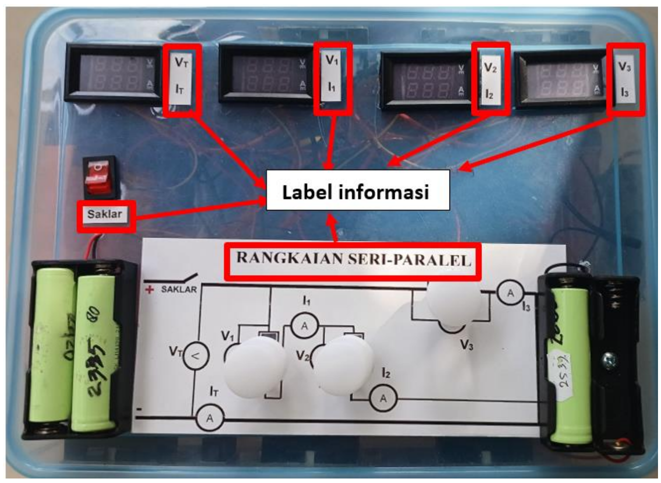

Figure 16. Labeling information on product parts

There are three tests conducted by the researcher, namely: Testing the DC voltmeter and ammeter involves measuring the series circuit, parallel circuit, and series-parallel circuit using the DC voltmeter and ammeter and then comparing the results with measurements taken using the digital multimeter DT-830B. The results of the voltage and current measurements can be seen in Table 2.

Table 2. Comparison of Product Design Measurements with Digital Multimeter DT-830B

Circuits	Quantities	Measurement			
		Multimeter DT-830B		Product Design	
Seri	Vs	18,6	volt	18,5	volt
	V1	8,81	volt	8,8	volt

Circuits	Quantities	Multimeter DT-830B		Measurement Product Design	
	V2	9,72	volt	9,7	volt
	Is	0,10	ampere	0,10	ampere
	I1	0,10	ampere	0,10	ampere
	I2	0,10	ampere	0,10	ampere
Paralel	Vp	7,00	volt	7,0	volt
	V1	7,00	volt	6,9	volt
	V2	6,90	volt	7,0	volt
	Ip	0,42	ampere	0,42	ampere
	I1	0,24	ampere	0,24	ampere
	I2	0,18	ampere	0,18	ampere
Seri-Paralel	VT	10,4	volt	10,5	volt
	V1	5,2	volt	5,1	volt
	V2	5,3	volt	5,3	volt
	V3	10,4	volt	10,4	volt
	IT	0,37	ampere	0,38	ampere
	I1	0,20	ampere	0,20	ampere
	I2	0,21	ampere	0,21	ampere
	I3	0,15	ampere	0,15	ampere

The researcher conducted practicum tests using the product, which consisted of three tests: the series circuit practicum test, the parallel circuit practicum test, and the series-parallel circuit practicum test.

After the researcher makes and tests the series circuit, parallel circuit, and series-parallel circuit practicum tools, the next step is product validation, which consists of material validation and media validation.

There are five assessment indicators in the material validation: series circuit, parallel circuit, and series-parallel circuit; current value measurement; voltage value measurement; use of power supply from used 18650 laptop batteries; and the alignment of theory with practice. The material validation was conducted by lecturers from the Faculty of Teacher Training and Education at Tadulako University, Physics Education Study Program, Mr. Dr. Supriyatman, S.Si., M.Pd., and lecturers from the Faculty of Tarbiyah and Teacher Training at UIN Datokarama Palu, Tadris Science Study Program, Mrs. Arda, S.Si., M.Pd.

The result of the material test obtained an average score of 3.9 with a feasibility percentage of 97.5%. The obtained score was then compared with Table 3, and the product was categorized as Very suitable. In addition to the product assessment results, the researcher received feedback from validators regarding the practical circuit tool product for series-parallel circuits, as shown in Table 4.

Table 3. Material Validation Results

No	Indicator	Validator Assessment validator 1	validator 2
1	Series, parallel and parallel series series	4	4
2	Current value measurement	4	4
3	Measurement of Voltage value	4	4
4	Use of source voltage from used laptop battery 18650	4	4
5	Compatibility of theory with practice	3	4
	The Total Score		39
The maximum score			40
Average score			3,9
Feasibility percentage			97,5 %
Category			Very suitable

Table 4. Material Validator Input

No	Feedback
1	The safety of practitioners when using the product should be prioritized.
2	The tool information needs to be improved.
3	The practitioner can perform calculations of voltage and current.

