DOI: 10.14421/impulse.2025.51-01

IMPULSE: Journal of Research and Innovation in Physics Education
Volume 5, Issue 1, 1 – 14

© ISSN (p): 2798–1762; ISSN (e): 2798-1754
http://ejournal.uin-suka.ac.id/tarbiyah/impulse

Voment Electrical (Volt Measuring Tools of Electrical Materials): Voice-activated DC Voltage Meter for the Blind

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ABSTRACT

Science learning involves studying natural phenomena in the universe, such as dynamic electricity. Dynamic electricity is a topic that frequently requires measurements during instruction. This presents a challenge for visually impaired students, because they are unable to read the measurement results displayed visually, therefore, innovation in measuring tools with audio output is necessary. Voment Electrical (Electric Voltage Measuring Instrument) is a DC voltage measuring instrument with audio output, which is a development of a digital voltmeter. This tool uses an Arduino Nano as a microcontroller and voltage sensor. The voltage value measured on this tool is output in the form of sound. Therefore, this tool can be an alternative measuring tool in dynamic electricity learning that can overcome the limitations of blind children in making measurements. The objectives of this study are 1) Designing Voment Electrical: a sound-output DC voltage measuring instrument for impaired children on dynamic electricity material, and 2) Testing Product Feasibility. This research is a development research with a 4D research method. Data was collected through evaluation sheets from media and subject-matter experts. Data analysis from the assessment sheets of media experts and material experts is used to determine the quality of the device developed. Based on the research results, the device's quality was rated "Excellent" by both media and subject-matter experts, with average scores of 3.54 and 3.42. Therefore, this voltage measuring tools of electrical materials for visually impaired students is appropriate for teaching dynamic electricity in physics learning.

INTISARI

Pembelajaran sains melibatkan pembelajaran fenomena alam di alam semesta, seperti listrik dinamis. Listrik dinamis merupakan topik yang seringkali membutuhkan pengukuran selama pembelajaran. Hal ini menjadi tantangan bagi siswa tunanetra, karena mereka tidak dapat membaca hasil pengukuran yang ditampilkan secara visual sehingga inovasi alat ukur dengan output audio perlu dilakukan. Voment Electrical (*Voltage Measuring Tools of Electrical Materials*)

ARTICLE HISTORY
Received: May 19, 2025
Accepted: October 8, 2025

KEYWORDS:
Blind, DC Voltage, Voltmeter, Microcontroller

KATA KUNCI:
Mikrokontrol, Tunanetra, Tegangan DC, Voltmeter

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adalah alat ukur tegangan DC dengan keluaran audio, yang merupakan pengembangan dari voltmeter digital. Alat ini menggunakan Arduino Nano sebagai mikrokontroler dan sensor tegangan. Nilai tegangan yang terukur pada alat ini dikeluarkan dalam bentuk suara. Oleh karena itu, alat ini dapat menjadi alternatif alat ukur dalam pembelajaran listrik dinamis yang dapat mengatasi keterbatasan anak tunanetra dalam melakukan pengukuran. Tujuan penelitian ini adalah 1) Merancang Voment Electrical: alat ukur tegangan DC dengan output audio untuk anak tunanetra pada materi listrik dinamis, dan 2) Menguji Kelayakan Produk. Penelitian ini merupakan penelitian pengembangan dengan metode penelitian 4D. Data dikumpulkan melalui lembar penilaian dari ahli media dan ahli materi. Analisis data dari lembar penilaian ahli media dan ahli materi digunakan untuk menentukan kualitas perangkat yang dikembangkan. Berdasarkan hasil penelitian, kualitas perangkat dinilai "Sangat Baik" oleh ahli media dan ahli materi, dengan rerata skor 3,54 dan 3,42. Oleh karena itu, alat ukur tegangan bahan listrik untuk siswa tunanetra ini layak untuk digunakan dalam pembelajaran fisika yang menggunakan listrik dinamis.

A. Introduction

The availability and accessibility of education are the rights of every Indonesian citizen to develop their abilities and potential. This is stated in Article 5, Paragraph 2 of the National Education System Law, which affirms that "citizens with physical, emotional, mental, intellectual, and/or social disabilities have the right to receive special education" [1]. This regulation implies that education is the right of all citizens without exception, including children with special needs (disabilities), such as blind students who face obstacles in their learning process.

