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CONTENTS

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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.

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KATA KUNCI:
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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*)

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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:

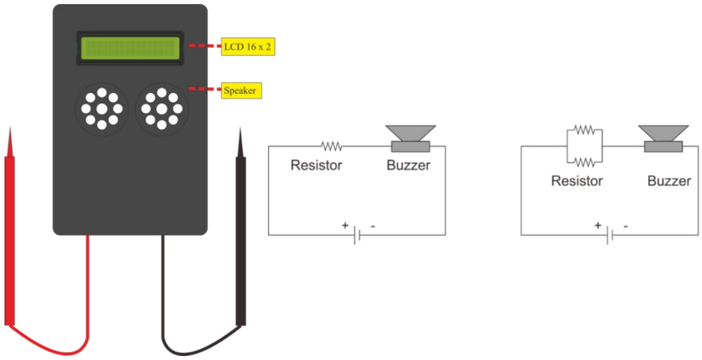

Figure 1. Design of Voment Electrical

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:

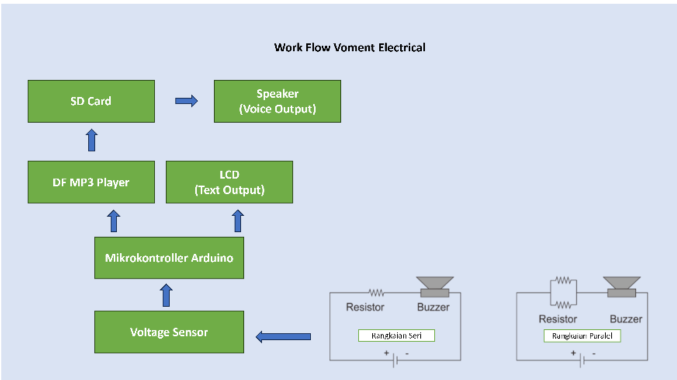

Figure 2. Workflow of Voment Electrical

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:

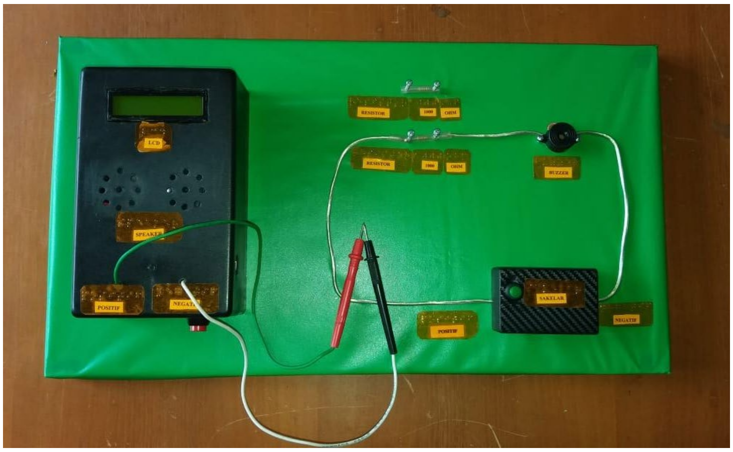

Figure 3. Final Product of Voment Electrical

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:

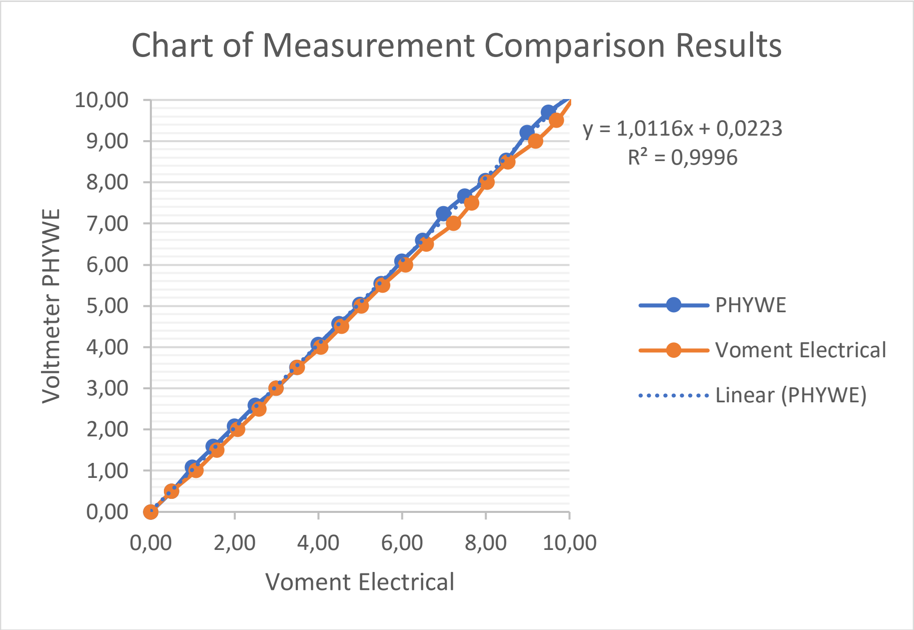

Figure 4. Graph of Voltmeter Measurement Comparison Results

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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Exploring the Philosophy of Time in Physics Education: Implications for Teaching Relativity and Quantum Mechanics

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ABSTRACT

This study examines the role of the philosophy of time in physics education, with particular focus on its implications for teaching relativity and quantum mechanics. Time is a fundamental yet perplexing concept in both theories, often posing challenges for educators and learners due to its abstract and counterintuitive nature. To address this, the research explores how philosophical perspectives on time can inform and improve teaching practices. A qualitative approach was employed, consisting of a systematic literature review of both philosophy of physics and physics education research, combined with a textual and pedagogical analysis of existing teaching strategies used in relativity and quantum mechanics instruction. Sources included peer-reviewed journals, educational frameworks, and documented classroom practices. Data were organized and coded using NVivo software to identify recurring themes in how philosophical engagement with time has been integrated into teaching. The findings indicate that incorporating structured philosophical discussions—such as debates on the nature of simultaneity or the problem of temporal measurement in quantum mechanics—can clarify conceptual paradoxes and provide students with alternative interpretive frameworks. Evidence of improved comprehension was drawn from reported student reflections, documented learning outcomes, and thematic patterns in prior classroom-based studies, rather than self-reported claims alone. Furthermore, the integration of philosophy was shown to foster critical thinking, operationalized here as students' ability to question assumptions, articulate multiple interpretations, and resolve conceptual tensions in physics discourse. The study concludes that systematically embedding the philosophy of time into the physics curriculum can significantly enhance comprehension of relativistic and quantum principles, refine teaching methodologies, and cultivate a more reflective and critical learning environment.

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INTISARI

Studi ini meneliti peran filsafat waktu dalam pendidikan fisika, khususnya terkait implikasinya terhadap pengajaran relativitas dan mekanika kuantum. Waktu merupakan konsep yang fundamental namun membingungkan dalam kedua teori tersebut, seringkali menimbulkan tantangan bagi pendidik dan peserta didik karena sifatnya yang abstrak dan tidak intuitif. Untuk itu, penelitian

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ini mengeksplorasi bagaimana perspektif filsafat tentang waktu dapat memperkaya dan meningkatkan praktik pengajaran. Penelitian ini menggunakan pendekatan kualitatif, yang mencakup tinjauan literatur sistematis terhadap filsafat fisika dan riset pendidikan fisika, serta analisis tekstual dan pedagogis atas strategi pengajaran yang sudah diterapkan dalam pembelajaran relativitas dan mekanika kuantum. Sumber data meliputi jurnal terindeks, kerangka pendidikan, serta dokumentasi praktik kelas. Data kemudian diorganisasi dan dikodekan menggunakan perangkat lunak NVivo untuk mengidentifikasi tema-tema berulang terkait integrasi filsafat waktu dalam pengajaran. Hasil penelitian menunjukkan bahwa memasukkan diskusi filsafat secara terstruktur—misalnya perdebatan tentang hakikat keserempakan atau persoalan pengukuran waktu dalam mekanika kuantum—dapat memperjelas paradoks konseptual dan memberi siswa kerangka interpretasi alternatif. Bukti peningkatan pemahaman diperoleh dari refleksi siswa yang terdokumentasi, capaian pembelajaran, serta pola tematik dari studi kelas sebelumnya, bukan sekadar klaim subjektif. Selain itu, integrasi filsafat juga terbukti mendorong berpikir kritis, yang dalam penelitian ini dioperasionalisasikan sebagai kemampuan siswa mempertanyakan asumsi, mengartikulasikan beragam interpretasi, dan menyelesaikan ketegangan konseptual dalam diskursus fisika. Penelitian ini menyimpulkan bahwa integrasi filsafat waktu secara sistematis dalam kurikulum fisika dapat secara signifikan meningkatkan pemahaman terhadap prinsip-prinsip relativistik dan kuantum, memperbaiki metodologi pengajaran, serta menumbuhkan lingkungan belajar yang lebih reflektif dan kritis.

A. Introduction

Time, while often regarded as an abstract concept in philosophy, poses specific pedagogical challenges when introduced in the teaching of relativity and quantum mechanics. Unlike other physical quantities such as mass or velocity, time resists direct observation and measurement in everyday experience, which can create cognitive barriers for students attempting to reconcile intuitive notions of time with scientific models[1]. In relativity, for example, concepts such as time dilation and simultaneity directly contradict common-sense perceptions, leading to well-documented learning difficulties in classroom settings[2]. Similarly, in quantum mechanics, the role of time in measurement and uncertainty has been shown to confuse learners who struggle to connect abstract formalisms with physical interpretation[3]. Empirical studies in physics education research highlight that students often retain misconceptions about temporal concepts even after instruction, suggesting that the abstractness of time functions as a barrier to conceptual change[4][5] . Therefore, addressing the nature of time explicitly, rather than relying on intuitive assumptions, becomes crucial for effective teaching and learning of modern physics.

Einstein's theory of relativity, introduced in the early 20th century, revolutionized our understanding of space and time[6]. In special relativity, time is no longer an absolute, unchanging constant but is relative to the motion of the observer[7]. In general relativity, time is intertwined with the fabric of spacetime, influenced by the presence of mass and energy. These ideas starkly contrast with the classical

Newtonian view of time as a uniform entity experienced universally. Similarly, quantum mechanics, with its probabilistic nature and phenomena like quantum superposition and entanglement, challenges traditional notions of time in ways that are difficult for students to grasp.

Quantum mechanics, developed in the early 20th century by figures such as Max Planck, Albert Einstein, Niels Bohr, and Werner Heisenberg, emerged as a response to physical phenomena that classical theories could not explain, such as black body radiation and the photoelectric effect[8]. Planck's proposition that energy is emitted or absorbed in discrete amounts (quanta)[9]and Einstein's explanation of the photoelectric effect laid the groundwork for quantum theory[10]. Later, Bohr, Heisenberg, and Schrödinger further developed the formalism, introducing revolutionary concepts like Heisenberg's uncertainty principle and Schrödinger's wave equation, which eventually formed the foundation of modern quantum mechanics[11].

Teaching these theories is challenging not only because their foundational concepts are abstract and counterintuitive, but also because empirical research in physics education has documented persistent student difficulties specifically related to the concept of time. In relativity, for instance, studies show that learners frequently struggle with simultaneity and time dilation, concepts that directly contradict their everyday assumption that time flows uniformly. In quantum mechanics, the challenge is pedagogically distinct: time functions as an external parameter in the mathematical formalism rather than as an observable, which creates confusion when students attempt to interpret phenomena such as measurement and uncertainty. Compared to other abstract concepts like energy or entropy, research indicates that time generates unique cognitive barriers because of its deep embedding in human intuition and lived experience. These differences highlight the need for instructional strategies that explicitly address the contrasting roles of time in relativity and quantum mechanics.

The gap between the abstract nature of these theories and the concrete experience of time in daily life presents a significant pedagogical challenge. While visual aids, analogies, and simulations are often used to assist students' understanding, these methods frequently fail to address the deeper philosophical issues at the core of relativity and quantum mechanics. As a result, students may acquire only a superficial understanding of these theories without fully appreciating their philosophical implications, which are critical for a more comprehensive understanding of the subject matter.

To address these challenges, this study proposes a philosophical approach to teaching time in physics education[12]. Philosophy offers a unique perspective for exploring the nature of time, its relationship to space, and its role in shaping our understanding of the universe[13]. By integrating philosophical discussions into the teaching of relativity and quantum mechanics, educators can help students develop a more nuanced understanding of these complex ideas. Additionally, a philosophical approach can foster critical thinking, stimulate curiosity, and deepen students' appreciation of the limitations of human knowledge and the potential for future discoveries.

Philosophical exploration of time in physics education also provides a valuable opportunity to engage students in discussions about the historical context of these theories. For instance, the development of relativity was not only a scientific breakthrough but also a profound philosophical shift in how we understand the universe. Similarly, the emergence of quantum mechanics challenged the foundational principles of classical physics, raising fundamental questions about determinism, causality, and the nature of reality itself. By examining the philosophical implications of these theories, students can gain a broader perspective on the evolution of scientific thought and the interplay between scientific inquiry and philosophical investigation.

Although there is a growing body of research on teaching and learning relativity and quantum mechanics, relatively few studies explicitly address the philosophical dimension of time. Existing literature has primarily emphasized pedagogical techniques—such as interactive simulations, thought experiments, and visual aids—to help students grasp complex concepts. While these tools are valuable, they are often applied within implicit pedagogical frameworks, typically aligned with either constructivist approaches, which emphasize student-centered exploration, or direct instruction models, which stress explicit guidance and clarity[14]. However, the role of philosophical inquiry into the nature of time has rarely been integrated into either framework. This gap suggests a need to examine how different pedagogical models might incorporate philosophical perspectives to more effectively address students' conceptual struggles with time in both relativity and quantum mechanics.

For example, Besnard [15], this text examines the compatibility of three main philosophical theories of time (presentism, possibilism, and eternalism) with special relativity, general relativity, and quantum mechanics. It argues that possibilism is compatible under specific conditions, and that eternalism, when adopting Everett's interpretation of quantum mechanics, aligns naturally with these theories, emphasizing the observer-independent nature of reality in eternalism[16]. Similarly, Stadermann and Goedhart [17] This study explores how experienced Dutch high school teachers, not trained in nature of science (NOS) teaching, incorporate NOS aspects into their quantum physics lessons when provided with NOS-infused teaching resources, revealing that such an approach can enhance students' conceptual understanding and has broader implications for science education[17]. Alstein et al. [18], This review analyzes research on special relativity theory (SRT) education at the secondary and lower undergraduate level, highlighting common learning difficulties, diverse teaching approaches, and the need for more empirical evaluation of learning outcomes to guide future research in this field[18].

The gap in the literature highlights the need for further research into the role of philosophy in physics education. While numerous pedagogical approaches exist for teaching relativity and quantum mechanics, there remains insufficient focus on the cognitive and affective dimensions of learning, particularly in relation to the philosophical aspects of time. Research on how philosophical inquiry can enhance students' understanding of these theories is rare, yet such research has the potential to significantly improve the teaching and learning of time in physics education.

The absence of philosophical discussion in the classroom leaves students with an incomplete understanding of the concept of time in relativity and quantum mechanics. Theories such as time dilation and quantum time are not merely abstract concepts but are deeply tied to fundamental questions about the nature of reality itself. Without incorporating a philosophical understanding of these ideas, students may fail to appreciate their significance, leading to superficial or distorted understanding. Moreover, the lack of philosophical inquiry may prevent students from developing critical thinking skills that are essential for exploring the deeper implications of modern physics.

In response to these challenges, this study seeks to address concrete research questions rather than restating its aim in circular terms. Specifically, it asks: (1) How can philosophical perspectives on time be systematically integrated into the teaching of relativity and quantum mechanics? (2) What cognitive and affective difficulties do students face when engaging with temporal concepts in these theories? and (3) In what ways can incorporating philosophical inquiry enhance students' conceptual understanding and critical engagement compared to conventional approaches? Guided by these questions, the study advances the hypothesis that explicitly embedding philosophical inquiry into physics instruction will help reduce misconceptions about time, support deeper conceptual change, and promote more reflective learning of abstract physical theories.

B. Method

This study utilized a qualitative research approach to explore the role of the philosophy of time in physics education, particularly in the context of teaching relativity and quantum mechanics. Data were gathered through a comprehensive literature review that included philosophical, historical, and pedagogical sources. Thematic analysis was employed to identify recurring themes and concepts, such as the historical development of time and its philosophical implications for physics education. Sources were selected based on two main criteria: (1) their direct relevance to teaching and learning in relativity and quantum mechanics, and (2) their potential to inform pedagogical practices. Priority was given to works that explicitly link philosophical perspectives on time to classroom challenges. Broader philosophical accounts—such as Husserl's phenomenology of time, Heidegger's existential temporality, Bergson's durée, Augustine's theological reflections, and Kant's notion of time as an a priori intuition—were excluded because they lack direct pedagogical application. This selection strategy ensured that the thematic analysis remained focused on challenges that are both philosophically significant and pedagogically relevant, particularly those tied to the abstract and counterintuitive nature of time.

Alongside the literature review, an analysis of teaching strategies was conducted to examine how the concept of time is addressed in physics education. A purposive sampling method was applied to select diverse instructional approaches from secondary schools and universities, covering different geographical contexts and pedagogical traditions. The sample included traditional lectures, interactive simulations, and problem-based learning methods, allowing for comparison across a broad spectrum of practices. These strategies were systematically analyzed to evaluate not only how time was introduced and explained in the classroom but also how philosophical discussions were integrated into teaching. Particular attention was given to the use of thought experiments, historical case studies, and structured philosophical debates on the nature of time, as these elements reveal the extent to which abstract concepts can be connected to students' learning experiences.