The product assessment by media expert validators consists of 5 evaluation indicators: effectiveness and efficiency, ease of operation, alignment of measuring instruments with components, practicum tool design, and clarity of information. The product validation of media substance was conducted by the same lecturers as the material expert validation. The results can be seen in Table 5.

Table 5. Media validation results

No	Indicator	Validator Assessment Validator 1	Validator 2
1	Effective and Efficient	4	4
2	Ease of operation	4	4
3	The alignment of the Measuring instrument and components.	4	4
4	The design of the practicum tool.	3	3
5	The clarity of information.	4	4
The total score			38
The maximum score			40
Average score			3,8
Feasibility percentage			95%
Category			Very suitable

The media test resulted in an average score of 3.8 and a feasibility percentage of 95%. The obtained score was then compared with Table 5, indicating that the product evaluated falls into the Very suitable category.

In the media validation stage, the validator provides feedback, as shown in Table 6.

Table 6. Media Validator Input

No	Feedback
1	The placement of the voltmeter and ammeter is precisely positioned to be equivalent.
2	The label is made to be waterproof.
3	The appearance of the box needs to be improved.
4	The fuse needs to be added as a safety feature in the circuit.

The researcher then used the input provided by the media validator to make product revisions, as shown in Figure 17.

Figure 17. Improvement of the measuring tool according to the input of the media validator

The series circuit, parallel circuit, and series-parallel circuit practicum tools were tested in two stages. The first was a preliminary trial conducted with students who had previously performed practicum with conventional tools for the series, parallel, and series-parallel circuits. The second was a limited trial given to students who had not yet participated in the practicum for these circuits.

In the preliminary trial, before the students began the practicum, the researcher provided a practicum instruction module for the series, parallel, and series-parallel circuits and a questionnaire to assess the practicum experience using the developed product. The results of the product assessment during the first stage of field testing can be seen in Table 7.

Table 7. Initial test results

Student	Question Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SK_1	2	2	2	2	2	2	2	2	2	1	2	2	2	2
SK_2	2	2	2	2	2	2	2	1	2	2	2	2	2	2
SK_3	2	2	2	2	2	2	2	2	2	1	2	1	2	2
SK_4	2	2	2	2	1	2	2	2	2	2	2	2	1	2
SK_5	2	2	2	2	1	2	2	2	2	1	2	2	2	2
The Score obtaned	10	10	10	10	8	10	10	9	10	7	10	9	9	10
The Total Score obtaned														132
Maximum Score														140
Average Grade														1,86
Feasibility Percentage														94,26%
Category														Very Suitable

Based on Table 8, the average score obtained is 1.86, with a feasibility percentage of 94.26%. Based on the average score obtained, the product falls into the "very suitable" category. Feedback from the practitioners regarding the product can be seen in Table 8.

Table 8. Feedback from the Preliminary Trial

No	Feedback
1	The button needs to be repaired again to prevent it from breaking easily.
2	The product could be better in terms of size.
3	Menambahkan USB Female
4	A resistor needs to be added to one leg of the DC LED light

The researcher then revised the product, including checking all buttons and replacing any damaged switches. Feedback regarding the product's size being less than ideal was not revised due to difficulties finding a box size that fit the product dimensions. The next suggestion was to add a USB female port to the box to stabilize the LED light when attached, as shown in Figure 18. Finally, the researcher added a resistor to the LED light's leg to prevent it from breaking easily, as shown in Figure 19.

The next field testing stage was the limited trial, where the researcher provided the practicum instruction module and assessment questionnaire to the student practitioners. The questionnaire and module contained the same content as in the preliminary trial.

The average score for assessing the practicum implementation using the developed product was 1.97, with a feasibility percentage of 98.57%, placing it in the " very suitable" category. In the limited trial, two suggestions from respondents were recorded, which can be seen in Table 9.