Children with special needs are categorized into several types, one of which is visual impairment. Visual impairment, or blindness, refers to individuals who experience limitations in their sense of sight [2]. It is generally divided into two categories: total blindness and low vision. Total blindness occurs when an individual cannot perceive any external light stimulation. Meanwhile, low vision refers to a condition in which individuals are still able to perceive light but must bring objects closer in order to see clearly due to blurred vision [3], [4]. Such conditions prevent blind students from receiving visual representations of phenomena or learning materials [5], making it difficult for them to correlate the teacher's explanations (usually delivered through audio) with the visualizations of physics phenomena (such as whiteboard illustrations, images, or presentations) [6]. Based on this description, it can be inferred that blind students are likely to encounter difficulties in understanding physics learning materials.

Physics encompasses phenomena that occur in the universe and involves a wide range of concepts. A concept in physics can be understood through a comprehensive process that combines theoretical knowledge with validation through experiments, demonstrations, or visualizations [7], [8]. This highlights the importance of practical activities in internalizing a thorough understanding of the material. For example, Newton's Laws require strong vector projection skills, particularly in interpreting visual representations of forces. This poses a challenge for blind students, as they are unable to visualize the vector components of the forces involved [9]. Therefore, innovations in physics learning tools are needed to reduce these challenges and support blind students during learning activities [10]. One such innovation can be realized through the development of learning media in the form of practical tools.

The development of experimental learning tools has increased significantly in the past ten years, driven by various factors. For example, Muliyati, Prastiawan, and Mutoharoh [11] developed student worksheets based on STEM-PjBL principles to align with the demands and competencies of the 21st century. Similarly, Rianti, Gunawan, Verawati, and Taufik [12] created a practical module to complement the PhET application, enabling its broader use among students. Research by Solmaz, Alfaro, Santos, Van Puyvelde, and Van Gerven demonstrates that the development of Augmented Reality and Virtual Reality learning media is based on student needs and potential for future innovation [13]. Further studies on the development of learning aids have been conducted by Pacala [14], presenting several findings, including the creation of a demonstration tool for light wave material with audio output for blind students by de Azevedo in 2014, as well as the development of an audio-based textbook by Alatas and Solehat in 2020. These studies indicate that the development of learning tools for blind students has become a consistent research trend over the past decade.

Based on interviews conducted during learning activities, several science topics were found to be difficult for students, namely electricity, light, and electromagnetism. The topic of electricity is taught at the Grade IX level in SMP/MTs LB A classes [15], [16]. Physics learning should not only be understood theoretically but should also involve practical activities in order to achieve a deeper understanding of the material [17], [18]. Observations of physics learning activities show that blind students tend to only memorize the material, while practical activities cannot be carried out. Therefore, an instructional aid is needed to help blind students better understand the material [19]. Currently, technology can be utilized in measurement activities, particularly in developing measuring instruments. For example, by using a microcontroller, it is possible to design a sound-based voltmeter that can measure DC voltage [20]. As described above, this study was conducted to develop a voltmeter that can be used by blind students through their senses of hearing and touch. The product to be developed is a DC voltage measuring instrument with sound output. With this tool, it is expected that blind students will be able to understand the concept of dynamic electricity and also use it as a measuring instrument during practical activities.

B. Method

This research is a Research and Development (R&D) project, which is a research method used to create a specific product and test its effectiveness [21], [22]. The product developed in this research is a voice-based DC voltage measuring device for visually impaired children. The development model used in this study is a procedural model—a descriptive framework that outlines the steps required to produce a product [23], [24] .

The procedural model applied is the Four-D (4D) Model by Thiagarajan, consisting of four stages: Define, Design, Develop, and Disseminate [25], [26]. However, this study was conducted only up to the third stage (develop). In the define stage, the researcher observed the learning obstacles faced by students in science education, identifying the needs of visually impaired students through interviews with both students and teachers. The design stage involved selecting an appropriate format, conducting a literature review, and creating an initial module and product design to develop a relevant "Voment Electrical" device In the Development stage, the product was validated by media experts, subject matter experts, and instrumentation experts to obtain critiques and suggestions for product improvement. The experts were selected with one validator each from the fields of Physics, Physics Instrumentation, and Physics Education. After revising the product, "Voment Electrical" was assessed by subject matter, media, and instrumentation experts, with one expert from each field. This assessment utilized a Likert scale research instrument with 4 scales [27], [28]. This product quality assessment omitted the neutral response option to ensure the assessments were decisive [29]. The criteria of assesment are showed in Table 1:

Table 1. Assessment Score Criteria

Score	Criteria
4	VG (Very Good)
3	G (Good)
2	P (Poor)
1	VP (Very Poor)

The average score for each assessed aspect can be calculated using the following equation.

$$\bar{X} = \frac{\sum x}{N.n} \quad (1)$$

Information:

$\bar{X}$: Mean score

$\sum x$: Total score

N : Number of assessors

n : Number of questionnaire items

The average score obtained for the product quality assessment aspects is converted into a qualitative value according to the assessment criteria [30]. The qualitative criteria are determined by first calculating the interval range between the Very Good (VG) and Very Poor (VP) levels using:

$$interval\ (i) = \frac{Highest\ Value - Lowest\ Value}{Number\ of\ Interval\ Classes} \quad (2)$$

$$interval\ (i) = \frac{4-1}{4} = 0{,}75$$

Information:
Highest Value = 4
Lowest Value = 1
Number of Interval Classes = 4 (VG, G, P, VP)
The criteria based on the obtained score ranges are showed in Table 2:

Table 2. Product Assessment Category

Score	Criteria
3.26 – 4.00	VG (Very Good)
2.56 – 3.25	G (Good)
1.76 – 2.50	P (Poor)
1.00 – 1.75	VP (Very Poor)

C. Result and Discussion

The research results include the development of Voment Electrical (Voltage Measuring Tools of Electrical Materials): a voice-based DC voltage measuring device for visually impaired students in dynamic electricity lessons, as detailed below.

Design and Final Product of Voment Electrical

Voment Electrical (Voltage Measuring Tools of Electrical Materials): A Voice-Based DC Voltage Measuring Device for the Visually Impaired serves as an innovative solution for measurement tools in laboratory experiments involving electric current. This device was developed in response to the current lack of accessible measuring instruments for visually impaired individuals [31]. The primary objective of Voment Electrical is to facilitate visually impaired students in understanding and conducting experiments related to electrical current measurements, particularly in measuring DC voltage in dynamic current, thereby providing a practical demonstration of Ohm's Law. The design of Voment Electrical is showed in Figure 1:

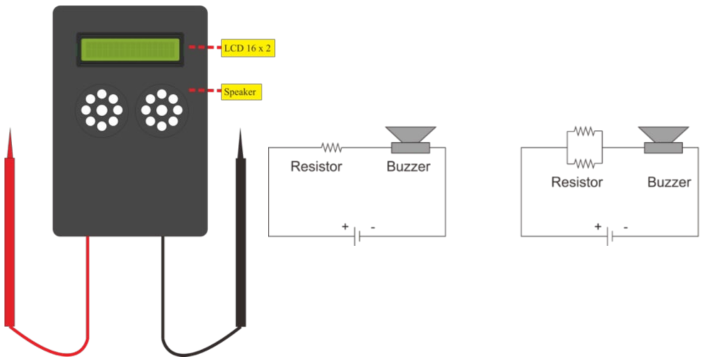

Figure 1. Design of Voment Electrical

The components comprising Voment Electrical are shown in Tabel 3:

Table 3. Tools and Materials

Component	Quantity (Unit)
Arduino Nano	1
16x2 LCD Displat	1
Blackbox	1
Speaker	1
DF Player MP3 Module	1
SD Card (4GB)	1
Buzzer	2
Resistor	As needed
Wiring	As needed
Rechargeable Battery	As needed

All the tools and materials were assembled according to the Voment Electrical design to form an initial prototype, with an operational system as showed in Figure 2:

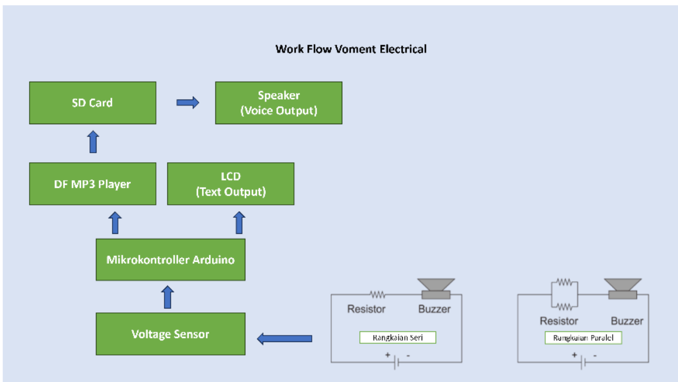

Figure 2. Workflow of Voment Electrical

Based on this workflow, Voment Electrical is used to measure the voltage from each circuit, whether series or parallel. The indicator of current flow within the circuit is signified by the emission of sound from the buzzer, enabling the user to ascertain that the electric current constitutes a closed circuit. Subsequently, Voment Electrical proceeds to read the voltage from the circuit, commencing with the Voltage Sensor component which functions as the voltage reader, transmitting the data to the Microcontroller. The Microcontroller then processes this data and issues commands to the respective output components as intended.

The Microcontroller commands the DF MP3 Player to play the audio output stored on the SD Card, based on the acquired data, and delivers the measured voltage output as audio through the speaker. Meanwhile, for the text output, the Microcontroller directly commands the LCD to display the measured voltage data according to the information received.The initial developed product was created based on the product design with several key improvements, including addition of a reset button and reduction of the audio output volume

Incorporating these modifications resulted in the final developed product as showed in Figure 3:

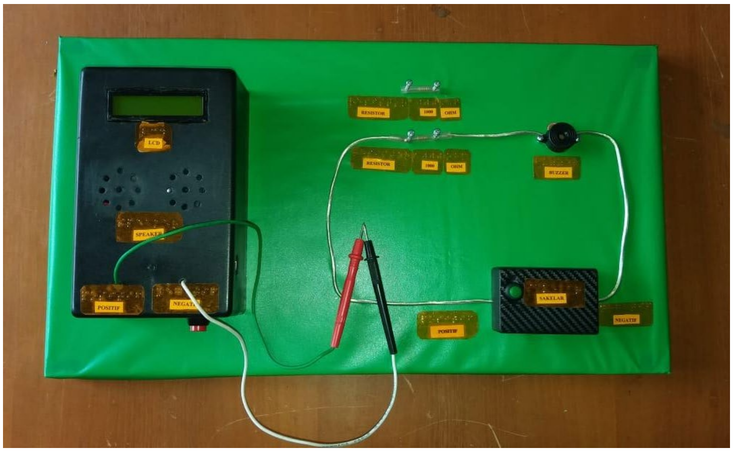

Figure 3. Final Product of Voment Electrical

Each external component of Voment Electrical is labeled with both Braille and Latin letters. The Braille labeling aims to help visually impaired individuals easily identify the general components of Voment Electrical, while the Latin letters assist those with normal vision in reading the Braille labels.

The use of Voment Electrical in physics education for blind students serves as a practical learning medium. Despite its limitations, it allows students to directly experience how electrical voltage is measured [32]. Based on our observations, blind students typically conduct electrical practical work guided by their teacher using 2 batteries arranged in series, 4 batteries, and 6 batteries to sum their voltages, with a maximum voltage of 9 Volts. The device's measurement capability is currently limited to a maximum of 10 volts. Consequently, future development could extend this range up to 25 volts.

The creation of this voltmeter is expected to assist blind students in playing a more active and independent role in their learning. This is because blind students tend to be more engaged in learning that involves concrete media [32], thereby making them more participative and enhancing their curiosity about the subject matter [33], [34]. This curiosity can be further developed by stimulating their senses of touch and hearing.

Feasiblity Test Results of Voment Electrical

Media Expert Evaluation

The product evaluation by media expert aims to assess the quality of the developed product from the perspective of physics media expert. The assessment conducted by media expert indicates that the developed product meets the criteria for Very Good (VG) quality, with an average score of 3.54, showed in Table 4:

Table 4. Product Evaluation Results by Subject Matter Expert

Aspect	Average Score	Category
Construction	3.67	VG
Easy of Use	3.57	VG
Readability	3.75	VG
Linguistic	3	G
Average	3.54	VG

Based on the media expert evaluation table from two assessors above, it can be seen that the product's construction aspect received a Very Good (VG) rating. This aspect consists of three evaluation criteria: product construction safety, product durability, and ease of maintenance. Next, the ease of use and product contribution, supported by an instruction manual to help students understand the lesson material, also received a Very Good (VG) rating. In this aspect, the product was assessed as easy to use and effective in assisting students' comprehension of the learning material. Furthermore, the readability aspect was rated Very Good (VG). This evaluation covers the clarity of Braille-based instructions on the product and the consistency between the measurement results displayed on the LCD and the corresponding audio output from Voment Electrical. Additionally, the linguistic component of the instruction manual received a Good (G) rating. The manual was rated positively in terms of language use, as it employs clear and straightforward wording that helps students understand the product's usage instructions without ambiguity.