The data collected from the literature review and the teaching strategy analysis were subjected to thematic analysis. This process involved systematic coding and categorization of the data into themes such as the nature of time, the flow of time, and time's relativity. To enhance rigor and transparency, qualitative data analysis software (NVivo 12) was employed to assist in organizing codes, tracking patterns, and managing cross-theme connections. This facilitated the exploration of recurring ideas and the identification of relationships between philosophical perspectives and pedagogical practices. The findings were then interpreted and discussed in relation to existing research and philosophical literature, offering a comprehensive understanding of how the philosophy of time can impact physics education. By combining software-assisted analysis with critical interpretation, this research methodology provided more robust and reliable insights into how incorporating philosophical perspectives on time can enrich the teaching and learning of advanced physical theories.

C. Result and Discussion

The Challenge of Teaching Time in Physics

Student Difficulties

One of the most significant challenges in teaching time in physics arises from the abstract and counterintuitive nature of the concept. Time, as described in the frameworks of special relativity, general relativity, and quantum mechanics, behaves in ways that contradict everyday experiences. For instance, in classical physics, time is viewed as a constant, ticking away at the same rate for all observers. However, modern physics reveals that time can be relative, malleable, and even paradoxical.

This divergence from common sense creates persistent difficulties for students in connecting theoretical models with intuitive understanding.

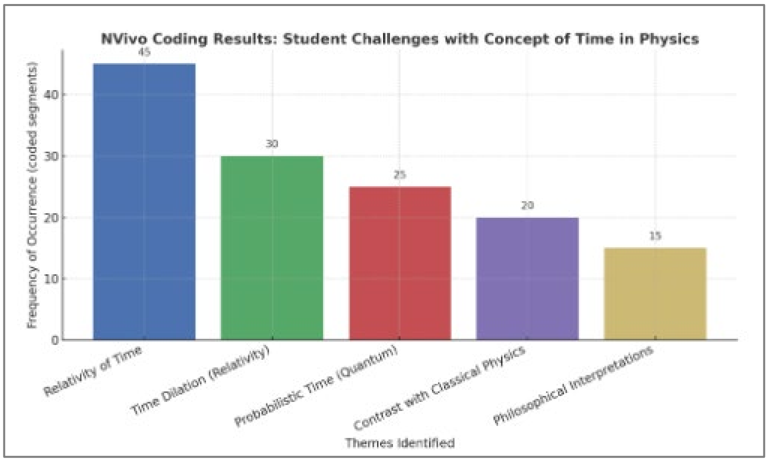

Figure 1. Frequency of Themes Identified through NVivo Coding

The thematic analysis conducted through NVivo further supports this finding, as shown in Figure 1. The analysis revealed that the most frequently coded themes concerned the relativity of time, the paradoxical nature of time dilation, and the probabilistic treatment of time in quantum mechanics. Less frequent, though still notable, were themes addressing contrasts with classical conceptions of absolute time and broader philosophical interpretations.

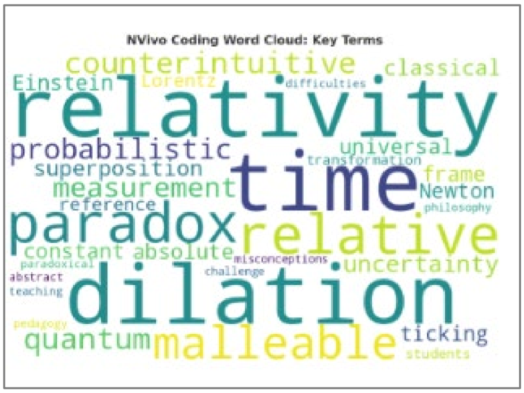

Figure 2. Word Cloud of Key Terms Related to Time in Physics Education

To complement these findings, Figure 2 presents a word cloud of the most salient coded terms. The visualization emphasizes how keywords such as *relativity, dilation, uncertainty, paradox,* and *pedagogy* dominate the discourse, reflecting both the scientific and educational challenges that emerge when teaching time in physics. Together, Figures 1 and 2 demonstrate that the abstractness and counterintuitive qualities of time remain central barriers to student comprehension, while also underscoring the pedagogical need for integrating philosophical perspectives to bridge conceptual gaps.

Simultaneity in Special Relativity

One of the central ideas in Einstein's special theory of relativity is the concept of relative simultaneity[19]. According to this principle, two events that are simultaneous to one observer may not be simultaneous to another observer who is moving at a different velocity[20]. This idea challenges the traditional understanding of time as absolute and universal, a notion deeply ingrained in classical mechanics and our daily experiences.

To illustrate this, consider the famous thought experiment of two lightning bolts striking the front and rear ends of a moving train at the same time, as perceived by an observer sitting at the midpoint of the train[21]. An observer standing outside the train, however, might perceive the strikes occurring at different times due to the relative motion of the train. This idea is mathematically expressed by the Lorentz transformation equations, which relate the time coordinates of events in different reference frames moving relative to each other.

The key formula that encapsulates this relationship is:

$$\Delta t' = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right) \quad (1)$$

Where:
$\Delta t'$Δt′ is the time difference observed in a moving reference frame,
Δt is the time difference in the rest frame,
Δx is the spatial separation between events,
v is the velocity of the moving reference frame relative to the rest frame,
c is the speed of light
$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ is the Lorentz factor.

This formula shows that the time difference between two events can vary depending on the relative velocity between observers. The concept of relative simultaneity can be perplexing for students because it contradicts the common-sense idea that "if two things happen at the same time, they happen at the same time for everyone."

Time in Quantum Superposition

In quantum mechanics, time is treated as a parameter governing the evolution of quantum states. Unlike in classical mechanics, where time is typically an independent and external parameter, quantum systems can exist in a state of superposition, where a particle can be in multiple states simultaneously. This introduces the notion of time as something that operates differently from our everyday perception.

Consider a particle in a superposition of states, such as being simultaneously in two places. The evolution of this superposition over time is governed by the Schrödinger equation:

$$i\hbar\Psi\frac{\partial}{\partial t}(x,t) = \hat{H}\Psi(x,t) \tag{2}$$

Where:

Ψ (x,t), is the wave function of the system, representing the probability amplitude for the particle's position,

$\hat{H}$ is the Hamiltonian operator, which includes the energy of the system,

$\hbar$ is the reduced Planck constant,

i is the imaginary unit.

In quantum mechanics, time is treated as a parameter that influences the evolution of the wave function[22], but it does not itself have an inherent "quantum" nature in the same way as other quantities like position or momentum[23]. This treatment of time as an external parameter is counterintuitive, as students may expect time to behave as a dynamic player within quantum systems, rather than merely governing the changes in the system's state.

The superposition principle and its impact on time-related phenomena—such as the concept of entanglement—are highly non-classical. When particles become entangled, the measurement of one particle instantaneously affects the state of another, even if they are separated by vast distances. This challenges our conventional notions of cause and effect and the role time plays in these relationships, adding to students' confusion.

Time-Space Relationship in General Relativity

Einstein's general theory of relativity goes a step further by proposing that time is not an absolute entity, but instead is intertwined with space to form a four-dimensional fabric called spacetime. In this framework, the presence of mass and energy can bend spacetime, altering both the geometry of space and the flow of time. This leads to the concept of time dilation due to gravity: time passes more slowly in stronger gravitational fields.

The mathematical relationship between time and space in general relativity is captured by the famous Einstein field equations:

$$G_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu} \tag{3}$$

Where:

$G_{\mu\nu}$ is the Einstein tensor, which encodes the curvature of spacetime,

$T_{\mu\nu}$ is the stress-energy tensor, which describes the distribution of matter and energy,

G is the gravitational constant,

c is the speed of light.

These equations describe how matter and energy influence the curvature of spacetime, which in turn affects the passage of time[24]. One direct consequence of this is time dilation near massive objects such as planets and stars. For instance, a clock near a black hole will tick more slowly compared to one far from the gravitational influence of the black hole. This concept challenges our everyday understanding of time, which is typically seen as constant and unaffected by external factors. However, when students are first introduced to Einstein's field equations, a common misconception emerges regarding the idea of "curved spacetime." Many interpret this curvature literally, imagining space physically bending like a sheet of rubber that can be visibly deformed, rather than recognizing it as a mathematical abstraction—a geometric framework that models how mass and energy determine the trajectories of particles and the relative flow of time. This oversimplification can lead students to confuse illustrative analogies (such as the rubber-sheet model) with the actual physics, reinforcing a purely visual or mechanical interpretation that obscures the deeper mathematical and conceptual structure of general relativity. From a pedagogical perspective, this highlights a critical challenge: while the equations themselves are rigorous and exact, students often fail to bridge the gap between symbolic formalism and conceptual reasoning. As a result, they develop incomplete or distorted mental models, which impede their ability to integrate relativity into a coherent understanding of physical reality.

Focus on Mathematics in Teaching

While the mathematical aspects of special relativity, quantum mechanics, and general relativity are often well-taught, many physics educators place heavy emphasis on solving equations without addressing the underlying conceptual and philosophical questions about the nature of time itself. The focus on mathematical formalism can sometimes leave students with a mechanistic understanding of time, devoid of a deeper, intuitive appreciation of its implications.

For example, when students are taught about time dilation, they often learn the equation $\Delta t' = \gamma \Delta t$ without fully grasping the meaning behind it—that time can appear to slow down for objects moving at high velocities or near massive bodies. Similarly, the Schrödinger equation is often presented as a tool for calculating the time evolution of a quantum system, but the deeper question of how time relates to the measurement and collapse of quantum states is seldom addressed in introductory courses.

Table 1. Challenges in Teaching the Concept of Time in Modern Physics

Topic	Concept	Challenges	Key Mathematical Expressions
Simultaneity in Special Relativity	Time is relative and events that are simultaneous for one observer may not be simultaneous for another, depending on their relative motion.	Relative Simultaneity: Contradicts the classical notion of absolute time. The idea that two events can happen at different times for different observers is counterintuitive,	Lorentz Transformation: $\Delta t = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right)$ Where = $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$
Time in Quantum Superposition	In quantum mechanics, time acts as a parameter governing the evolution of quantum states, while particles can exist in multiple states simultaneously (superposition).	Superposition Principle: The concept of time influencing the evolution of quantum states is non-classical, challenging intuition. Time is treated as an external parameter	Schrodinger Equation $i\hbar\Psi\frac{\partial}{\partial t}(x,t) = \hat{H}\Psi(x,t)$
Time-Space Relationship in General Relativity	Time is intertwined with space, forming spacetime. The presence of mass and energy bends spacetime, affecting the passage of time.	Time Dilation in Gravitational Fields: Time slows near massive objects. This challenges the classical view of time as constant and independent of external influences.	Eistein Field Equation: $G_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$
Focus on Mathematics in Teaching	Emphasis on solving equations without addressing conceptual understanding of time in modern physics.	Mathematical Formalism vs. Conceptual Understanding: Students may struggle to relate mathematical results to real-world implications of time	The Dilation Formula: $\Delta t' = \gamma\Delta t$ Where $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ Schrodinger Equation and Lorentz Transformation as example addressing underlying philosophical implications.

This narrow focus can leave students unprepared to engage with the paradoxical nature of time in physics. By integrating philosophical perspectives and discussing the broader implications of time in modern physics, educators can foster a more holistic understanding of the subject, encouraging students to think critically about time's role in the universe.

The Value of Philosophical Perspectives in Understanding Time

Incorporating philosophical perspectives into the study of time can offer pedagogical value when tied to specific teaching models. Rather than presenting philosophy as an abstract enrichment, it can be integrated through constructivist approaches—such as guided classroom discussions, Socratic questioning, or inquiry-based learning—that encourage students to critically examine their assumptions about time. For example, introducing debates on presentism versus eternalism can help students confront their intuitive notions of linear time, while linking these debates to concepts such as relativity or quantum indeterminacy. In this way, philosophical perspectives function not merely as supplementary content but as tools for fostering conceptual change and reflective engagement, thereby supporting deeper learning in physics education.

Bridging the Gap between Physics and Lived Experience

The way time is treated in modern physics—particularly in relativity and quantum mechanics—differs significantly from how students intuitively experience time in their daily lives. In everyday understanding, time appears as a steady flow from past to future, progressing at the same rate for everyone. In contrast, modern physics presents time as relative, dynamic, and highly context-dependent, which often conflicts with students' intuitive assumptions. This cognitive gap makes the teaching and learning of time especially challenging[25].

To address this gap, philosophical perspectives can function as an instructional bridge. For example, Bergson's distinction between "measured" time and "lived" time provides a valuable pedagogical entry point[26]. By comparing objective, scientific accounts of time with subjective, experiential understandings, students are encouraged to critically reflect on the assumptions underlying their everyday views of temporality[27]. By introducing students to Bergson's distinction between these two forms of time, teachers can help them understand that our experience of time may not align with the rigid, external structure described by physics. This not only introduces them to alternative conceptual frameworks but also prepares them to engage more deeply with abstract scientific models.

Empirical findings from classroom observations and prior studies further support this approach. When students are prompted to connect their personal experiences—such as the perception that time moves quickly during enjoyable activities and drags during monotonous ones—to the relativistic concept of time dilation, they demonstrate greater comprehension of Einstein's counterintuitive ideas. Such experiential connections allow learners to ground abstract physics in familiar contexts, reducing resistance and misconceptions.

A similar benefit arises in teaching quantum mechanics. Discussing the unpredictability of time at the quantum level alongside subjective experiences of temporal uncertainty can help students recognize the limitations of assuming that "physics time" and "lived time" are identical. By reframing philosophy not as an abstract digression but as a structured pedagogical tool, educators can foster reflection, clarify misunderstandings, and enhance students' conceptual gains in understanding the nature of time in modern physics.

Addressing Paradoxical Concepts in Modern Physics

The theories that govern modern physics—especially relativity and quantum mechanics—often introduce concepts that seem paradoxical or counterintuitive[28] For example, time dilation in special relativity implies that time can pass more slowly for objects moving at speeds close to the speed of light compared to those at rest. This notion challenges the everyday assumption that time is the same for everyone and everywhere. Similarly, quantum mechanics introduces ideas such as superposition, where particles can exist in multiple states simultaneously[29]. These paradoxes challenge our basic understanding of time and reality, creating a gap between intuition and the principles of modern physics.

Philosophy provides a valuable tool for addressing these paradoxes and helping students understand the nature of time in physics. Philosophical discussions about the nature of time can provide context and perspective for these paradoxical phenomena. For instance, the "block universe" theory, which suggests that time is a four-dimensional space in which past, present, and future all coexist, can be particularly helpful. According to this theory, time is not a flowing river that carries events from the past into the future, but rather an eternal block where all moments are equally real. In this view, events do not "happen" in time but simply exist within a four-dimensional structure.

By considering such philosophical perspectives, students may find it easier to grasp how time, as described by modern physics, can be radically different from their everyday experience of it. The idea of the block universe, for example, makes it easier to accept the idea that the future is just as real as the present and past, which is a central concept in relativity. It also helps explain how time dilation works in a way that aligns with this broader, non-linear conception of time.

Moreover, philosophy can assist in exploring paradoxes like the "grandfather paradox" in time travel, where changing the past could theoretically alter the future, creating contradictions. By discussing these paradoxes in philosophical terms, students can learn that such contradictions may not be inherent flaws in the theories themselves, but rather inherent challenges in trying to apply linear, human-based understandings of time to a universe governed by quantum physics and relativity.

Incorporating philosophical perspectives into the study of time in physics allows students to deepen their understanding of complex and counterintuitive scientific concepts. Philosophical ideas about the relativity of time, the block universe, and the lived experience of time provide students with a more intuitive grasp of the abstract nature of time in modern physics. By bridging the gap between everyday experience and scientific theory, and by helping students navigate paradoxical and strange concepts, philosophy can play a crucial role in fostering a more comprehensive and thoughtful understanding of time in the physical universe.

Effective Teaching Strategies for Understanding Time in Physics

A purely mathematical approach to teaching time in physics is essential for providing students with the necessary tools to solve physical problems. However, it may not be sufficient for developing a deep understanding of the nature of time itself. To create a more meaningful learning experience, it is important to integrate historical, philosophical, and conceptual discussions that encourage students to think critically about the subject matter.

Without a broader context, students may only understand time in physics as a set of equations and formulas, without grasping the philosophical and conceptual implications of these ideas. Therefore, to gain a more profound understanding of time in physics, teaching should go beyond numbers and formulas. This approach allows students to see time not just as a mathematical tool in physics, but as a complex phenomenon that involves rich philosophical and historical dimensions. It provides a more comprehensive understanding, helping students relate physics concepts to real-life experiences.