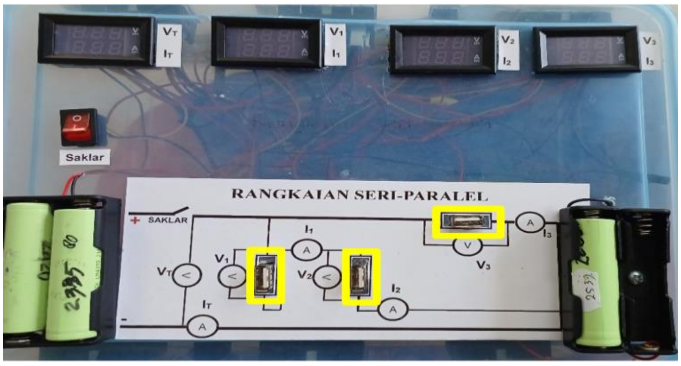

Figure 18. shows the addition of a USB female port

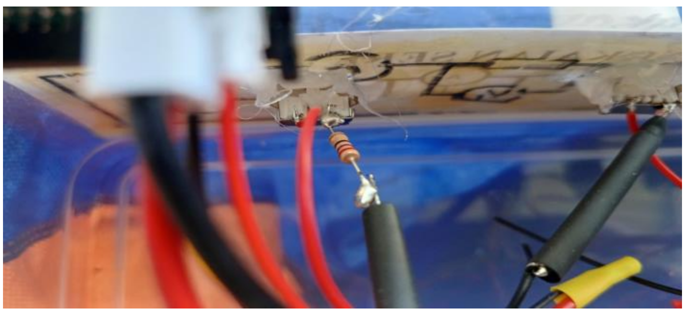
Figure 19. shows the addition of a resistor to one of the legs of the LED light.

Table 9. Feedback from Limited Field Testing

No	Feedback
1	The product could be better in terms of size.
2	The USB female port easily detaches

The preliminary study was the first stage used to collect data. The data obtained in the initial study included the absence of digital-based voltage and current measuring devices and the voltage source originating from used 18650 batteries. Based on these issues, a solution was needed to create or develop a practicum medium.

The practicum medium has several advantages: it can assist educational institutions that lack laboratories, enhance conceptual understanding, and is portable. To address the identified problems, this research developed a practicum tool consisting of a digital-based voltmeter, ammeter, series circuit, parallel circuit, series-parallel circuit, and input voltage sourced from used 18650 batteries.

The next step was product planning and design. In this stage, the researcher created a product with a primary circuit comprising a digital-based voltmeter, ammeter, series circuit, parallel circuit, series-parallel circuit, and input voltage from used 18650 batteries. These circuits were then subjected to testing.

The first test measured voltage and current using the developed product compared to a DT-830B digital multimeter. The results of the measurements from both devices showed differences. To align the readings, the screw on the back of the DC voltmeter and the ammeter on the product was adjusted with a screwdriver until the values matched those of the DT-830B digital multimeter.

The following product test was the practicum test for the series, parallel, and series-parallel circuits. The results indicated that the relationship between voltage and current in these circuits aligned with the theoretical concepts.

Media and material validation testing was the third step in this research and development process. The practicum product's material validation test achieved a 97.5% feasibility percentage in the "very suitable" category, while the media validation test achieved 95% in the same category. Both validation tests provided feedback, which the researcher incorporated into revisions.

Field testing was the fourth step of this research, divided into preliminary trials and limited field tests. The initial trial obtained a product feasibility percentage of 94.26% in the " very suitable " category. Perfect scores demonstrated this on a questionnaire evaluating indicators such as ease of use, readability of the voltmeter/ammeter values, theoretical alignment of the circuits, product functionality in measuring voltage and current, and clarity of symbols on the practicum product.

From the perspective of learning media, the practicum tool aligns with good criteria for learning media selection, including meeting objectives, practicality, and suitability for supporting factual, conceptual, principle-based, and generalized content.

The limited field test yielded an assessment percentage of 98.57% in the "very suitable " category, showing an improvement in product feasibility. The improvements were observed in indicators such as the functionality of the switch buttons, the product's operation using 18650 batteries, and alignment between practicum results and theory.

The final stage of the research produced a practicum tool comprising a series circuit, parallel circuit, and series-parallel circuit with several testing phases. The final product included a digital-based voltmeter, an ammeter, an acrylic circuit board, input voltage from used 18650 batteries, and accessories such as fuses and switches.

The final product of this research and development is a practicum tool media that features two digital measuring instruments: a voltmeter and an ammeter. The product is integrated with an input voltage sourced from a used 18650 battery. This practicum tool includes series, parallel, and series-parallel circuits, all housed in an acrylic box. Users only need to connect the 18650 battery and a DC LED light and turn on the modified switch to activate the circuit.

There are both advantages and disadvantages to the series, parallel, and series-parallel practicum tool product. The advantages include: (1) The digital-based series, parallel, and series-parallel practicum tools can measure voltage and current values. (2) The voltmeter and ammeter are digital, eliminating the need for long periods to read the scale. (3) The practicum tool uses a power source from a used 18650 battery.