In accordance with the media expert' assessment results, the developed product meets the Very Good (VG) quality criteria, with an average score of 3.54. Achieving this high rating indicates that Voment Electrical is suitable as a learning medium for visually impaired students in dynamic electricity lessons. The product is safe, easy to understand and operate, and effectively supports students in conducting experiments related to dynamic electricity.

Subject Matter Evaluation Expert

The product evaluation by subject matter expert aims to assess the quality of the developed product from the perspective of physics subject matter expert [35]. The assessment was conducted based on several aspects, as shown in the following Table 5:

Table 5. Product Evaluation Results by Subject Matter Expert

Aspect	Average Score	Category
Aligment with Teaching Materials	3.57	VG
Accuracy & Precision of Measurement	3.75	VG
Practical Guidebook	3.00	G
Average	3.42	G

Based on the assessment table by two material specialists above, it can be explained that the aspect of the tool's suitability with the teaching materials received the category Very Good. This aspect includes two points of suitability: alignment with the Basic Competencies in the dynamic electricity material and alignment with the learning objectives. Next, the aspect of accuracy and precision of measurement results also received the Very Good category. This aspect has two accuracy points: the measurement results have precise values, and the LCD output matches the audio output. Furthermore, the aspect of tool manual suitability received the Good category. The assessment of the tool manual covers the Core Competencies, Basic Competencies, and learning objectives, the main material on dynamic electricity, and student work instructions.

According to the assessment results conducted by the subject matter expert, the developed product meets the quality criteria of Good (B) with an average score of 3.42. The quality criteria achievement of the Voment Electrical product indicates that it can be used as a learning medium for visually impaired students in the dynamic electricity material, there by addressing the difficulties visually impaired students face in learning physics.

Results of Comparative Testing with an Analog Multimeter

This product testing aims to compare the measured voltage values between the voice-based voltmeter and the PHYWE voltmeter [36]. The voltage source used in this test is a 0-10V power supply. All data results are showed in Figure 4:

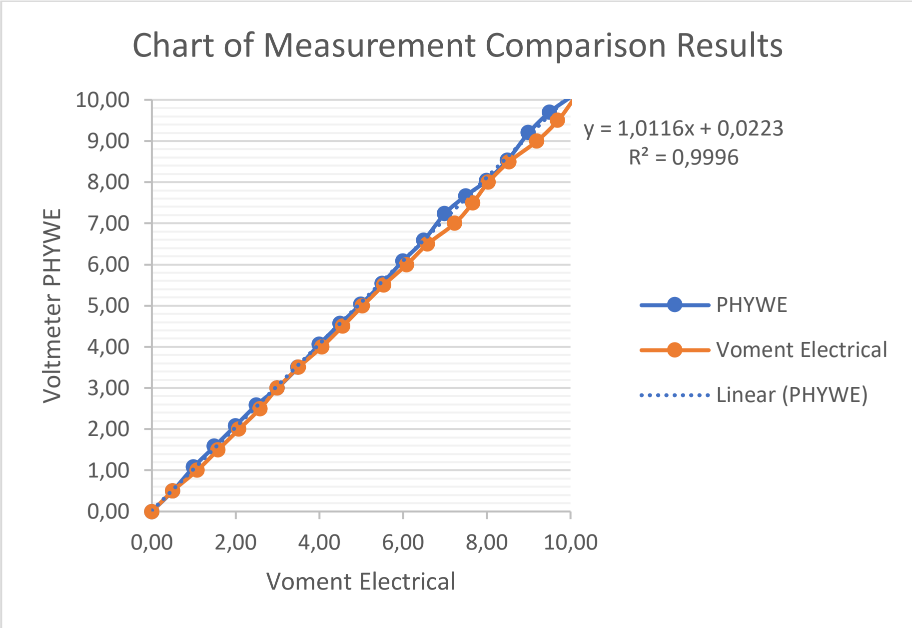

Figure 4. Graph of Voltmeter Measurement Comparison Results

Root Mean Square Error (RMSE) is the magnitude of the error in a prediction. It is calculated by taking the square root of the average of the squares of the actual and predicted values. The smaller the RMSE (closer to 0), the more accurate the prediction [37], [38].