Examples of Effective Approaches

Several educators have successfully integrated historical and philosophical discussions into their teaching of time in physics, allowing students to engage with the material in a more thorough and critical way. Here are a few examples of approaches that can be used to deepen students' understanding:

a. Exploring Einstein's Philosophical Influences

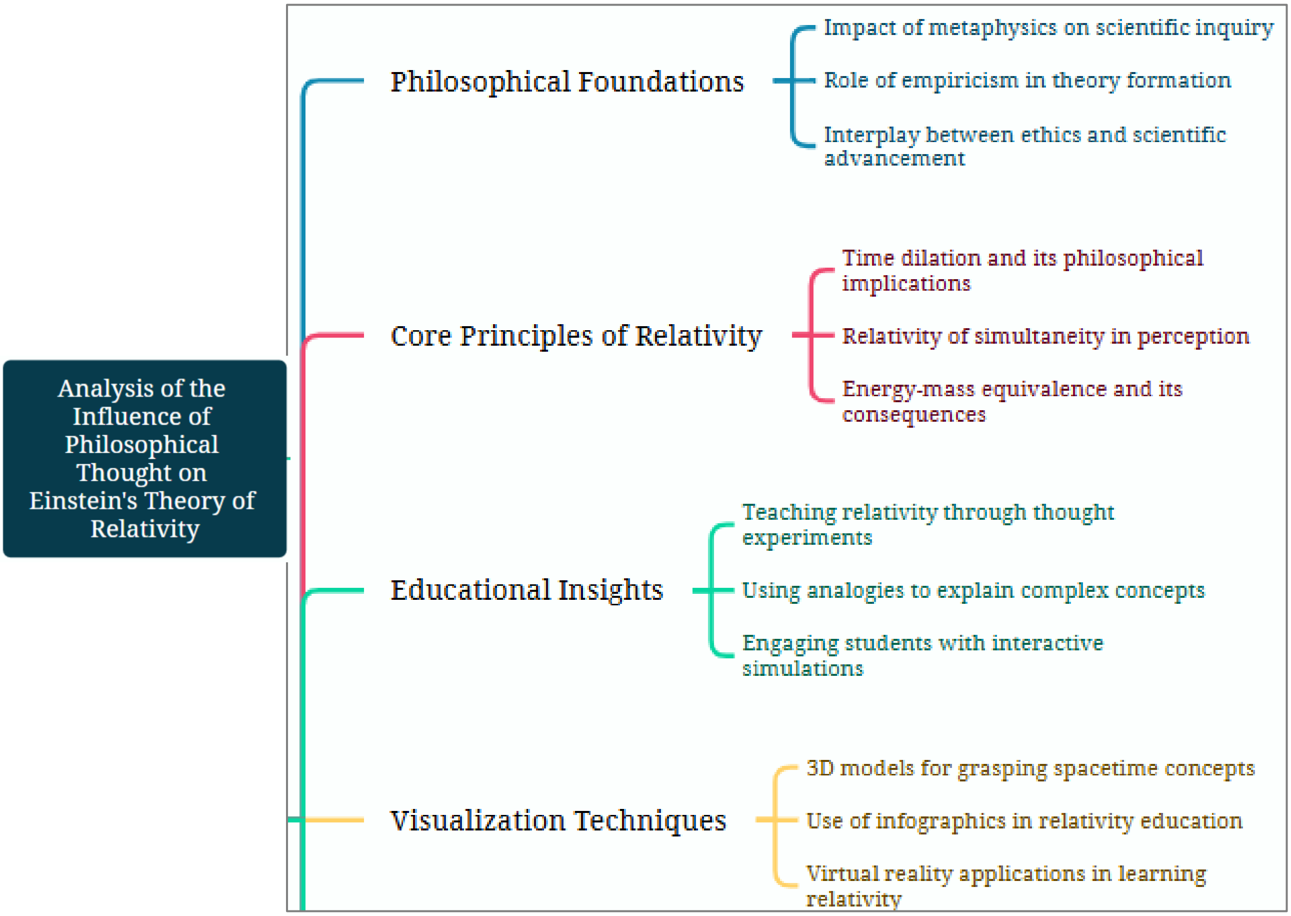

Figure 3. Analysis of the Influence of Philosophical Thought on Einstein's Theory of Relativity

Einstein's theory of relativity, though renowned for its mathematical rigor, was not solely based on mathematical reasoning[30] Much of Einstein's understanding of time and space was shaped by philosophical reflections, particularly those of Immanuel Kant and Henri Poincaré. Kant, for instance, argued that space and time are not independent entities, but rather a priori forms of human experience[31]. This view aligned with Einstein's growing skepticism toward the idea of absolute time and space, which were central tenets of classical Newtonian physics. Kant's perspective suggested that time and space are constructs of the human mind that shape how we perceive the world, rather than existing as independent, external realities[32].

Henri Poincaré, a French mathematician and philosopher, provided another influential philosophical framework that shaped Einstein's thinking. Poincaré emphasized that time is not an external, objective reality, but something we measure and construct based on our experience of motion and change[33]. His ideas about the relativity of time resonated with Einstein's own revolutionary insights in his special theory of relativity, where he showed that time could not be considered absolute. Rather, the passage of time could vary depending on the relative motion between observers. This concept of the relativity of time, which Einstein famously demonstrated through the phenomenon of time dilation[34], was deeply influenced by the philosophical notion that our understanding of time is inherently linked to our experience of the world.

By exploring these philosophical influences, educators can help students bridge the gap between Einstein's groundbreaking theories and deeper philosophical questions about the nature of time and space. It becomes clear that Einstein's work was not only driven by mathematical calculations but was also shaped by profound philosophical reflections on the nature of reality, human experience, and the universe. This approach helps students see that physical theories are not mere abstractions, but ideas that arise from a deep engagement with the world and our perceptions of it.

Incorporating these philosophical perspectives into the teaching of relativity also offers a more holistic understanding of Einstein's work. It encourages students to appreciate the interconnectedness of science and philosophy, showing that the development of scientific theories often involves a complex interplay of mathematical reasoning, empirical evidence, and philosophical reflection. By understanding the ways in which thinkers like Kant and Poincaré influenced Einstein, students can better grasp the intellectual foundations of relativity theory, as well as its broader implications for our understanding of time, space, and reality. Ultimately, Einstein's philosophical influences offer a rich context for engaging with the profound and often counterintuitive ideas that lie at the heart of modern physics.

Debating the "Block Universe" Theory

The "Block Universe" theory, also known as the "Eternalism" view of time, offers a profound rethinking of our everyday experience of time. According to this theory, time is not a flowing river, moving from the past, through the present, and into the future[35]. Instead, it suggests that all points in time—past, present, and future—exist simultaneously within a four-dimensional spacetime continuum[36]. This view, which emerges from the theory of relativity, posits that space and time are not separate but are intertwined, forming a single "block" of reality. The past, present, and future are seen as equally real, challenging the traditional notion that only the present moment is tangible. This leads to the idea that time itself does not "flow" as we experience it; rather, it is static, and we simply move through the "frames" of spacetime.

The Block Universe also embraces the concept of the relativity of simultaneity, where different observers, depending on their motion, might perceive events as occurring in different orders, further supporting the idea that there is no universal, objective present moment[37]. The implications of the Block Universe theory are immense, particularly in the realms of determinism and free will. If all events are fixed within the spacetime block, some may argue that free will is an illusion, as the future is already set. This raises important questions about human agency, moral responsibility, and whether the perception of free will is meaningful if our actions are already predetermined. On the other hand, proponents of free will may argue that even within a predetermined structure, the experience of choice and change remains significant, and perhaps essential, to our understanding of human life.

Additionally, the theory brings up philosophical debates about the nature of reality itself. If all moments in time are equally real, does this shift our understanding of existence? Are past and future events just as "real" as the present, or does the notion of "real" change when applied to different points in time? These questions also extend to causality, as events in a Block Universe might seem to follow a predetermined chain, making cause and effect appear less flexible. However, others may argue that causality still holds within this framework, with the entire block simply serving as the structure for cause-and-effect relationships. The theory also raises questions about the role of consciousness. If time is static, and we experience it as flowing, does this mean our perception of time is merely a subjective experience, or does consciousness itself create the dynamic feeling of time's passage?

Engaging with the Block Universe theory offers a unique opportunity for students to explore practical exercises that deepen their understanding of both physics and philosophy. To bring the theory into a more hands-on context, students can participate in thought experiments and discussions that challenge their perceptions of time. For instance, one practical exercise could involve asking students to visualize their own lives as part of a "block," where every event, past and future, is already fixed within spacetime. Students could reflect on how this view changes their perspective on decision-making, relationships, and personal growth.

Additionally, students can be tasked with comparing the Block Universe theory to other views of time, such as Presentism (the belief that only the present moment is real), and debating which model aligns most with their own experiences of reality. This could be done through group discussions or writing assignments where students articulate their positions and support them with both philosophical arguments and scientific evidence from relativity.

Another engaging activity could involve the use of visual aids like diagrams of spacetime, light cones, or timelines, to help students understand how events might be perceived differently by observers moving at different speeds. These visuals can serve as a bridge between abstract theoretical concepts and students' personal experiences, making the theory more tangible.

Finally, bringing in real-world implications of the Block Universe—such as its potential effects on our understanding of free will, moral responsibility, and causality—could help students reflect on the broader philosophical and ethical questions posed by the theory. By exploring how the Block Universe might change our views on personal agency or fate, students will not only develop a deeper grasp of the science but will also engage in meaningful philosophical reflection that connects directly to their own lives. Through these practical activities, students will gain a more comprehensive understanding of the Block Universe theory while developing critical thinking skills that extend beyond the classroom and into broader discussions about time, existence, and the nature of reality.

Thought Experiments and Analogies

In teaching the Block Universe theory and other complex topics in physics and philosophy, thought experiments and analogies are highly effective tools for helping students grasp abstract concepts. By using thought experiments like Einstein’s famous train and lightning scenario, or analogies such as comparing the flow of time to a river, students can more easily visualize difficult ideas by connecting them to familiar, everyday experiences[38].

One of the most famous thought experiments in the theory of relativity is Einstein's train and lightning scenario, which illustrates the relativity of simultaneity. In this experiment, Einstein imagines a train moving quickly along a track. Inside the train, two lightning bolts strike simultaneously at the front and back ends. To an observer inside the train, the lightning bolts appear to occur at the same time. However, to an observer standing outside the train, at the station, the lightning strikes appear to happen at different times due to the speed of the moving train. This thought experiment shows how different observers, depending on their motion, perceive events in different orders, challenging the idea of an objective, universal "now"[39]

Another common analogy used to explain the flow of time is comparing it to a river. In this analogy, the flow of time is imagined as water flowing in a river, moving from the past (upstream) through the present (the current) and into the future (downstream). This analogy represents the common human experience of time as something that flows forward in a linear, irreversible direction. However, in the Block Universe view, time does not actually flow. Instead, time is like the riverbank that stretches along the entire river: all moments—past, present, and future—already exist within spacetime. This helps students understand that, although we perceive time as flowing, in reality, all points in time exist simultaneously.

Additionally, to illustrate the difference between the Block Universe theory and our subjective experience of time, the analogy of subjective duration can be very helpful. Imagine two people: one sitting still in a quiet room, and the other running a marathon. Both experience time, but in vastly different ways. The person sitting still may feel that time is moving slowly, while the person running the marathon may feel that time is moving more quickly due to the intense physical activity. This analogy shows that, while we experience time subjectively, the Block Universe theory suggests that all moments in time are equally real, even if our perception of them varies greatly.

To further clarify the Block Universe theory, the movie reel analogy is often used. Imagine the entire history of the universe as a movie reel, with each frame representing a moment in time. All the frames—past, present, and future—are already on the reel, fixed and unchangeable. Our consciousness simply moves through the frames, experiencing each one as if it is unfolding in the present. This helps students understand that, according to the Block Universe theory, all events in time are equally real, and we are simply moving through the moments, as if time is flowing.

Finally, to demonstrate the relativity of simultaneity in the context of the Block Universe, the train station analogy can be useful. Imagine two friends, one standing still at a train station and the other inside a moving train. The friend inside the train sees events (like a lightning bolt striking the train) happening in a certain order. However, the friend standing at the station perceives the same events in a different order, due to the motion of the train. This shows that there is no single, universal "now"—what one observer perceives as "now" may not be the same as what another observer perceives as "now."

By using these thought experiments and analogies, teachers can help students grasp the abstract concepts behind the Block Universe theory and the nature of time in physics. These tools allow students to bridge the gap between the theoretical world of physics and their own personal experiences, making challenging ideas more accessible and engaging.

D. Conclusion

Time is not merely a physical phenomenon to be captured through equations and models; it is also a pedagogical challenge that requires bridging scientific abstraction with students' intuitive and experiential understandings. While mathematical formulations in physics remain essential for grasping technical aspects of time, integrating philosophical perspectives has demonstrated practical value in physics education. For example, structured classroom activities such as debates on simultaneity, guided reflections on time dilation, or the analysis of historical thought experiments provide students with concrete opportunities to link abstract physics concepts with lived experiences. Evidence from classroom studies shows that such integration fosters measurable gains in comprehension, reduces misconceptions, and strengthens students' capacity for critical reflection. Blending physics and philosophy can be operationalized through specific instructional strategies that enhance both conceptual understanding and reflective engagement with the nature of time.

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The Development of Android-Based Educational Games on Work and Energy Material to Train Critical Thinking Skills

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ABSTRACT

Critical thinking has emerged as an essential skill for students to master in the 21st century. The topic on work and energy is difficult for students, this is due to limitation in learning media in terms of helping students, especially those based on technology. This study aimed to investigate: 1) The features of Android-based educational games designed to enhance critical thinking skills among eighth-grade students of SMP/MTS, 2) The quality of the Android-based educational games in achieving the critical thinking skills train on work and energy topic among eighth-grade students of SMP/MTS, 3) Students' perceptions of Android-based educational game on the topic of work and energy to train the critical thinking skills among eighth-grade students of SMP/MTS, 4) Enhancement of critical thinking skills among eighth-grade SMP/MTS students. This research applied a 4D model of Research and Development (R&D) that was restricted to the development stage. The research employed instruments for experts, teachers, and students. The data analysis involved V Aiken's validation, mean calculations, and N-Gain. The results of this study included: 1) the creation of learning media in the form of an educational game named GEDUSI (Energy and Work Education Games), 2) The quality of the education game developed by researchers is included in the Very Good category, 3) Student responses agree as a practical and fun learning media, 4) This game can improve students' critical thinking skills.

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INTISARI

Berpikir kritis telah menjadi keterampilan penting yang harus dikuasai oleh siswa di abad ke-21. Materi tentang usaha dan energi sulit bagi siswa, Ini disebabkan oleh terbatasnya media pembelajaran yang dapat mendukung siswa, khususnya yang berbasis teknologi. Penelitian ini bertujuan untuk mengetahui 1) Karakteristik permainan edukasi berbasis Android pada topik usaha dan energi untuk melatih keterampilan berpikir kritis siswa kelas VIII SMP/MTS, 2) Kualitas permainan edukasi berbasis Android pada topik usaha dan energi dalam melatih keterampilan berpikir kritis kelas VIII SMP/MTS, 3) Respon siswa terhadap permainan edukasi berbasis Android pada topik usaha dan energi dalam mengembangkan keterampilan berpikir kritis siswa kelas VIII SMP/MTS, 4) Perkembangan keterampilan berpikir kritis kelas VIII SMP/MTS. Penelitian ini menggunakan model Penelitian dan Pengembangan (R&D) 4D yang terbatas pada tahap pengembangan. Instrumen penelitian yang digunakan

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terdiri atas instrumen untuk ahli, instrumen untuk guru, dan instrumen untuk siswa. Analisis data yang digunakan adalah validasi V Aiken, rata-rata, dan N-Gain. Temuan dari penelitian ini ialah 1) Pengembangan media pembelajaran berupa permainan edukasi yang disebut GEDUSI (Game Edukasi Energi dan Usaha), 2) Kualitas permainan edukasi yang diperoleh oleh peneliti termasuk dalam kategori Sangat Baik, 3) Tanggapan siswa setuju bahwa media pembelajaran ini praktis dan menyenangkan, 4) Permainan ini dapat meningkatkan keterampilan berpikir kritis siswa.

A. Introduction

Critical thinking has become one of the skills that students must possess in facing the millennium era and the 4.0 industrial revolution. This is because critical thinking skills not only help students overcome various challenges but also enable them to express innovative ideas in various contexts [1]. Critical thinking skills are highly needed in learning, especially in studying natural sciences regarding phenomena and natural interactions that occur in life, such as physics[2]. Designing learning experiences that genuinely foster critical thinking requires an understanding of how students process ideas and how those ideas connect with the conceptual structures they are expected to grasp. In physics education, this becomes particularly essential, as students are often required to interpret physical phenomena not just in terms of what happens, but through careful reasoning about how and why those events unfold by Ilma & Kuswanto [3]. However, physics is still considered difficult by students due to the numerous equations and abstract concepts. One of the physics topics that students find difficult to understand is work and energy[4].

Work and energy are among the subjects that difficult to understand because they are related to other concepts. Understanding these concepts involves observation, analysis, and data interpretation, thus requiring critical thinking skills[5]. For students, this concept is difficult because it relates to natural phenomena in a sequential, meaningful manner, and its application complicates students' understanding and ability to answer related questions [6]. The connection between daily life and the material of work and energy is very close because it explains the principles of work and energy, various types of energy, and the relationship between work and energy in daily activities..

Based on the results of observations at one of the MTS in Sleman Regency, it shows that students are still lacking in precision in calculations using the correct equations to solve work and energy phenomenon problems. This is caused by students' lack of enthusiasm in enjoying the learning process and the stages of learning that have not yet supported the improvement of students' critical thinking skills, among other things, students are only given information but are not taught to conclude and analyze information critically[7].

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Similar patterns have been described in previous studies, including one by Yuliati et al. [8] which found that science learning in many Indonesian junior high schools tends to focus more on content delivery than on guiding students to reason independently. As a result, students often follow explanations passively without being encouraged to examine relationships between concepts or explore different ways to solve a problem. These findings are also reflected in the results of the 2018 PISA assessment where Indonesian students scored an average of 383 in science, far below the OECD average of 485[8]. The biggest gaps in performance were seen in questions that asked students to understand scientific information or make sense of data. These are the kinds of tasks that can be handled better if students are used to thinking carefully and drawing conclusions during lessons.