However, the developed product still has some shortcomings, including: (1) The size of the box could be better. (2) The product's smallest scale values (NST) are 0.1 V and 0.01 A.

Conclusion

Based on the research conducted, the following conclusions can be drawn: (1) The digital-based series, parallel, and series-parallel practicum tools are designed to simplify practicum implementation. This practicum tool features two main measuring instruments, a voltmeter and an ammeter, whose measurements can be displayed on an LCD. Additionally, there are series, parallel, and series-parallel circuits on each side of the acrylic box. The input voltage is sourced from 18650 batteries that were used; (2) The research and product development results showed that the product received a "very feasible" category in four tests: material validation, media validation, preliminary trial, and limited field testing. The media and material validation tests obtained 97.5% and 95% feasibility percentages, while the initial trial and limited field testing received 94.26% and 98.57%. Based on these results, the product is very suitable for the practicum of series, parallel, and series-parallel circuits in the introductory science concepts course.

Acknowledgments

I want to express my gratitude to the Rector, the Head of LP2M, the validators, and the Tadris Science Study Program students at UIN Datokarama Palu. You have all greatly assisted me in this research.

Author Contributions

M. D. M. contributed to conceptualizing the research idea, developing the product, collecting data, analyzing data, and writing the article. S. R. A. managed the research activities from conceptualizing the research idea to writing, reviewing, and editing the article. U. K. provided advice and input for developing the series-parallel circuit practical tool using lithium 18650 batteries. All authors have read and approved the published version of the manuscript.

Funding

This research did not receive any external funding.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

References

Andris, V., Driana, E., & Yuliawati, S. (2022). Evaluasi Program Laboratorium Dalam Pembelajaran Ipa Di Madrasah Tsanawiyah Negeri 15 Jakarta Utara. *Jurnal Penelitian Dan Penilaian Pendidikan*, *4*(1). https://doi.org/10.22236/jppp.v4i1.8477

Belenos, A., Wood, E. L., Hu, M., Kozak, D., Xu, X., & Fisher, A. C. (2023). Product Quality Research for Developing and Assessing Regulatory Submissions for Generic Cyclosporine Ophthalmic Emulsions. In *AAPS Journal* (Vol. 25, Issue 1). https://doi.org/10.1208/s12248-023-00781-x

Bezsonov, I. I., Nadimpalli, S., Waller, G. H., & Hendricks, C. (2022). Strain and Temperature Behavior of Lithium-Ion 18650 Cylindrical Batteries. *ECS Meeting Abstracts*, *MA2022-02*(6). https://doi.org/10.1149/ma2022-026592mtgabs

Gallach, I. C., Contreras, R. V., Catalán, J. P. C., & Vela, M. J. G. (2020). The interactive classroom methods for science classes. *International Conference on Higher Education Advances*, *2020-June*. https://doi.org/10.4995/HEAd20.2020.11010

Garrido Wainer, J. M. (2022). Understanding the development and use of tools in neuroscience: the case of the tungsten micro-electrode. *Synthese*, *200*(6). https://doi.org/10.1007/s11229-022-03934-1

Ghulam, S. T., & Abushammala, H. (2023). Challenges and Opportunities in the Management of Electronic Waste and Its Impact on Human Health and Environment. In *Sustainability (Switzerland)* (Vol. 15, Issue 3). https://doi.org/10.3390/su15031837

Gutierrez-Bucheli, L., Kidman, G., & Reid, A. (2022).

Sustainability in engineering education: A review of learning outcomes. In *Journal of Cleaner Production* (Vol. 330). https://doi.org/10.1016/j.jclepro.2021.129734

Kemdikbud. (2021). Kamus Besar Bahasa Indonesia," in Kamus Besar Bahasa Indonesia. *Kamus Besar Bahasa Indonesia*.