$$RMSE = \sqrt{\frac{\sum(X-Y)^2}{n}} \qquad (3)$$

$$RMSE = \sqrt{\frac{0.23}{20}}$$

$$RMSE = 0.11$$

The RMSE calculated is 0.11, indicating that the measurement using the electrical voice input is accurate.

Table 6. Calibration Voment Electrical with PHYWE Voltmeter

PHYWE (Volt)	Calibration Voment Electrical (volt)										Mean
	1	2	3	4	5	6	7	8	9	10	
Y											X
0.5	0.50	0.55	0.49	0.48	0.51	0.50	0.49	0.50	0.50	0.50	0.5
1	1.25	1.22	1.25	1.26	1.15	1.12	1.10	1.11	0.70	0.68	1.1
1.5	1.75	1.72	1.75	1.76	1.65	1.62	1.60	1.61	1.20	1.18	1.6
2	2.18	2.15	2.11	2.10	2.09	2.06	2.06	2.06	2.06	2.00	2.1
2.5	2.68	2.65	2.61	2.60	2.59	2.56	2.56	2.56	2.56	2.50	2.6
3	3.11	3.02	3.10	2.98	2.99	2.99	2.97	2.96	2.91	2.99	3.0
3.5	3.61	3.52	3.60	3.48	3.49	3.49	3.47	3.46	3.41	3.49	3.5
4	4.09	4.08	4.01	4.11	4.03	4.07	4.07	4.05	4.04	4.07	4.1
4.5	4.59	4.58	4.51	4.61	4.53	4.57	4.57	4.55	4.54	4.57	4.6
5	5.19	5.26	5.11	5.19	4.96	4.96	4.93	4.95	4.93	4.92	5.0
5.5	5.69	5.76	5.61	5.69	5.46	5.46	5.43	5.45	5.43	5.42	5.5
6	6.13	6.20	6.20	6.12	6.10	6.11	6.04	6.01	6.00	5.99	6.1
6.5	6.63	6.70	6.70	6.62	6.60	6.61	6.54	6.51	6.50	6.49	6.6
7	7.10	7.10	7.10	7.20	7.02	7.05	7.44	7.52	7.43	7.42	7.2
7.5	7.50	7.60	7.40	7.40	7.50	7.50	7.94	8.02	7.93	7.92	7.7
8	8.16	8.11	8.06	8.10	8.04	8.01	8.00	7.97	8.03	7.91	8.0
8.5	8.66	8.61	8.56	8.60	8.54	8.51	8.50	8.47	8.53	8.41	8.5
9	9.24	9.22	9.23	9.18	9.25	9.23	9.15	9.18	9.16	9.17	9.2
9.5	9.74	9.72	9.73	9.68	9.75	9.73	9.65	9.68	9.66	9.67	9.7
10	10.22	10.14	10.17	10.17	10.07	10.05	9.97	10.01	9.93	9.93	10.1

Based on the sensor calibration data, the results obtained between the PHYWE voltmeter and the electrical voment are similar so that the accuracy is close to that of the calibrated tool, but there are some differences of 0.1 to 0.2 volts. This device can only output text on the LCD and sound through the speaker, as the microcontroller used does not support internet of things connectivity. Replacing the microcontroller with an ESP32 allows for real-time data acquisition via a mobile phone. Furthermore, this device was designed to measure a maximum of 10 volts, as the program can only output sound up to 10 volts.

D. Conclusion

The Voment Electrical (Voltage Measurement Tools for Electrical Materials) has been successfully developed - a voice-based DC voltmeter designed for visually impaired students studying dynamic electricity concepts, utilizing the 4D development methodology. Feasibility testing results demonstrate that the Voment Electrical system, as a voice-operated DC voltage measurement device for dynamic electricity instruction, meets all requirements for implementation in physics education. Furthermore, both Hypothesis 1 and Hypothesis 2 in this research were confirmed, as the product demonstrated proper functionality and met all usability requirements.

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