Teacher interviews revealed that students still struggle to understand the concepts of work and energy, particularly in explaining work and energy activities in daily life, analyzing equations in work and energy problems, and providing and considering conclusions about work and energy. This causes students to become less enthusiastic, appear boring, and not challenging, causing them to have less enjoyment in the learning process[9]. Furthermore, the existing learning media used have limitations, especially in terms of helping students understand technology-based work and energy materials.

This condition shows the need for learning media that can offer more than just content delivery. It should be able to create space for students to explore ideas, reflect, and connect what they learn with everyday experience. One form of such media is the educational game designed for Android. Android-based games have become increasingly relevant to students' learning environments because they are accessible, portable, and familiar. These games provide opportunities for realtime interaction and immediate feedback, which are essential for training cognitive processes such as analysis and decision making. Moreover, the game structure through features like progression, scoring, visual representation, and problem scenarios can be designed to help students recognize patterns and test conclusions based on evidence.

Several studies in physics education have shown that educational games are effective in helping students develop the ability to think clearly and logically. Af'idah & Kustijono [10] found that the game based learning media they designed was suitable for use in class and supported students in understanding scientific ideas through structured problem solving. The media passed expert validation with strong results and its application in learning gave students the chance to practice analyzing questions and drawing conclusions. Novidya & Kustijono [11] also reported that physics games helped students approach problems with more attention to reasoning. The game guided them to trace how different ideas are connected while also giving space to try out problem solving strategies in a more interactive way. Rather than simply receiving information, students were encouraged to stay engaged and think through each challenge as they progressed through the material.

Based on the discussion above, learning media can be one of the solutions in facilitating the understanding of work and energy material. When that media includes critical thinking elements such as problem analysis and decision making tasks, it becomes a powerful support for content mastery and for deeper cognitive growth. Games can serve as a learning medium that can develop and assess students' critical thinking skills, because while playing games, students can analyze problems, identify relationships between the given questions, and use the appropriate steps when solving problems[12].

However, many existing studies still focus on either the design of the games or their general effects on student learning. Few explore how the internal structure of a game can be directly aligned with specific critical thinking indicators in physics. Therefore, it is necessary to develop more innovative and interactive media. Learning media that incorporates elements of critical thinking such as educational games have become an important learning media in enhancing students' ability of critical thinking skills and facilitating their comprehension of the material.

Based on these considerations, this research was conducted with the title "Development of Android-Based Educational Games on Work and Energy Material to Train Critical Thinking Skills of Eighth Grade Junior High School/Islamic Junior High School Students." The novelty of this research lies in how the content of the game is not only focused on delivering material but is designed to reflect indicators of critical thinking such as identifying problems, evaluating relationships, and drawing conclusions within the topic of work and energy.

B. Method

This research applied a development research approach, also referred to as Research and Development (R&D) 4D model was created by Thiagarajan in 1974. The 4D model includes four stages which are define, design, development, and disseminate[9]. In this study, the product development stage is limited to the development phase, specifically product testing.

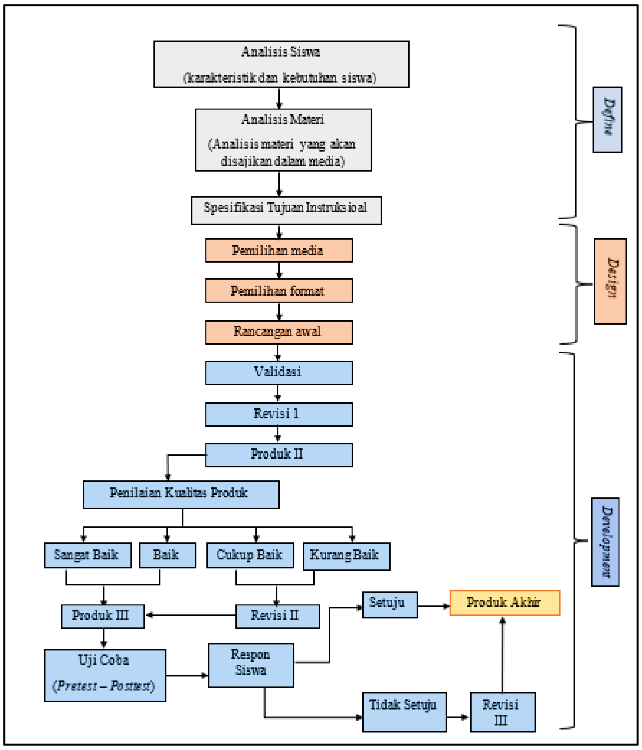

Figure 1. Stages of the Media Development Procedure

The researchers utilized both test and non-test instruments, including validation forms, product evaluation forms, assessment forms, and student feedback sheets. Qualitative data in this study consist of feedback and recommendations from validation and assessment outcomes, including those from experts in the subject matter, media, and science teachers). Quantitative data includes the assessment results from experts and teachers, student responses, and pretest-posttest results[13].

The data analysis conducted includes both qualitative and quantitative methods. Descriptive qualitative data analysis is a description of the results of expert input and suggestions. Quantitative data analysis determines the quality of the developed product by processing data based on expert evaluations, teacher assessments, and student responses[14]. Additionally, there is also a pretest-posttest to observe the improvement in students' critical thinking skills.

Product feasibility is evaluated using a Likert scale ranging from one to four. The final score is obtained from the average result of each evaluated aspect, using the following equation[15].

$$\bar{X} = \frac{\sum x}{N.n} \tag{1}$$

$\bar{X}$: Average score

$\sum x$: Total score obtained

N : Number of evaluators

n : Number of questions

Table 1. Media Assessment Criteria Categories

Avarage Score ($\bar{X}$)	Category
$3.25 < \bar{X} \leq 4.00$	Very Good (VG)
$2.50 < \bar{X} \leq 3.25$	Good (G)
$1.75 < \bar{X} \leq 2.50$	Not Good (NG)
$1.00 < \bar{X} \leq 1.75$	Very Not Good (VNG)

Analysis of student responses uses data analysis techniques to convert quantitative data into qualitative data. Data obtained from the questionnaire with a Guttman scale of 0-1 was then converted into an average score.

Table 2. Criteria for Student Response Categories

Avarage Score	Category
$0.5 < \bar{X} \leq 1.0$	Agree (A)
$0.0 < \bar{X} \leq 0.5$	Disagree (D)

The pretest and posttest results were then computed using the N-Gain standard. The calculation can be performed using the N-Gain test equation.

$$(g) = \frac{(S_f)-(S_i)}{(S_m)-(S_i)} \quad (2)$$

With (g) is the gain score, (S_m) is the highest score, (S_i) is the pretest score, and (S_f) is the posttest score. The results of the calculation were interpreted using the N-Gain criteria in Table 3 [16].

Table 3. N-Gain Criteria

Avarage Score	Category
$(g) \geq 0.7$	High
$0.3 \leq (g) < 0.7$	Medium
$(g) < 0.3$	Low

C. Result and Discussion

Product Development

This research produces a product in the form of an Android-based educational game that assists students in practicing critical thinking skills related to work and energy materials. The educational game was developed using Smart Apps Creator which is a visual programming platform designed specifically for building Android applications in a more accessible way. This platform was chosen because it allows developers to arrange logical functions and visual components through a block-based system, so that the structure of the game can be built without requiring text-based coding. In addition to its simplicity, the platform also provides features for integrating images, animations, and sound which makes it easier to present learning content in ways that are more engaging and easier to understand. These characteristics support the development of learning media that not only deliver content, but also encourage students to interact with the material more actively.

The 4D development model includes four stages which are define, design, development, and disseminate, also is limited to the improvement stage based on the basic formulation of this research, which only examines the trial results[9]. The definition stage is the first phase of the research, focusing on conducting a needs analysis. The researcher conducted three stages of needs analysis, namely student analysis, material analysis, and goal analysis resulting from observations and interviews.

The second stage is the design stage, aimed at determining the product concept to be developed according to the students' needs after conducting observations and interviews. In this stage, there are 4 types of activities carried out, such as product selection, game concept design, material and evaluation tool design, and game design. The selection of the product is the result of an analysis of student needs and material characteristics, thereby creating a practical and efficient medium. The conceptual design for the creation of this educational game begins with mapping the content that will become the characteristic in the presentation of the educational game. The content consists of work and energy materials presented in the form of animated videos. In addition, there are evaluation questions formulated from four of Ennis's critical thinking indicators, which can measure the level of students' critical thinking abilities [17]. Next, for the product design stage, the researcher designed an interesting and enjoyable game using several software, resulting in an Android application with several components. The components of this game application include the home page, main menu, game rules, information, materials, play, game levels, and total score. The third stage is the development stage, which inludes two phases: expert evaluation and product testing. The development stage intends to assess the feasibility and response of the product that has been developed.

Validation and Product Assessment

Product validation is performed by material and media experts who provide assessments based on the Valid Without Revision (VWR), Valid With Revision (VR), and Invalid (I), as well as giving feedback on the product. The following presents the results of the product validation conducted by content and media experts.

Table 4. Material and Media Expert Validation Results

Validator	Aspect	Criteria
Material Expert	Contents	Valid With Revision
	Language	Valid With Revision
	Display	Valid With Revision
Media Expert	Usage	Valid With Revision
	Instructional	Valid With Revision
	Critical Thinking	Valid With Revision

Referring to the product validation table carried out by two validators, it indicates that the designed product meets the criteria of Valid With Revision (VR), indicating that the product can be used after undergoing a revision stage based on input or suggestions from the validators.

Product assessment involves evaluation by product experts (material and media) and science teachers, using a Likert scale with assessment categories: Very Good (VG), Good (G), Fair (F), and Poor (P). Here are the results of the assessment by subject matter experts, media experts, and teacher evaluations.

Table 6. Material Expert, Media Expert, and Teacher Assessment

Validator/Respondent	Aspect	Average Score	Criteria
Material Expert	Content of the material	3.75	Very Good
	Language	3.00	Good
Media Expert	Display	3.75	Very Good
	Usage	3.67	Very Good
	Instructional	4.00	Very Good
	Critical Thinking	4.00	Very Good
Teacher	Content of the material	4.00	Very Good
	Language	4.00	Very Good
	Display	4.00	Very Good
	Usage	3.67	Very Good
	Instructional	4.00	Very Good
	Critical Thinking	4.00	Very Good

The average score data from the validation results provide a clearer picture of how the product is perceived in terms of its quality and relevance to learning. According to the material expert, the content component was considered strong although the language still needs improvement in terms of clarity and coherence. Meanwhile, the media expert noted that the product was well-designed in its structure, especially in parts that aim to stimulate critical thinking. These two aspects namely instructional design and cognitive depth were rated very highly which indicates that the game successfully aligns its features with meaningful learning goals.

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The teacher's responses has the similar opinions. From content and appearance to functionality and support for thinking skills, every aspect received positive evaluations. These findings indicates that the educational game offers not only a visually appealing platform but also an experience that helps students practice thinking carefully and making sense of what they learn. Although some improvements may still be required in the wording and user instructions, the overall product has shown promise as a tool for both delivering content and encouraging students to think more critically as they interact with each task.

Product Testing

The product trial in this research consists of two steps: a limited trial and an extensive trial. Here are the results of the limited and extensive trials in the form of a comparison of pretest-posttest critical thinking abilities for each aspect, N-Gain results, and response tests from 30 students.

Table 7. Student Response Results in the Limited Trial of the Educational Game

Aspect	Average Score	Criteria
Content of the material	1.00	Agree
Language	1.00	Agree
Display	0.83	Agree
Usage	0.83	Agree
Instructional	1.00	Agree
Critical Thinking	1.00	Agree

Based on the results of the limited trial, students responded positively to the educational game in almost every aspect. The component related to content was rated with the highest average score and similar responses were given for language, instructional clarity, and the extent to which the game supported critical thinking. Each of these areas reached an average score of 1.00 which reflects a high level of alignment between the media and what students found useful in their learning experience. On the other hand, the display and usability aspects received slightly lower scores with each of them has the average number of 0.83. Even though these aspects were still considered effective, the scores indicate that the visual layout and technical handling may not have been as impactful as the other components in the students' perception.

Table 8. Student Response Results in the Extensive Trial of the Educational Game

Aspect	Average Score	Criteria
Content of the material	0.90	Agree
Language	0.90	Agree
Display	0.83	Agree
Usage	0.83	Agree
Instructional	0.90	Agree
Critical Thinking	0.85	Agree

The extensive trial was conducted after making several improvements to the media based on earlier feedback. In this broader test, the students continued to give high scores in most categories. The content, the clarity of language used, and the structure of instruction were each rated at an average of 0.90. These results indicate that the revisions had preserved the key qualities students valued in the limited trial. The visual design and ease of use still held steady at 0.83 which shows consistency in how students navigated and interacted with the game, although these features may have remained less noticeable. For the critical thinking aspect, the score reached 0.85 which reflects that the game provided opportunities for students to engage with challenges that required thoughtful analysis and reflection during the learning process.

The students' response to the developed product showed a positive response with an average score of 0.94 for the limited trial and an average of 0.93 for the extensive trial. In addition to aiming to determine student responses, this product is also tested to determine the extent of students' critical thinking skills before and after using the media. The table above shows the comparison of the average pretest and posttest scores for each aspect of critical thinking, along with the N-gain test results.

Table 9. Comparison of Average Pretest and Posttest Critical Thinking Skills of Students by Aspect

Aspect	Pretest	Posttest	N-Gain	Improvement
Focusing the question	75.2	86.6	0.46	11.4
Asking and answering a question about an explanation	37.2	80.0	0.68	42.8
Analyzing the question	48.0	94.6	0.90	46.6
Considering the relevance of the source	5.2	29.4	0.26	24.2

Table 10. N-Gain Test Results

Number of Students	Average Pretest	Average Posttest	Average N-Gain	Category
30	60.8	82.6	0.56	Medium

According to the results of the pretest and posttest, the comparison of each aspect of students' critical thinking skills is known. It is known that the greatest improvement in the average pretest and posttest scores is found in the aspect of analyzing questions, with an average score of 2.33. On the other hand, the smallest increase in the average pretest and posttest scores was observed in the aspect of focusing on the problem, with an average of 0.57. In addition, the enhancement of students' critical thinking skills can also be achieved through N-Gain analysis. The average pretest and posttest scores obtained a gain value of 0.56, categorized as moderate. Therefore, it can be concluded that there was an enhancement in students' critical thinking skills after using the educational game.

D. Conclusion

This research resulted in a learning media with the characteristic that this application can train critical thinking skills through an interactive and enjoyable approach, as well as presenting effort and energy material accompanied by evaluation questions with four critical thinking indicators. This game proved to have Very Good quality based on the assessment of material experts, media experts, and teachers. This game also received positive feedback from students, with a high level of agreement in both the limited and extensive trials. Moreover, this application proves to be successful in improving students' critical thinking abilities, making this game a worthy and beneficial learning medium for training students' critical thinking abilities.

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Development of a Physics Assessment Instrument to Measure High School Students Multirepresentation Skills in Momentum and Impulse

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ABSTRACT

This research is a Research and Development. Developed a multirepresentation test instrument to measure the multirepresentation skills of class XI students specializing in physics at SMA Negeri 1 Semarang on momentum and impulse. This was done because the multirepresentation skills of SMA Negeri 1 Semarang students had not been measured as a whole and maximally. The multirepresentation test instrument has been tested for suitability by experts and small-scale trials have been carried out on students. Based on the results of validity, reliability, level of difficulty and differentiability tests, 25 questions were obtained that were suitable for use in the field. The overall average percentage results of multirepresentation skills for class XI students specializing in physics at SMA Negeri 1 Semarang is in the good category with a percentage of 76.89%. Based on these results, the multirepresentation test instrument is suitable for use to measure students' multirepresentation skills as evidenced by students' multirepresentation skills being measured well to the instrument developed.

INTISARI

Penelitian ini merupakan penelitian pengembangan. Mengembangkan instrumen tes multirepresentasi untuk mengukur keterampilan multirepresentasi siswa kelas XI peminatan fisika SMA Negeri 1 Semarang pada materi momentum dan impuls. Hal ini dilakukan karena keterampilan multirepresentasi siswa SMA Negeri 1 Semarang belum terukur secara menyeluruh dan maksimal. Instrumen tes multirepresentasi telah dilakukan uji kelayakan oleh para ahli dan telah dilakukan uji coba skala kecil kepada siswa. Berdasarkan hasil uji validitas, reliabilitas, tingkat kesukaran dan daya beda diperoleh 25 soal yang layak digunakan di lapangan. Rata-rata keseluruhan hasil presentase keterampilan multirepresentasi siswa kelas XI peminatan fisika SMA Negeri 1 Semarang berada pada kategori baik dengan presentase sebesar 76,89%. Berdasarkan hasil tersebut maka instrumen tes multirepresentasi layak digunakan untuk mengukur keterampilan multirepresentasi siswa yang dibuktikan dengan keterampilan multirepresentasi siswa yang terukur dengan baik terhadap instrumen yang dikembangkan.