Large, S. J., Ehrich, J., & Sivak, D. A. (2021). Free-energy transduction within autonomous systems. *Physical Review E*, *103*(2). https://doi.org/10.1103/PhysRevE.103.022140

Lemian, D., & Bode, F. (2022). Battery-Supercapacitor Energy Storage Systems for Electrical Vehicles: A Review. In *Energies* (Vol. 15, Issue 15). https://doi.org/10.3390/en15155683

Li, N., Jiang, P., Li, C., & Wang, W. (2022). College Teaching Innovation from the Perspective of Sustainable Development: The Construction and Twelve-Year Practice of the 2P3E4R System. *Sustainability (Switzerland)*, *14*(12). https://doi.org/10.3390/su14127130

Lysov, N., Temnikov, A., Chernensky, L., Orlov, A., Belova, O., Kivshar, T., Kovalev, D., & Voevodin, V. (2021). Artificial negative polarity thunderstorm cell modeling of nearby incomplete upward discharges' influence on elements of monitoring systems for air transmission lines. *Energies*, *14*(21). https://doi.org/10.3390/en14217100

Mo, T., Zeng, L., Wang, Z., Kondrat, S., & Feng, G. (2022). Symmetrizing cathode-anode response to speed up charging of nanoporous supercapacitors. *Green Energy and Environment*, *7*(1). https://doi.org/10.1016/j.gee.2021.05.001

Nadia Dwi Apriani, Muhammad Alif Rachmatullah, Rian Sukamto, & Yosi Apriani. (2021). Pngertian Baterai Lithium. *Jurnal Rekayasa Elektro Sriwijaya*, *3*(1).

Nasser, R., & Saldriani, P. (2019). Perancangan Dan Pembuatan Aplikasi Simulasi Toefl Berbasis Desktop. *Prosiding Semantik*, *2*(2011).

Nur, M. D. M., Hartati, H., & Palu, M. A. N. K. (2023). *Proceeding of International Conference on Islamic and Interdisciplinary Studies (ICIIS), 2023 The Analysis Of Capabilities At The Ex-Laptop 18650 Lithium Ion Battery*. 35–41.

Rohimat, S. (2023). Studi Literatur: Pemanfaatan Laboratorium Maya Pada Portal Rumah Belajar Untuk Pembelajaran Praktikum MIPA. *Journal of Educational Learning and Innovation (ELIa)*, *3*(1). https://doi.org/10.46229/elia.v3i1.493

Santhyami. (2021). Praktikum Virtual Laboratory IPA dan Biologi Di Era Abad 21 Bagi Guru IPA dan Biologi Se-Jawa Tengah: Ekologi Populasi Serangga Metode Capture Recapture. *Sasambo: Jurnal Abdimas (Journal of Community Service)*, *3*(3). https://doi.org/10.36312/sasambo.v3i3.513

Schlatter, E., Molenaar, I., & Lazonder, A. W. (2021). Learning scientific reasoning: A latent transition analysis. *Learning and Individual Differences*, *92*. https://doi.org/10.1016/j.lindif.2021.102043

Setiyono, J., Sulanjari, S., & Sahudin, E. C. (2023). Komparasi Instalasi PLTS Kapasitas 100 WP Pemasangan Seri Dan Pararel Untuk Pengisian ACCU 12 Volt-65 AH. *Jurnal Inovasi Ilmu Pengetahuan Dan Teknologi*, *4*(2). https://doi.org/10.32493/jiptek.v4i2.30463

Sommerville, R., Zhu, P., Rajaeifar, M. A., Heidrich, O., Goodship, V., & Kendrick, E. (2021). A qualitative assessment of lithium ion battery recycling processes. *Resources, Conservation and Recycling*, *165*. https://doi.org/10.1016/j.resconrec.2020.105219

Sugiono 2016 dalam Fakhri. (2021). Metode Penelitian Purposive Sampling. *2021*.

Surya Wardhana, A., Sahrin, A., & Kusuma Dewi, A. (2021). Rancang Bangun Penyimpanan Energi Listrik Pada Photovoltaic Menggunakan Baterai Lithium Untuk Aplikasi Dc House. *Sntem*, *1*(November).

Tan, D. H. S., Xu, P., Yang, H., Kim, M. cheol, Nguyen, H., Wu, E. A., Doux, J. M., Banerjee, A., Meng, Y. S., & Chen, Z. (2020). Sustainable design of fully recyclable all solid-state batteries. *MRS Energy and Sustainability*, *7*(1). https://doi.org/10.1557/mre.2020.25

Wang, C., Yang, C., & Zheng, Z. (2022). Toward Practical High-Energy and High-Power Lithium Battery Anodes: Present and Future. In *Advanced Science* (Vol. 9, Issue 9). https://doi.org/10.1002/advs.202105213

Wang, Y., Li, W., Fang, R., Zhu, H., & Peng, Q. (2022). Capacities prediction and correlation analysis for lithium-ion battery-based energy storage system. *Control Engineering Practice*, *125*. https://doi.org/10.1016/j.conengprac.2022.105224