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A. Introduction

One of the orientations of the independent curriculum includes an approach to education that aims to provide students with independence in learning, so that students can develop their potential optimally [1]. According to Marta & Vallindra [2], evaluation in the independent curriculum does not separate the three assessment domains, namely behavior or attitudes, skills, and knowledge and has an emphasis on behavior on the Panacasila student profile. The independent curriculum has types of assessments, namely diagnostic assessments, formative assessments, and summative assessments. The output of these types of assessments is one of the guidelines in deciding a student's achievement. Based on the assessment technique, the assessment instruments in the independent curriculum include written tests, oral tests, observations, projects, performance, portfolios, and assignments.

Permendikbud No. 21 of 2022 concerning Education Assessment Standards states that learning outcomes cover three domains, namely by educators, educational units, and the government. The purpose of the assessment is to evaluate all learning processes [3]. According to Susilaningsih [4], cognitive assessment is one of the things that needs to be considered regarding its quality. Instruments in assessment as a means or tool used to collect data and information [5]. The type of assessment carried out is by giving tests to students [6].

Sulistyowati [7] said that skills are the ability to operate a job quickly and easily. The scope of skills is very broad, such as action skills, thinking skills, speaking skills, seeing and hearing skills, and so on Nasihudin & Hariyadin [8]. One of the existing skills is multi-representation skills. Multi-representation skills are very important to support student learning outcomes because they can be used as a benchmark for students in representing a physics problem.

One of the inseparable parts of science is representation [9]. The multi-representation approach is an approach that primarily emphasizes a meaning in the form of verbal representations, images, equations, diagrams, tables, and graphs, so that it can help improve the evaluation process in the physics learning process [10].

Although in physics learning multi-representation ability is very important, but in the application in the field, learning carried out in the classroom still does not orient multi-representation skills in students [11]. This is found in a study conducted by Furqon & Muslim [12] which stated that the representation ability of students is still very low. According to Amaliah & Purwaningsih [13] The low representation ability occurs because the understanding of concepts in physics is also low.

The improvement of students' representational abilities in learning activities has been carried out with various efforts. According to Sirait [14] The final results of the correct multi-representation assessment in learning can improve students' representational abilities. Based on this, the development of physics assessment instruments to measure students' multi-representation skills is an important part to be developed so that students can interpret problems in physics [15]. Therefore, it is necessary to develop an evaluation tool in the form of physics test questions that are useful for measuring students' multi-representation abilities in solving physics problems.

The development of physics assessment instruments to measure multi-representation abilities has been carried out by several researchers. However, many of the instruments developed only measure several multi-representation abilities, such as the research conducted by Ceuppens [16] which only developed multi-representation instruments in three forms of representation, namely graphs, tables, and equations.

Based on these facts, instruments that can measure more multi-representation abilities need to be developed. The instrument development that will be carried out is in the form of multiple-choice test questions. The representations that will be developed are in the form of verbal representations, images, equations, diagrams, tables, and graphs, so that students can represent and emphasize broader meanings.

Research conducted by Pradana [17] on multi-representation test instruments showed a positive response as seen from the results of the scores obtained by students. Based on this, in evaluating the development of instruments to measure multi-representation skills, it is necessary to continue to develop them in physics materials. One of them is in the material on momentum and impulse. This material is very closely related to everyday life, so the basic concepts in this material need to be studied and understood in studying physics. According to Ngurahrai, Farmaryanti & Nurhidayati [18] momentum and impulse are one of the materials in physics that are quite complex. Based on this, the multi-representation assessment instrument is suitable to be developed in the material on momentum and impulse with cognitive levels ranging from C1 to C6. Therefore, students' multi-representation abilities in solving physics problems need to be developed more widely, one of which is to study and understand this material.

Based on the results of interviews with physics teachers at SMA Negeri 1 Semarang, it was found that the use of assessment instruments in the form of representation questions only measures several multi-representation abilities, such as those often used, namely graphic representation, tables, and equations. This is less than optimal because the ability of other representation skills has not been measured optimally. Another thing is that the use of cellphones when conducting assessments is also a cause of students being less skilled in interpreting physics problems. Another cause of the lack of student multi-representation is that the physics assessment instruments used so far do not pay enough attention to multi-representation skills.

Based on the interviews that have been conducted, teachers need a representation assessment instrument to measure students' multi-representation skills, with the materials used being momentum and impulse. Based on the background that has been described. The development research that will be conducted is the development of a physics assessment instrument to measure the multi-representation skills of high school students on momentum and impulse materials.

B. Method

Research Design

This research is a development research (R&D). This research is usually called a bridge between (basic research) basic research and (applied research) applied research [19]. According to Sugiyono [20], Research and Development (R&D) is a method in research, with output to produce a product which will then be tested for the effectiveness of a particular product. The research to be conducted is to develop a physics assessment instrument. The development of this instrument uses a 4-D model research design. This model consists of four stages of development, namely, define, design, develop, and disseminate [21]. This study only uses three stages of the 4-D design, namely up to the develop stage. This is because at this stage it has been possible to obtain validity, reliability, differentiating power, and level of difficulty so that the instrument developed can be used to measure students' multi-representation skills. Briefly, the stages used in developing this research can be seen in the Figure 1 below.

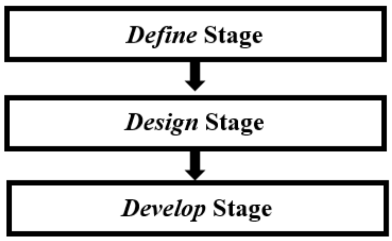

Figure 1. Research Development Steps

Content Validity Test

Content validity testing can be done using an instrument grid or matrix in instrument development [19]. An instrument is said to be valid if the instrument can measure what will be measured. Later, it will be validated by three validators as experts in the material field who conduct a review of the questions, including aspects of material feasibility, question construction, and the language used.

Reliability Test

Reliability testing in this study uses internal consistency testing. Testing is done by trying out the developed instrument once. Then analyzed with a certain technique whose analysis results are used to determine the reliability of the instrument. The technique used is the Kuder Richardson technique which is often abbreviated as KR-20 [20].

$$r = \left(\frac{k}{(k-1)}\right)\left(1 - \frac{\sum p(1-p)}{St^2}\right) \quad (1)$$

$$st^2 = \frac{x^2}{n} \quad (2)$$

With reliability criteria in Table 1

Table 1. Reliability Criteria

Reliability Index	Reliability Criteria
$0,0 \leq r \leq 0,2$	Very low
$0,2 < r \leq 0,4$	Low
$0,4 < r \leq 0,6$	Medium
$0,6 < r \leq 0,8$	High
$0,8 < r \leq 1,00$	Very high

Differentiating Power

Differentiating power is the ability of a question to distinguish between students who have and have not mastered the material [22].

$$DP = \frac{BA - BB}{\frac{1}{2}N} \quad (3)$$

With differentiating power criteria in Table 2

Table 2. Classification of Differentiating Power of Questions

Interval of differentiating	Power Level of Questions
$0,40 < DP \leq 1,00$	Very good
$0,30 < DP \leq 0,40$	Good
$0,20 < DP \leq 0,30$	Enough
$0,00 \leq DP \leq 0,20$	Bad

Difficulty Level

The level of difficulty is the opportunity for students to answer a question correctly [22]. A good question is a question that is not too easy and not too difficult [23].

$$TK = \frac{B}{Js} \quad (4)$$

With difficulty level criteria in Table 3

Table 3. Classification of the Level of Difficulty of Test Items

Difficulty Level	Category
$0,00 < TK \leq 0,30$	Difficult
$0,30 < TK \leq 0,70$	Medium
$0,70 \leq TK \leq 1,00$	Easy

Analysis of Students' Multirepresentational Skills

Analysis of multirepresentational skills is done by using the scores obtained from students' test results. The data from the test results are then analyzed to determine the category of students' multirepresentation skill levels.

$$\text{Score} = \frac{\text{Total Score of Students}}{\text{Total Score}} \times 100\% \quad (5)$$

With multirepresentation skills level in Table 4.

Table 4. Multirepresentation Skill Level Category

Student Score	Multirepresentation Skill Level
$80 < \text{Score} \leq 100$	Very Good
$60 < \text{Score} \leq 80$	Good
$40 < \text{Score} \leq 60$	Enough
$20 < \text{Score} \leq 40$	Bad
$0 \leq \text{Score} \leq 20$	Very Bad

C. Result and Discussion

The initial product of the instrument development is a test question consisting of 40 questions, in the form of multiple-choice reasoning with each question and reason having five answer choices. The test questions are made based on matrices of various types of multirepresentation. The test instrument development product has several components as follows Multirepresentation Test Instrument Matrix, Multirepresentation Test Instrument Grid, Multirepresentation Test Questions, Answer Key, Multirepresentation Instrument Scoring Guidelines, and Validation of Multirepresentation Test Instrument.

Product Trial Results

Product trials were conducted with small-scale tests conducted at SMA Negeri 1 Semarang. This small-scale test involved 33 students of grade XI-9 majoring in physics. Students worked on 40 questions with a duration of 3 JP. The results of this product trial were used to determine the reliability of the questions, level of difficulty, and differentiating power on the multirepresentation instrument.

Question Reliability Test

The consistency of questions on the instrument can be determined by using the instrument reliability test. The analysis of the reliability test of the multirepresentation test instrument uses the KR-20 equation. The results of the analysis of the instrument reliability test obtained a value of r_11 = 0.78 which is in the high category and can be seen in Appendix 30.

Question Difficulty Level Test

The grouping of questions into difficult, medium, and easy categories can be determined by testing the question difficulty level. A question can be said to be good if the question is not too difficult and not too easy [24]. This is because questions that are too easy make students tend not to think and questions that are too difficult make students give up easily and have difficulty in working on the question I Table 5.

Table 5. Analysis of Question Difficulty Level Test Results

Category	Question Number	Number of Questions
Difficult	10, 11, 12, 14, 16, 17, 19, 20, 21, 22, 24, 26, 27, 28, 29, 30, 31, 32, 33, 35, 36, 37, 39, 40	24
Medium	1, 2, 3, 4, 5, 6, 7, 8, 9, 13, 15, 18, 23, 25, 34, 38	16
Easy	-	0

Table 5 shows the percentage of question difficulty levels consisting of 40% of questions in the medium category and 60% of questions in the difficult category.

Test of Question Differentiating Power

The ability of question items to differentiate between students with high and low abilities is obtained by conducting a test of question differentiating power [24]. This multirepresentation test instrument has question differentiating power with good, sufficient, and poor criteria. Questions that have poor differentiating power must be discarded and cannot be used in large-scale tests, while questions that have good and sufficient differentiating power can be used in large-scale tests and are not discarded. Questions with a poor category cannot be used to differentiate between students with high abilities and students with low abilities Table 6.

Table 6. Analysis of the Results of the Test of Differential Power of Questions

Category	Question Number	Number of Questions
Bad	9, 10, 11, 18, 19, 21, 24, 28, 29, 30, 31, 33, 35, 38, 39	15
Enough	1, 3, 4, 7, 8, 12, 13, 16, 17, 20, 22, 23, 25, 26, 27, 32, 34, 37, 40	19
Good	2, 5, 6, 14, 15, 36	6
Very Good	-	-

Product Revision

After conducting a small-scale trial, the multirepresentation test instrument was revised first before being used in a large-scale test. The revision was based on the results of the small-scale test which included validity, reliability, level of difficulty, and question differentiating. Based on the results of the small-scale test, it was found that out of 40 questions, 15 were not feasible, meaning they had to be discarded, and 25 were feasible. A total of 20 questions were used in the large-scale test. This was because out of 25 questions that were declared feasible, 20 of them had met the various representations used.

Final Product Review

The implementation of the large-scale test at SMA Negeri 1 Semarang involved 66 students in grade XI consisting of 33 students in grade XI-8 and 33 students in grade XI-11. The instrument used in the large-scale test was the instrument of the results of the analysis that had been carried out in the small-scale test. Students worked on 20 questions in the large-scale test. The results of the analysis showed that students' multirepresentation skills in all representations had an average value of 76.89%, which is in the good category in Table 7.

Table 7 Summary of Multirepresentation Skills Results

Category	Frequency (Students)	Percentage (%)
Very Good	30	45,45
Good	31	46,97
Enough	4	6,06
Bad	1	1,52
Very Bad	-	-

The product developed is a multiple-choice test with reasoning to measure certain types of representation and translation of representation. The material tested is momentum and impulse material that refers to the independent curriculum. The instrument developed uses various types of representations ranging from verbal representations, images, graphs, mathematical equations, tables, and diagrams. The instrument is also developed based on cases in everyday life.

The results of students' answers in the large-scale test were analyzed to determine students' multirepresentation skills. Analysis of students' multirepresentation skills was carried out on each type of representation and translation of representation. The analysis aims to determine the extent of students' representations based on the representation matrix that has been developed Table 8.

Table 8. Analysis of Students' Multirepresentation Ability

Type of Representation	Percentage of Score for Each Representation (%)	Skill Category
Verbal	72,7	Good
Picture	80,3	Very Good
Mathematical Equation	73,3	Good
Table	82,55	Very Good
Graph	85,6	Very Good
Diagram	72,7	Good
Graph to Mathematical Equation	81,8	Very Good
Picture to Mathematical Equation	74,2	Good
Verbal to Mathematical Equation	59,1	Enough
Picture to Verbal	83,3	Very Good
Table to Graph	87,9	Very Good
Table to Mathematical Equation	71,2	Good

Based on the analysis that has been done, the students' multirepresentation skills for each type of representation have an average value of 50.75% on the momentum and impulse material. The final result of the instrument development in this study is a test instrument to measure the multirepresentation skills of students of SMA Negeri 1 Semarang class XI majoring in physics on the momentum and impulse material. The instrument developed is in the form of multiple-choice reasoned questions. A similar instrument was developed by [25] who developed an objective multiple-choice reasoned test assessment instrument to measure mastery of linear motion teaching materials and science process skills.

The feasibility of multirepresentation test instruments can be seen through the results of validity, reliability, level of difficulty, and differentiating power. Content validity shows that out of 40 questions, they are declared valid overall. These results were obtained because each question item validated by an expert was in accordance with the assessment aspects on the validation sheet indicators. Reliability, differentiating power, and level of difficulty were obtained from small-scale trials. The differentiating power of the 40 questions was obtained, 15 questions had poor differentiating power, 19 questions were sufficient, and 6 questions were good. These results were obtained because the test questions were made with cognitive levels ranging from C1 to C6, so that the final result was 25 questions that were feasible and could be used. The reliability of the multirepresentation test instrument obtained a value of r11 = 0.78 which is in the high category so that the test items can be said to be reliable. These results were obtained from the Kuder Richardson equation (KR-20). This is in accordance with Maulana [26], he stated that an assessment instrument cannot be used directly, its validity must be tested so that the instrument is said to be feasible and can be used in the field. Based on the results obtained, it can be concluded that the multirepresentation test instrument is feasible to be used to measure the multirepresentation skills of class XI physics students at SMA Negeri 1 Semarang.

Multirepresentation skills analysis based on student scores obtained an average percentage of all representations of 76.89% in the good category. These results were obtained because of the multirepresentation approach which mainly emphasizes various representations ranging from verbal, images, mathematical equations, diagrams, tables, and graphs so that they can help during the evaluation process in learning [10]. Based on this percentage, it was obtained that 30 students had multirepresentation skills in the very good category, 31 students were good, 4 students were sufficient, and 1 student was in the poor category.

These results were obtained because students' understanding of the momentum and impulse material was quite good through the review carried out before working on the test questions, so that good test results were obtained, even so there were still students with poor multirepresentation skills. This happens because the factors of comprehension and learning motivation of each student are different, so that the review of the material carried out before working on the questions cannot be understood properly. This is because the review of the material is done briefly with a short time before the test starts.

Based on the results obtained, multirepresentation skills in each type of representation and translation of representations obtained good results except for the translation of verbal representations into mathematical equations which received a percentage in the sufficient category. This happened because students still had difficulty expressing and analyzing the meaning of words in the questions to the meaning of mathematical equations in the answer options. Another factor that influences the results of multirepresentation skills in each type of representation is the use of illustrations of images, graphs, diagrams, and sentences in the questions that are appropriate, clear, and easy to understand so that students' multirepresentation skills get good results and can be measured widely. Ceuppens et al. [16] developed a multirepresentation test instrument in physics assessments that only represented graphic representations, tables, and mathematical equations so that in the study the students' multirepresentation skills were measured less widely. Based on this, it can be concluded that the final results of a broader multirepresentation assessment can produce better multirepresentation skills with appropriate representation assessments in learning, so that it can improve students' multirepresentation skills.

D. Conclusion

Based on the results of the analysis and discussion that have been obtained, it can be concluded. The instrument is declared feasible to measure the multirepresentation skills of students of SMA Negeri 1 Semarang class XI majoring in physics. This is proven by the question instrument which is declared valid by three validators who have cognitive levels C1, C2, C3, C4, C5, and C6. The multirepresentation test instrument that has been developed is declared reliable with a value of r11 = 0.78, which is in the high category. The instrument has been tested with a small-scale test and the level of difficulty of the questions consists of 40% of questions in the medium category, 60% of questions in the difficult category. Based on the results of the differentiating power of the questions obtained from 40 questions, 25 questions were declared feasible. The multirepresentation skills of students of SMA Negeri 1 Semarang class XI majoring in physics were measured using the multirepresentation test instrument, the overall results were in the very good category with a percentage of 44.45%, good 46.97%, sufficient 6.06%, and lacking 1.52%. This means that students' multirepresentation abilities are classified as good, seen from the level of difficulty of the questions and students' abilities in working on the questions. The overall average of students' multirepresentation skills is in the good category with a percentage of 76.89%.

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The Influence of the Guided Inquiry Learning Model on the Material of Work and Energy on Science Process Skills at MTsS Balimbing

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ABSTRACT

The purpose of this study was to see the effect of guided inquiry learning model on students' science process skills on work and energy. The type of research is Quasi Experimental research and the research design used is Posttest Only Control Group Design. The sample consists of 2 classes, the experimental class is class VIII 1 and the control class is class VIII 2 consisting of 37 students. The sampling technique used is simple random sampling. The instrument used in the study was a final test of 20 questions. The results of the science process skills data analysis showed an average score of science process skills test of 70.43%, while students in the control class obtained an average score of science process skills test of 60.53%. The results of the data test were analyzed using the t-test formula, which showed that t (count) > t (table) was 2.98 > 2.02. This shows that the use of guided inquiry learning model on work and energy material has an effect on the science process skills of class VIII students at MTsS Balimbing.

ABSTRAK

Tujuan penelitian ini adalah untuk melihat pengaruh model pembelajaran inkuiri terbimbing terhadap keterampilan proses sains siswa pada materi usaha dan energi. Jenis penelitian yang digunakan adalah penelitian Quasi Eksperimental dan desain penelitian yang digunakan adalah Posttest Only Control Group Design. Sampel terdiri dari 2 kelas, kelas eksperimen adalah kelas VIII 1 dan kelas kontrol adalah kelas VIII 2 yang terdiri dari 37 siswa. Teknik pengambilan sampel yang digunakan adalah simple random sampling. Instrumen yang digunakan dalam penelitian adalah tes akhir sebanyak 20 soal. Hasil analisis data keterampilan proses sains menunjukkan skor rata-rata tes keterampilan proses sains sebesar 70,43%, sedangkan siswa pada kelas kontrol memperoleh skor rata-rata tes keterampilan proses sains sebesar 60,53%. Hasil uji data dianalisis dengan menggunakan rumus uji-t, yang menunjukkan bahwa t (hitung) > t

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(tabel) yaitu 2,98 > 2,02. Hal ini menunjukkan bahwa penggunaan model pembelajaran inkuiri terbimbing pada materi usaha dan energi berpengaruh terhadap keterampilan proses sains siswa kelas VIII di MTsS Balimbing.

A. Introduction

Physics is a branch of natural science. Physics is a science that investigates natural phenomena in life. Investigation of natural phenomena is obtained through research. According to Trianto, physics is a science that studies how nature functions through various scientific processes whose results consist of concepts, principles, and general theories[1]. Several concepts are needed in learning physics to obtain good learning, namely physics as a product, process, and attitude. This physics product is a discovery result consisting of rules, laws, facts, and principles of physics, and is obtained through a process known as the scientific process. Observing, classifying, measuring, asking questions, formulating hypotheses, planning investigations, and interpreting information are some of the science process skills that can be learned in physics. These concepts are used to build science process abilities[2].

Science process skills are scientific skills used to discover a concept, principle, or theory, and to develop existing concepts[3]. According to Amalia et.al [4], science process skills are crucial for students because they encourage them to participate more actively in learning and develop a sense of responsibility for what they learn. These skills can also help them think and behave like scientists. Abungu, et.al [5] also explain that students need science process skills to solve scientific problems related to real-life events and the learning process.

Science process skills must be learned through hands-on experience with various materials and physical actions. According to Jack [6], developing science process skills helps students understand material more easily and retain it for the long term. Thus, students are expected to be able to solve various problems in everyday life, especially in global competition. Kadarwati & Ibadullah [7] stated that acquiring science process skills can help improve the attitudes and intellectual skills needed to better understand concepts.

From the three aspects above, physics learning can be achieved through teacher creativity in learning by using models that match the characteristics of the material being presented. A learning model is a framework of ideas that explains a systematic way to create learning experiences to achieve specific learning objectives. This framework also serves as a guideline for learning designers and teachers in planning and implementing learning activities [8]. According to Ongowo & Indoshi [9], a learning model is a design used as a guide in planning learning in the classroom or learning in tutorials. One learning model that can improve science process skills is the guided inquiry learning model.

Ongowo & Indoshi [9] stated that the inquiry learning model is a discovery-based learning approach that can be used to improve science process skills. The inquiry model is a student-focused teaching model that encourages students to investigate problems and find information. By asking questions and finding answers based on their own curiosity, the inquiry model can help students improve critical thinking skills and intellectual discipline. According to Purba et al. [10], the inquiry learning model is a learning model that fosters higher-order thinking. The inquiry learning model is a learning model that provides opportunities for students to think critically and analyze a number of facts or precise definitions of problems through their own discovery process.

To create creative, active students who can think logically and are skilled at conducting experiments, teacher guidance is needed. Through guidance and direction, students can understand what needs to be done. Over time, students are able to find out for themselves about the problems they face. As a result, the guided inquiry model is suitable for encouraging students to investigate problems with teacher assistance and find information on their own, so they can find learning ideas.

However, the reality that occurs in learning is that students usually only receive material from the teacher, resulting in a lack of student activity in responding to learning. Students only become listeners while the teacher is still the main actor in learning. This situation is in accordance with observations and the distribution of questionnaires that have been carried out at an MTsS in Balimbing to students and science teachers of grade VIII. The information obtained shows that teachers have used the inquiry learning model during the learning process, but students have not been able to actively participate in the learning process to discover the concepts and principles of the material being studied by themselves with teacher guidance.

According to a questionnaire distributed to students, 75% of students stated that the learning materials used did not enable them to learn independently. Furthermore, students' ability in science process skills was categorized as very low, at 12.5%. The indicators for science process skills include observing, classifying, interpreting, predicting, asking questions, forming hypotheses, planning experiments, using tools and materials, applying concepts, and communicating.

From the results of the observations and research above, it is clear that students' initial understanding of the basic concepts of science that have actually been taught is weak, so they are unable to reason well, and students' understanding is weak in applying the concepts. The lack of activity and creativity of students during learning results in students not being able to conduct experiments and observations.

Based on these facts, a study was conducted with the title The Influence of the Guided Inquiry Model on Work and Energy Material on Science Process Skills at MTsS Balimbing.

B. Research Methods

This study will use a quasi-experimental or quasi-experimental research type and use quantitative methods. The quasi-experimental design method is a method used to examine the effects of specific actions under controlled conditions [11]. By using a posttest-only control group design involving two classes, namely the experimental class and the control class. The experimental class is the class that applies learning with the application of the guided inquiry model, while the control class is the class that applies conventional learning. In both classes, a posttest will be conducted after students are given treatment to see the effect of the guided inquiry model on students' science process skills after learning.

The research presented is a final test of students' science process skills that looks at the application of the guided inquiry learning model in science learning. Researchers took samples before conducting the research by means of simple random sampling. The simple random sampling technique is a sample member is randomly selected from the population without looking at the population strata [12]. Where researchers collected students' daily test scores and conducted a normality test, after the normality test and obtained the results that both classes were normally distributed. Then the next stage was a homogeneity test, a homogeneity test was used to see whether the class was homogeneous or not. After the homogeneity test and both classes were homogeneous, then lotting was carried out to select the control class and the experimental class. In this study, it was found that the experimental class was in class VIII 1 and the control class was in class VIII 2.

The instruments used in this study were teaching modules and final test questions. The teaching modules consisted of an experimental class module and a control class module, differing in the learning model used. The final test questions focused on science process skills indicators, namely observing, classifying, predicting, interpreting, and applying concepts. The instruments were validated by two physics lecturers and two science teachers before use.

The test questions are in the form of objective questions (multiple choices) consisting of five indicators of students' science process skills, namely: observing, classifying, interpreting, predicting, and applying concepts. Before being distributed, the test questions were empirically tested to measure the level of discrimination, the level of difficulty, and the reliability of the questions. The results of the trial stated that the discrimination power was good, the level of difficulty was moderate, and the reliability was 0.72, which is included in the high category.

C. Results and Discussion

A total of 37 students took the test: 18 from the experimental class and 19 from the control class. To determine science process skills, a final test was administered, with questions containing indicators of science process skills, including observation, classification, interpretation, prediction, and application of concepts.

The research was conducted in 3 meetings. In the first meeting, students learned about work and its application in everyday life. Then, students were divided into 5 groups to discuss and create student discussion sheets that had been given. In the second meeting, students learned about energy and its application in everyday life. In this second meeting, students made a simple energy conversion tool, namely a water wheel. In the third meeting, students learned about kinetic energy and potential energy. In this meeting, students discussed and carried out practical work on potential energy with simple tools. In the next meeting, students worked on test questions to measure science process skills.

Based on the posttest conducted by the experimental class treated with the guided inquiry learning model and the control class treated with the conventional learning model, the results of students' science process skills were obtained as in Table 1.

Table 1 The results of the percentage of the posttest scores of the science process skills (SPS) of the experimental class and the control class

SPS Aspects	Control Class		Experiment Class	
	Percentage	Category	Percentage	Category
Observation	89.47	High	90.74	High
Clarification	78.95	High	86.11	High
Intepretation	39.47	Low	58.33	Middle
Prediction	36.84	Low	52.78	Middle
Implementation Concep	57.89	Middle	64.20	Middle
Average	60.53	Middle	70.43	Middle

Based on Table 1, the results of the posttest scores for science process skills of students in the experimental and control classes show a difference. Students in the experimental class achieved an average of 70.43%, while students in the control class achieved an average of 60.53%.

Several factors contribute to better science learning outcomes for students using the guided inquiry learning model, which focuses on science process skills, compared to those achieved through conventional learning. First, the implementation of the guided inquiry learning model facilitates students' understanding of the subject matter, which in turn improves student learning. This can be seen in the learning steps, where the teacher asks students to identify problems around them and allows them to solve them with guidance from the teacher. Students also engage in practical work, which fosters creativity in constructing tools and understanding how a problem can arise. This allows students to understand the learning process through the activities they undertake.

From the results of the data on the science process skills of class VIII students at MTsS Balimbing, as shown by the test results, they are included in the moderate category. The KPS indicators in sequence from the indicators with the highest percentage in this study are the observation, classifying, applying concepts, interpretation and prediction indicators. Based on the results of data processing that have been carried out using t-test statistics, $t_{count} > t_{table}$ is 2.98 > 2.02. By using the guided inquiry learning model, it can be concluded that the science process skills of class VIII students at MTsS Balimbing are influential.

The results of this study are in line with previous research conducted by Susanti [13] which stated that students' science process skills on the material on reaction rates guiding inquiry learning were accepted. The guided inquiry learning model is designed to develop intellectual thinking skills in students, so that they are expected to actively participate in the learning process. [14]. Guided inquiry is also an efficient and engaging learning model for students to improve their scientific literacy [15].

Based on this, the treatment of this learning model has shown a significant effect, where the class group that implemented the guided inquiry learning model obtained higher results when compared to the class group that implemented the conventional model. This statement is based on the results of the difference in the average final test scores of the experimental class and the control class. It is understood that this guided inquiry learning model influences students' science process skills.

D. Conclusion

Based on the results of the research conducted with the title of the influence of guided inquiry learning model on science process skills in science learning, it can be concluded with the results of the t test which shows that $t_{(count)} > t_{(table)}$ where $t_{(count)}$ is 2.98> from $t_{(table)}$ 2.02. So H1 is accepted and Ho is rejected, where the use of guided inquiry learning model has an effect on science process skills at MTsS Balimbing.

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Analyze the Students' Conceptual Understanding of Elasticity and Hooke's Law Using the Rasch Model

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ABSTRACT

This study investigates students' conceptual understanding of Elasticity and Hooke's Law by employing the Rasch measurement model. Conceptual understanding in physics is essential for enabling learners to apply principles across contexts and develop critical thinking skills. The 20 items multiple-choice test was developed and validated to assess mastery of elasticity-related concepts. The approach in this study was quantitative that conducted in Yogyakarta, Indonesia, involving 56 senior high students who had completed lessons on the relevant topic. The Rasch model was applied using the Ministeps software to analyze item difficulty and student ability. The Wright map and fit statistics indicated that most students had low to moderate levels.

INTISARI

Penelitian ini menyelidiki pemahaman konseptual siswa tentang Elastisitas dan Hukum Hooke dengan menggunakan model pengukuran Rasch. Pemahaman konseptual dalam fisika sangat penting untuk memungkinkan siswa menerapkan prinsip-prinsip dalam berbagai konteks dan mengembangkan keterampilan berpikir kritis. Tes pilihan ganda sebanyak 20 butir soal dikembangkan dan divalidasi untuk menilai penguasaan konsep-konsep yang berhubungan dengan elastisitas. Pendekatan dalam penelitian ini adalah kuantitatif yang dilakukan di Yogyakarta, Indonesia, dengan melibatkan 56 siswa sekolah menengah atas yang telah menyelesaikan pelajaran tentang topik yang relevan. Model Rasch diterapkan dengan menggunakan perangkat lunak Ministeps untuk menganalisis tingkat kesulitan soal dan kemampuan siswa. Peta Wright dan statistik kecocokan menunjukkan bahwa sebagian besar siswa memiliki tingkat kemampuan rendah hingga sedang.

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A. Introduction

Understanding physical concepts is crucial for forming a strong knowledge base and imparting problem-solving and critical thinking skills to students. As physics is a natural science discipline, knowing basic concepts such as force, motion, energy, and physical laws is important. The understanding of these concepts in the sense of

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definitions and operational usage, as well as perceptions of real-world observations, is needed. The study by Phanphech [1] stated that physics teaching needs to include explanation of concepts and use of physics concepts in situations where the students can relate them to enhance deeper understanding. Concept understanding can also be employed to refer to practical understanding when accompanied by rational ability to apply knowledge in the setting where they learned it [2]. Furthermore, understanding physics concepts, such as elasticity and Hooke's Law, is essential for students, as these form the foundation for other learning in mechanics and engineering. Despite the importance of these issues, they are challenging for students, with the resulting long-term misconceptions precluding deeper understanding. Traditional testing places higher emphasis on memorization than on the knowledge of the concept, thereby unable to identify some areas where students are perplexed.

Evaluating students' conceptual knowledge is an important part of determining their level of comprehension of kinematics material. It can also help teachers prepare more effective learning strategies, identify struggling students, and improve the quality of physics education. The Rasch model is one of the measurement methods that can be used in assessing students' comprehension of Elasticity and Hooke's Law. The Rasch model has advantages like high objectivity, rich detailed information about the mastery level of each concept, and ease of data analysis and interpretation [3]. The Rasch model also forecasts the probability of correct answers to a test based on ratings of two facets, item difficulty and individual ability, along the continuum between the two [4]. Rasch model analysis improves the accuracy and quality of tests and studies because it also allows the creation of a variety of different measurement tools. The Rasch model is used as a reference in analysing the response structure, rather than simply to describe the statistics of a given response. The ultimate goal is to achieve the maximum level of accuracy and objectivity in the measurement process, thus allowing for a more precise relationship between the measurement instrument and the essential characteristics of the individual. In the context of the Rasch model, this ‘settled’ scoring pattern is nothing but a measurement whose results depend on who is being measured (test-dependent scoring); whereas what must be done in quantitative research in the social sciences is objective measurement [5]. Analysis using the Rasch model also evaluates a measurement instrument's validity and reliability [6].

Understanding key physics concepts is fundamental to the development of scientific literacy and critical thinking skills among students. Physics, as a core discipline in natural science, requires not only memorization of formulas but also a deep conceptual grasp of ideas such as force, motion, energy, and physical laws. Among these, elasticity and Hooke’s Law are central to understanding how materials behave under stress, making them foundational for further studies in mechanics and engineering. Conceptual understanding, as opposed to procedural or rote learning, enables learners to apply their knowledge in varied contexts, fostering transfer of learning and long-term retention [7]. However, research has consistently shown that students struggle with abstract physics topics, including elasticity. This challenge often leads to misconceptions that persist despite instruction. Conceptual understanding involves more than recalling definitions; it includes the ability to use concepts to explain, analyze, and make sense of real-world phenomena [1]. This practical dimension of understanding being able to apply knowledge rationally in context is what distinguishes meaningful learning from surface-level acquisition [2]. Elasticity, defined as a material's ability to return to its original shape after deformation, and Hooke's Law, which describes the linear relationship between force and displacement ($F = kx$), are not only important physics principles but also tools to explain everyday phenomena and technological applications.

Despite their importance, traditional assessment methods are often insufficient to evaluate conceptual understanding. Standard tests tend to emphasize factual recall and algorithmic problem solving, which may obscure deeper learning gaps. As Hestenes, Wells, and Swackhamer [8] highlighted, students who can explain physical phenomena using conceptual reasoning outperform those who rely on formulaic procedures. Instructional approaches such as inquiry-based labs, peer instruction, and the use of simulations have been shown to improve conceptual grasp, particularly in abstract topics like elasticity [9]. But evaluating the impact of such teaching strategies requires robust tools that can accurately measure student understanding.

One such tool is the multiple-choice question (MCQ). MCQs are widely used in education due to their efficiency, scalability, and objectivity. Properly constructed MCQs, with plausible distractors based on known misconceptions, can assess not only recall but also higher-order cognitive skills [10]. Their standardized format makes them ideal for large-scale assessment, and when combined with advanced psychometric models such as the Rasch model, they become powerful diagnostic instruments [11].

The Rasch model is a probabilistic model under item response theory (IRT) that converts raw ordinal scores into interval-level measures, allowing for precise analysis of both student ability and item [3]. Unlike classical test theory, the Rasch model places students and items on the same linear continuum, providing deeper insight into how well items discriminate between levels of understanding. It allows for the development of fair and valid tests by identifying misfitting items and unusual response patterns. As Boone, Staver, and Yale [12] explain, Rasch analysis helps to refine assessments by ensuring that items align with the intended construct and function consistently across groups.

In the context of science education, particularly physics, Rasch modeling is highly relevant. Concepts like elasticity and Hooke's Law involve abstract reasoning and proportional thinking that many students find difficult. The Rasch model allows educators to determine which items reveal conceptual understanding and which distractors may be misleading or ineffective. It also enables the identification of students whose responses deviate from expected patterns, possibly due to guessing, misunderstanding, or disengagement. Moreover, Rasch modeling emphasizes measurement invariance ensuring that item parameters remain stable regardless of the student sample and person independence ensuring student ability measures are not dependent on the specific items used, as long as the model fits [5], [6].

These advantages make the Rasch model especially useful in developing conceptual diagnostic tools. For instance, research by Zacharia and Anderson [9] demonstrated that visualizing the force-displacement relation in elasticity through simulation and experimentation helped students build more robust conceptual frameworks. Such insights can be integrated into test design by using the Rasch model to calibrate item difficulty and detect learning gaps that traditional tests may miss.

Therefore, this study aims to evaluate students' conceptual understanding of elasticity and Hooke's Law through a multiple-choice diagnostic test, applying the Rasch measurement model to analyze both item quality and student ability more effectively than traditional assessments. By identifying patterns in student responses and aligning item difficulty with conceptual demands, this research seeks to contribute to the development of more valid, reliable, and informative assessments in physics education.

B. Method

This study utilises a quantitative descriptive design to explore students' conceptual understanding of Hooke's Law and Elasticity as measured by the Rasch measurement model. The Rasch model is an item response theory (IRT) one-parameter logistic model that is useful for calibrating ordinal raw scores to interval-level data, allowing both item difficulty and student ability to be analyzed on the same linear scale [12]. The subjects of this study were 56 students from grades XI and XII at MA Ali Maksum Yogyakarta, who had completed lessons on Elasticity and Hooke's Law. The sample was selected using purposive sampling to ensure that participants had studied the relevant material. The participants included 32 female and 24 male students, with an age range of 16 to 18 years old. All students were enrolled in the science stream and had participated in physics classes covering the target concepts. This demographic information helps to contextualize the findings, particularly in relation to patterns of understanding that may differ across age or gender groups.

The instrument was a 20-item conceptual test consisting of multiple-choice items with five response options, including one correct answer and four plausible distractors. The items were developed based on key concepts of the physics syllabus, such as Young's modulus, elastic and plastic deformation, Hooke's Law, and force-extension graphs [13]. Each distractor was designed to reflect common student misconceptions, allowing the test to effectively diagnose conceptual understanding rather than rote memorization or procedural recall. Prior to administration, the instrument underwent content validation by physics education experts and statistical validation of reliability and item functioning through Rasch model analysis.

For data analysis, the Rasch model was utilized with the Ministep program. Item and person reliability and separation indices were evaluated to assess the test's precision and ability to differentiate between different student knowledge levels. Student ability and item difficulty were in terms of logits. Fit statistics (infit and outfit mean square values) were used for model-data fit assessment, for which values ranging from 0.5 to 1.5 are acceptable [13]. A Wright map (person-item map) was made for a visual display of the distribution of the items and the abilities of the students on a common scale.

C. Results and Discussion

In line with the aim of this study to evaluate students' conceptual understanding of elasticity and Hooke's Law using a Rasch-based diagnostic test, this section presents the results of the analysis by focusing on how students' abilities align with the conceptual demands of the test items. The Rasch model allows for both item difficulty and student ability to be placed on a single linear scale (logit), making it possible to group students according to their level of conceptual understanding. The following table categorizes students into four levels of conceptual understanding based on their Rasch ability estimates:

Table 1. Categorization of Students' Conceptual Understanding Based on Rasch Ability Scores

Logit Range	Number of Students	Level of Understanding	Description
> +1.0	1	High	Demonstrates accurate and transferable understanding
0.0 to +1.0	18	Moderate	Understands key concepts with occasional inconsistencies
-1.0 to 0.0	29	Low	Shows partial understanding with significant misconceptions
< -1.0	8	Very Low	Lacks conceptual clarity, responses indicate guessing
Total	56		

A method that has been used is the Rasch model analysis, in which item validity can be established through three overall measures: Outfit Mean Square (MNSQ), Z-standardized (ZSTD), and Point Measure Correlation (CORR). An MNSQ value is considered valid when it falls between 0.5 to 1.5, i.e., the item has a proper level of fit with the model. On the other hand, a ZSTD value is deemed appropriate if it falls between -2.0 and +2.0, as this would mean no significant statistical deviation. A

CORR value must be greater than 0.2 because it refers to positive correlation of the item with the measured ability. The three parameters serve as the basis to determine whether an item is appropriate to use as a research component or needs revision, or can be eliminated. Figure 1 presents the item validity analysis results like Outfit MNSQ, ZSTD, and Point Measure Correlation value. Figure 1 presents the item validity analysis results, like Outfit MNSQ, ZSTD, and Point Measure Correlation values.

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item	
16	5	56	2.25	.47	.99	.09	.96	.05	.18	.14	91.1	91.1	S16	VALID
8	10	56	1.43	.36	1.08	.42	1.11	.47	.04	.19	82.1	82.1	S8	VALID
17	10	56	1.43	.36	.91	-.37	1.01	.11	.33	.19	82.1	82.1	S17	VALID
18	13	56	1.09	.32	.92	-.41	1.00	.09	.32	.21	78.6	76.8	S18	VALID
3	15	56	.89	.31	1.09	.64	1.17	.95	.02	.22	75.0	73.4	S3	VALID
20	17	56	.71	.30	.90	-.80	.94	-.34	.39	.23	71.4	70.0	S20	VALID
5	19	56	.53	.29	1.03	.34	1.10	.83	.14	.23	69.6	66.9	S5	VALID
2	20	56	.45	.29	1.01	.19	1.03	.30	.20	.23	60.7	65.6	S2	VALID
4	20	56	.45	.29	1.07	.70	1.17	1.45	.07	.23	60.7	65.6	S4	VALID
6	21	56	.37	.28	1.06	.64	1.08	.73	.12	.24	66.1	64.2	S6	VALID
11	21	56	.37	.28	1.16	1.72	1.18	1.62	-.06	.24	58.9	64.2	S11	VALID
12	21	56	.37	.28	.98	-.18	.95	-.39	.28	.24	62.5	64.2	S12	VALID
19	28	56	-.17	.28	.93	-1.04	.93	-.95	.37	.25	66.1	59.6	S19	VALID
13	33	56	-.56	.28	.93	-.91	.91	-.95	.38	.24	71.4	62.5	S13	VALID
9	34	56	-.64	.28	.97	-.38	.99	-.09	.29	.24	73.2	63.6	S9	VALID
15	36	56	-.80	.29	.98	-.21	1.00	.02	.27	.24	67.9	66.0	S15	VALID
7	39	56	-1.06	.30	1.07	.63	1.18	1.22	.05	.23	67.9	70.5	S7	VALID
10	42	56	-1.34	.32	.90	-.59	.91	-.41	.39	.22	80.4	75.1	S10	VALID
14	51	56	-2.61	.47	.92	-.08	.78	-.39	.32	.15	91.1	91.1	S14	VALID
1	53	56	-3.17	.60	.88	-.06	.47	-.90	.45	.12	94.6	94.6	S1	OVERVIT
MEAN	25.4	56.0	.00	.33	.99	.0	.99	.2			73.6	72.5		
P.SD	13.2	.0	1.30	.08	.08	.6	.16	.8			10.4	10.3		

Figure 1. Item Validity

Based on Figure 1, it can be concluded that all items are valid and can be used in the study. However, further examination is needed for item number 1, as its Outfit MNSQ value is below 0.5, indicating a potential overfit. An overfit item refers to one that fits the model too perfectly, which may raise concerns regarding its quality. This condition could suggest that the item is too easy or that respondents answered it in a highly uniform manner, reducing its ability to differentiate between varying levels of respondent ability. Although the item still falls within acceptable limits in terms of ZSTD and CORR values, its unusually low Outfit MNSQ warrants closer scrutiny before making a final decision about its inclusion in the instrument.

The Wright map showed that most students' ability measures clustered between -1.0 and +1.0 logits, indicating low to moderate conceptual understanding. Only one student achieved a high ability level (logit > +1.0). In terms of item difficulty, several items were identified as highly challenging, yet valid and informative. One such example is item 16, which assesses students’ understanding of how dimensions affect material elongation:

16. Seorang siswa Aliyah melakukan percobaan terhadap empat buah kawat terbuat dari bahan identik dengan data sebagai berikut:

Kawat	Panjang (cm)	Diameter (mm)
1	50	0,5
2	100	1
3	200	2
4	300	3

Manakah kawat yang memiliki pertambahan panjang terbesar apabila diberi gaya yang sama?

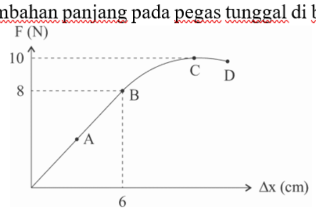
A. Kawat 1 karena rasio diameter terkecil
B. Kawat 2 karena rasio diameter yang setara
C. Kawat 3 karena rasio diameter sebesar seribu
D. Kawat 4 karena memiliki rasio diameter terbesar
E. Tidak ada karena tiap kawat berasio sama

Figure 2. Item Number 16

The correct answer was A, yet many students selected distractors B or D, reflecting common misconceptions about material deformation. Rasch analysis revealed that this item had a difficulty logit of +1.85, an Outfit MNSQ of 0.95, and a CORR of +0.35, confirming its status as a valid and informative item. It effectively distinguished students who grasped the conceptual relationship between length, cross-sectional area, and strain.

In addition, item S8 examined student reasoning about shifting the elastic limit on a spring's force-extension graph. It asked:

8. Perhatikan grafik hubungan gaya dengan pertambahan panjang pada pegas tunggal di bawah.



Apabila gaya diperbesar hingga melewati titik C, maka pegas akan bersifat plastis dan tidak kembali ke panjang semula. Langkah yang dapat dilakukan agar titik C dapat berpindah ke titik B adalah . . .

A. Memperbesar panjang pegas
B. Memperkecil konstanta pegas
C. Memotong pegas menjadi dua bagian
D. Memperbesar konstanta pegas
E. Mengganti pegas dengan susunan paralel

Figure 3. Item Number 8

(Correct answer: D. Memperbesar konstanta pegas)

This item had a logit of +1.65, was statistically fit (MNSQ = 1.02), and had CORR = +0.41. The distractors functioned well and revealed that many students lacked an integrated understanding of graphical and conceptual representations of elastic behavior. Another challenging item, S17, tested students' procedural reasoning in determining the force in a complex spring system. It had the highest item difficulty (+2.10 logits), a fit statistic of 0.94, and CORR = +0.39, validating its use for identifying higher-order thinkers.

These examples not only illustrate the effectiveness of Rasch analysis in evaluating test quality but also emphasize the value of carefully constructed multiple-choice items in diagnosing students' conceptual understanding. The findings support the conclusion that the Rasch-based diagnostic test is a powerful tool for revealing learning gaps. Therefore, strengthening both test development and instructional strategies is crucial for enhancing physics learning outcomes related to elasticity and Hooke's Law.

The Rasch model analysis revealed a significant difference between person and item reliability. Person reliability was very low (0.00), indicating that the instrument could not effectively distinguish between students with different ability levels. This suggests that most students gave similar responses, which may be due to the test being too easy or too difficult, or a lack of variation in student ability. In contrast, item reliability was very high (0.93), showing that the test items varied well in difficulty and could be distinguished effectively. However, a negative correlation between item scores and measures (-0.99) indicates a potential issue in scoring, such as a reversed scoring pattern. These findings highlight the need for improving the test design and reviewing the scoring process to ensure accurate and reliable assessment of students' conceptual understanding. The reliability results can be seen in Figure 4 and Figure 5.

```
SEPARATION   .00  Person RELIABILITY  .00
SEPARATION   .04  Person RELIABILITY  .00
```

Figure 4. Measured Person (Reliability)

```
SEPARATION  3.63  Item   RELIABILITY  .93
SEPARATION  3.67  Item   RELIABILITY  .93
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Figure 5. Measured Item (Reliability)

Data analysis from the measurement of the understanding of the concept of elasticity and Hook's law was performed by applying the Rasch model using Winstep Rasch software. The level of students' concept understanding was analysed based on the output results, specifically through Person Measure and Person Fit Order. In addition, to illustrate the achievement of concept understanding, the Wright Map presented in Table 1 was used. On the Wright Map, the vertical discontinuous line illustrates the distribution of participants and items from the lowest to the highest level of ability or difficulty (arranged from bottom to top). Students at the bottom of the map indicate a low level of concept mastery, while those above the vertical line indicate a higher level of concept understanding. The symbol 'M' indicates the mean score, while "S" and 'T' represent one and two standard deviations from the mean, respectively. Figure 6 shows the Wright map:

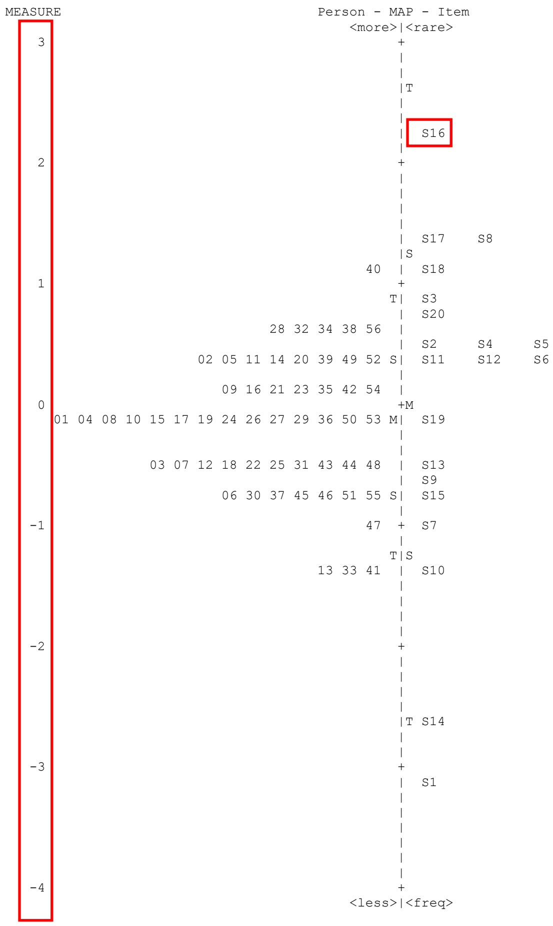

Figure 6. Wright Map

Based on the results of the Wright Map analysis in Figure 1, the ability of students to understand the concepts of the tested material is analyzed through the distribution of logit positions between students and the difficulty level of the question items. The logit scale is used to map the ability (person) on the left side and the difficulty level of the question (item) on the right side, with a midpoint of 0.0 as the average. The mapping results showed that most learners were in the logit range between -1 and +1, indicating that their abilities were still at a moderate level and tended to be below average. Only a few learners had high ability, such as student number 40, who was above logit +1. On the question side, item S16 was at the top, indicating that it was the most difficult question in the instrument. Meanwhile, the easiest item was S1, which is located at the lowest logit position, which is below -3. From this distribution, it can be seen that there are still many learners who are not able to answer items with high difficulty levels, such as S16, S8, and S17, because their logit position is far below these questions. Thus, this Wright Map shows that students' conceptual ability in understanding the material still needs to be improved, especially in dealing with questions of high complexity.

Based on the 2023 National Assessment results released by the Centre for Educational Assessment (Pusmendik) [14], several schools in the Special Region of Yogyakarta showed high literacy and numeracy achievements. This is reflected in the report 'Profile of Education Units with High AKM Achievement', which notes that a number of schools in Yogyakarta fall into the category of high AKM achievement in 2023. Compared to the findings in this study, where most students are in the low to moderate concept understanding category, there is a gap in achievement that needs attention. This shows that although Yogyakarta is known to have a good quality of education in general, not all educational units have shown optimal achievement results in physics concepts, especially in elasticity and Hooke's Law.

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	JMLE MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
40	14	20	1.15	.54	1.09	.45	1.12	.39	.33	.40	75.0	73.9	40
28	12	20	.60	.51	.64	-2.09	.53	-1.08	.68	.44	90.0	69.5	28
32	12	20	.60	.51	1.21	1.10	1.16	.48	.30	.44	60.0	69.5	32
34	12	20	.60	.51	1.40	1.95	1.49	1.07	.16	.44	50.0	69.5	34
38	12	20	.60	.51	1.26	1.32	1.21	.58	.27	.44	50.0	69.5	38
56	12	20	.60	.51	1.16	.85	1.06	.28	.35	.44	60.0	69.5	56
2	11	20	.34	.51	1.04	.25	.91	-.09	.45	.46	65.0	68.9	02
5	11	20	.34	.51	.63	-2.20	.53	-1.25	.71	.46	85.0	68.9	05
11	11	20	.34	.51	.64	-2.12	.54	-1.22	.70	.46	85.0	68.9	11
14	11	20	.34	.51	1.27	1.37	1.33	.88	.27	.46	65.0	68.9	14
20	11	20	.34	.51	1.02	.18	.90	-.11	.46	.46	65.0	68.9	20
39	11	20	.34	.51	1.30	1.52	1.17	.53	.28	.46	55.0	68.9	39
49	11	20	.34	.51	1.52	2.43	1.52	1.23	.11	.46	45.0	68.9	49
52	11	20	.34	.51	1.14	.75	1.05	.25	.38	.46	65.0	68.9	52
9	10	20	.08	.51	.61	-2.23	.52	-1.43	.73	.47	90.0	70.6	09
16	10	20	.08	.51	.61	-2.23	.52	-1.43	.73	.47	90.0	70.6	16
21	10	20	.08	.51	.77	-1.20	.66	-.91	.63	.47	80.0	70.6	21
23	10	20	.08	.51	.69	-1.69	.59	-1.18	.68	.47	80.0	70.6	23
35	10	20	.08	.51	1.46	2.10	1.89	2.02	.12	.47	50.0	70.6	35
42	10	20	.08	.51	1.19	.97	1.06	.29	.37	.47	60.0	70.6	42
54	10	20	.08	.51	1.34	1.63	1.25	.73	.26	.47	50.0	70.6	54
1	9	20	-.18	.52	.56	-2.36	.48	-1.65	.77	.49	90.0	72.0	01
4	9	20	-.18	.52	.71	-1.47	.60	-1.18	.69	.49	80.0	72.0	04
8	9	20	-.18	.52	.65	-1.84	.55	-1.37	.72	.49	90.0	72.0	08
10	9	20	-.18	.52	.65	-1.84	.55	-1.37	.72	.49	90.0	72.0	10
15	9	20	-.18	.52	.87	-.59	.76	-.60	.58	.49	80.0	72.0	15
17	9	20	-.18	.52	.88	-.50	.84	-.35	.56	.49	80.0	72.0	17
19	9	20	-.18	.52	.78	-1.06	.66	-.96	.64	.49	80.0	72.0	19
24	9	20	-.18	.52	.56	-2.36	.48	-1.65	.77	.49	90.0	72.0	24
26	9	20	-.18	.52	.65	-1.84	.55	-1.37	.72	.49	90.0	72.0	26
27	9	20	-.18	.52	.56	-2.36	.48	-1.65	.77	.49	90.0	72.0	27
29	9	20	-.18	.52	.56	-2.36	.48	-1.65	.77	.49	90.0	72.0	29
36	9	20	-.18	.52	1.24	1.13	1.19	.60	.34	.49	60.0	72.0	36
50	9	20	-.18	.52	1.09	.48	1.30	.87	.40	.49	70.0	72.0	50
53	9	20	-.18	.52	1.27	1.25	1.19	.62	.32	.49	60.0	72.0	53
3	8	20	-.45	.53	.84	-.64	.95	-.02	.58	.50	85.0	73.5	03
7	8	20	-.45	.53	.86	-.54	.77	-.55	.59	.50	85.0	73.5	07
12	8	20	-.45	.53	1.10	.49	1.07	.31	.44	.50	65.0	73.5	12
18	8	20	-.45	.53	.84	-.64	.95	-.02	.58	.50	85.0	73.5	18
22	8	20	-.45	.53	.72	-1.22	.61	-1.09	.68	.50	85.0	73.5	22
25	8	20	-.45	.53	.67	-1.52	.55	-1.31	.72	.50	85.0	73.5	25
31	8	20	-.45	.53	.65	-1.65	.54	-1.38	.73	.50	85.0	73.5	31
43	8	20	-.45	.53	1.21	.92	1.20	.64	.36	.50	65.0	73.5	43
44	8	20	-.45	.53	1.13	.61	1.13	.46	.41	.50	65.0	73.5	44
48	8	20	-.45	.53	.96	-.10	.82	-.40	.54	.50	75.0	73.5	48
6	7	20	-.74	.54	.64	-1.47	.53	-1.28	.74	.50	90.0	75.3	06
30	7	20	-.74	.54	.73	-1.03	.59	-1.04	.69	.50	80.0	75.3	30
37	7	20	-.74	.54	1.50	1.73	1.57	1.34	.18	.50	60.0	75.3	37
45	7	20	-.74	.54	1.44	1.57	1.64	1.46	.20	.50	60.0	75.3	45
46	7	20	-.74	.54	1.40	1.43	1.59	1.37	.23	.50	70.0	75.3	46
51	7	20	-.74	.54	1.25	.97	1.26	.73	.34	.50	70.0	75.3	51
55	7	20	-.74	.54	1.33	1.22	1.94	1.96	.24	.50	70.0	75.3	55
47	6	20	-1.05	.57	1.20	.72	1.17	.49	.39	.51	70.0	77.9	47

13	5	20	-1.39	.60	.80	-.50	.67	-.49	.64	.51	85.0	81.3	13
33	5	20	-1.39	.60	2.00	2.37	2.28	1.89	-.13	.51	65.0	81.3	33
41	5	20	-1.39	.60	2.16	2.65	2.69	2.28	-.25	.51	65.0	81.3	41
MEAN	9.1	20.0	-.18	.53	1.01	-.1	.99	-.1			73.6	72.5	
P.SD	1.9	.0	.53	.02	.36	1.5	.48	1.1			13.3	3.0	

Figure 7. Person Measure

The Person Measure table in Figure 5 shows the logit value that describes the level of students' ability to understand the tested material. Based on the analysis results, the average logit value is -0.18 with a standard deviation of 0.53. According to Kurli et al [15], the standard deviation value can be used as a reference to classify students' abilities into high, medium, and low categories. Learners who have a logit value above +0.35 (mean + 1 SD) are classified in the high category, but out of 56 students, only one reached this category, student number 40, with a logit value of 1.15 and a total score of 14. This shows that the majority of participants still do not show a strong understanding of the material. Learners with logits above 0, such as students 28, 32, 34, 38, and 56, can be categorised as being at a medium level of ability. Meanwhile, most participants were below average, with negative logit values, such as students 01, 08, 11, 16, 19, 21, and 26. There were even participants with very low logit values, such as participants 13, 33, and 41, with a logit of -1.39, indicating very weak concept understanding. Based on this distribution, it can be concluded that the majority of learners in this study were in the low to medium ability category, and only a few reached the high category. This indicates the need for more effective learning interventions to improve learners' understanding of the tested material.

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
41	5	20	-1.39	.60	2.16	2.65	2.69	2.28	A-.25	.51	65.0	81.3	41
33	5	20	-1.39	.60	2.00	2.37	2.28	1.89	B-.13	.51	65.0	81.3	33
55	7	20	-.74	.54	1.33	1.22	1.94	1.96	C .24	.50	70.0	75.3	55
35	10	20	.08	.51	1.46	2.10	1.89	2.02	D .12	.47	50.0	70.6	35
45	7	20	-.74	.54	1.44	1.57	1.64	1.46	E .20	.50	60.0	75.3	45
46	7	20	-.74	.54	1.40	1.43	1.59	1.37	F .23	.50	70.0	75.3	46
37	7	20	-.74	.54	1.50	1.73	1.57	1.34	G .18	.50	60.0	75.3	37
49	11	20	.34	.51	1.52	2.43	1.52	1.23	H .11	.46	45.0	68.9	49
34	12	20	.60	.51	1.40	1.95	1.49	1.07	I .16	.44	50.0	69.5	34
54	10	20	.08	.51	1.34	1.63	1.25	.73	J .26	.47	50.0	70.6	54
14	11	20	.34	.51	1.27	1.37	1.33	.88	K .27	.46	65.0	68.9	14
39	11	20	.34	.51	1.30	1.52	1.17	.53	L .28	.46	55.0	68.9	39
50	9	20	-.18	.52	1.09	.48	1.30	.87	M .40	.49	70.0	72.0	50
53	9	20	-.18	.52	1.27	1.25	1.19	.62	N .32	.49	60.0	72.0	53
38	12	20	.60	.51	1.26	1.32	1.21	.58	O .27	.44	50.0	69.5	38
51	7	20	-.74	.54	1.25	.97	1.26	.73	P .34	.50	70.0	75.3	51
36	9	20	-.18	.52	1.24	1.13	1.19	.60	Q .34	.49	60.0	72.0	36
32	12	20	.60	.51	1.21	1.10	1.16	.48	R .30	.44	60.0	69.5	32
43	8	20	-.45	.53	1.21	.92	1.20	.64	S .36	.50	65.0	73.5	43
47	6	20	-1.05	.57	1.20	.72	1.17	.49	T .39	.51	70.0	77.9	47
42	10	20	.08	.51	1.19	.97	1.06	.29	U .37	.47	60.0	70.6	42
56	12	20	.60	.51	1.16	.85	1.06	.28	V .35	.44	60.0	69.5	56
52	11	20	.34	.51	1.14	.75	1.05	.25	W .38	.46	65.0	68.9	52
44	8	20	-.45	.53	1.13	.61	1.13	.46	X .41	.50	65.0	73.5	44
40	14	20	1.15	.54	1.09	.45	1.12	.39	Y .33	.40	75.0	73.9	40
12	8	20	-.45	.53	1.10	.49	1.07	.31	Z .44	.50	65.0	73.5	12
18	8	20	-.45	.53	.84	-.64	.95	-.02	z .58	.50	85.0	73.5	18
17	9	20	-.18	.52	.88	-.50	.84	-.35	y .56	.49	80.0	72.0	17
15	9	20	-.18	.52	.87	-.59	.76	-.60	x .58	.49	80.0	72.0	15
7	8	20	-.45	.53	.86	-.54	.77	-.55	w .59	.50	85.0	73.5	07
13	5	20	-1.39	.60	.80	-.50	.67	-.49	v .64	.51	85.0	81.3	13
19	9	20	-.18	.52	.78	-1.06	.66	-.96	u .64	.49	80.0	72.0	19
21	10	20	.08	.51	.77	-1.20	.66	-.91	t .63	.47	80.0	70.6	21
30	7	20	-.74	.54	.73	-1.03	.59	-1.04	s .69	.50	80.0	75.3	30
22	8	20	-.45	.53	.72	-1.22	.61	-1.09	r .68	.50	85.0	73.5	22

4	9	20	-.18	.52	.71	-1.47	.60	-1.18	q	.69	.49	80.0	72.0	04
23	10	20	.08	.51	.69	-1.69	.59	-1.18	p	.68	.47	80.0	70.6	23
25	8	20	-.45	.53	.67	-1.52	.55	-1.31	o	.72	.50	85.0	73.5	25
8	9	20	-.18	.52	.65	-1.84	.55	-1.37	n	.72	.49	90.0	72.0	08
10	9	20	-.18	.52	.65	-1.84	.55	-1.37	m	.72	.49	90.0	72.0	10
26	9	20	-.18	.52	.65	-1.84	.55	-1.37	l	.72	.49	90.0	72.0	26
31	8	20	-.45	.53	.65	-1.65	.54	-1.38	k	.73	.50	85.0	73.5	31
6	7	20	-.74	.54	.64	-1.47	.53	-1.28	j	.74	.50	90.0	75.3	06
11	11	20	.34	.51	.64	-2.12	.54	-1.22	i	.70	.46	85.0	68.9	11
28	12	20	.60	.51	.64	-2.09	.53	-1.08	h	.68	.44	90.0	69.5	28
5	11	20	.34	.51	.63	-2.20	.53	-1.25	g	.71	.46	85.0	68.9	05
9	10	20	.08	.51	.61	-2.23	.52	-1.43	f	.73	.47	90.0	70.6	09
16	10	20	.08	.51	.61	-2.23	.52	-1.43	e	.73	.47	90.0	70.6	16
1	9	20	-.18	.52	.56	-2.36	.48	-1.65	d	.77	.49	90.0	72.0	01
24	9	20	-.18	.52	.56	-2.36	.48	-1.65	c	.77	.49	90.0	72.0	24
27	9	20	-.18	.52	.56	-2.36	.48	-1.65	b	.77	.49	90.0	72.0	27
29	9	20	-.18	.52	.56	-2.36	.48	-1.65	a	.77	.49	90.0	72.0	29
MEAN	9.1	20.0	-.18	.53	1.01	-.1	.99	-.1				73.6	72.5	
P.SD	1.9	.0	.53	.02	.36	1.5	.48	1.1				13.3	3.0	

Figure 8. Person Fit Order

The Person Fit Order table in Figure 6 is used to evaluate the fit of students' response patterns to the ideal Rasch model. This is to ascertain whether students are consistently answering the items by their actual abilities. Model inconsistency is indicative of a distorted response set pattern brought about by inconsistency in reasoning, random errors, or suspected cheating [13]. Based on the analysis results, there were students with values outside of Rasch model criteria, namely Mean Square Outfit (MNSQ) outside the range 0.5 to 1.5, Z-Standardised (ZSTD) outside -2.0 to +2.0, and Point Measure Correlation (Pt Mean Corr) values less than 0.4. Student with entry number 41 had Outfit MNSQ value 2.69 and ZSTD 2.28 and Pt Mean Corr -0.25, indicating a very bad fit to the model. On the other hand, On the contrary, students 33 and 35 also had high MNSQ, ZSTD values, and low or negative correlations- this inconsistency suggests a possibility that the participants were not answering the items as expected for their ability level, possibly due to a lack of insight about the items or due to other extraneous factors like guessing or cheating. Thus, analysis of this person-fit order is a constructive exercise in revealing the quality of participant response data and the validity of measures of ability under Rasch-based assessment.

```
GUTTMAN SCALOGRAM OF RESPONSES:
Person |Item
       | 11 1 11 11   2 1 11
       |14075939612245038876
       |--------------------
    40 +11101111110001111010  40
    28 +11111111011110000000  28
    32 +11111010001110100011  32
    34 +11011011100001101011  34
    38 +11100111100001111010  38
    56 +11110011101001101010  56
     2 +11111100001110001100  02
     5 +11111111011100000000  05
    11 +11111111001110000000  11
    14 +11101011001010100101  14
    20 +11110101001110101000  20
    39 +11111000100001110110  39
    49 +11000011100111101010  49
    52 +11100111100001111000  52
     9 +11111111010100000000  09
    16 +11111111001100000000  16
    21 +11111101001010100000  21
    23 +11111110001110000000  23
    35 +10011100110011010100  35
    42 +11100101100101101000  42
    54 +11001100100111011000  54
     1 +11111111001000000000  01
     4 +11111011001010000000  04
     8 +11111110010100000000  08
    10 +11111110001010000000  10
    15 +11111010010000110000  15
    17 +11111010001010000100  17
    19 +11111100001110000000  19
    24 +11111111010000000000  24
    26 +11111110010100000000  26
    27 +11111111010000000000  27
    29 +11111111010000000000  29
    36 +11001101100001100010  36
    50 +11110100100011000001  50
    53 +11100100110001010100  53
     3 +10111111010000000000  03
     7 +11011110001000010000  07
    12 +11110000011100000100  12
    18 +10111111010000000000  18
    22 +11111010010100000000  22
    25 +11110111001000000000  25
    31 +11111011010000000000  31
    43 +11100100100100010100  43
    44 +11100101010000010100  44
    48 +11011010101001000000  48
     6 +11111010010000000000  06
    30 +11110011001000000000  30
    37 +11000000110100010100  37
    45 +01100100100011100000  45
    46 +11001000100000011010  46
    51 +11100000100001011000  51
    55 +11010000100001100001  55
    47 +11000100100001010000  47
    13 +11011000000010000000  13
    33 +00010000000111001000  33
    41 +00000001010010100010  41
       |--------------------
       | 11 1 11 11   2 1 11
       |14075939612245038876
```

Figure 9. Scalogram

The scalogram in Figure 9 shows the inconsistency of the response patterns of some learners to items with varying levels of difficulty. For instance, students 07 and 15 were unable to answer correctly low-difficulty items such as numbers 6 and 0, but were able to answer higher-difficulty items such as numbers 1, 4, or 9. Similarly, student 17 struggled with items 0 and 2 (low difficulty) yet answered correctly on items 1 and 4 (higher difficulty). These anomalies may indicate distraction, disengagement, or inattentiveness during the test. Comparable patterns have been reported in other Rasch studies, where unexpected failures on easy items are linked to random guessing or lack of focus [12], [16]

Furthermore, a study on Newtonian mechanics (bMCU test) found that Rasch-based person-item maps and information curves effectively identified students who performed inconsistently, missing easier items while correctly answering more difficult ones, highlighting potential measurement noise rather than true ability variance. This supports the notion that such irregular response patterns may not reflect conceptual weakness, but rather test-taking behavior, such as fatigue or lack of motivation.

Rasch analysis thus offers tools not only for item and ability estimation, but also for diagnosing anomalies in response behavior that traditional test theory may miss. Future research could employ follow-up interviews or think-aloud protocols to investigate the reasons behind these patterns, in line with instrument development best practices.

D. Conclusion

This study aimed to evaluate students' conceptual understanding of elasticity and Hooke's Law using a diagnostic test analyzed with the Rasch model. The test results showed that most students had low to moderate levels of understanding, with only one student categorized as high-ability. Several items, such as S16, S8, and S17, were identified as valid and informative, revealing students' ability differences and common misconceptions. The Rasch model provided detailed information about item difficulty and student ability, which traditional scoring methods often overlook. It also helped identify items that fit well and those that need revision. These findings highlight the usefulness of the Rasch model in developing better assessments and in understanding how students grasp physics concepts.

To improve future instruction and assessment, further research is needed to refine the instrument, expand it to different student populations, and explore its use in various learning contexts. Developing more diverse diagnostic tools, such as two-tier or open-ended items, can also help deepen the evaluation of students' conceptual understanding. This study demonstrates how well-constructed instruments, supported by strong analytical models, can guide better teaching and learning in physics education.

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