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Evaluating Effectiveness, Relevance, and Endurance in a Solar-Powered DC Hands-On Activity Using Rasch Modeling

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Abstract

Hands-on experimental kits are essential for enhancing student engagement and conceptual understanding in physics education. This study evaluates the feasibility of a Solar-Powered Direct Current (SP-DC) experimental kit, focusing on its effectiveness, relevance, and endurance as perceived by users. A quantitative design was employed using a closed-ended questionnaire comprising 14 items. Participants (n=79) consisted of undergraduate students from Universitas Kristen Indonesia (n=36) and high school students from SMA N 11 Jakarta (n=43). Prior to completing the questionnaire, students engaged in assembling the SP-DC kit and measuring current and voltage. Data were collected between June 2022 and June 2023 and analyzed using the Rasch model through Winstep version 5.9.00. Fit validity was determined by item and person statistics (MNSQ, ZSTD, PTMEA), while descriptive analysis included item measures and score distributions. Findings confirmed that all questionnaire items met Rasch model validity criteria, with PTMEA correlations above 0.7. In terms of effectiveness, participants reported favorable perceptions of ease of use and assembly, though aspects such as portability and storage required improvement. Relevance was demonstrated through the kit's role in supporting understanding of series and parallel circuits, motivating interest in renewable energy, and strengthening connections between theory and practice. Endurance analysis revealed that the kit was generally durable and safe, though operational robustness could be enhanced. The SP-DC experimental kit is a feasible educational tool that supports effectiveness, curricular relevance, and endurance. These results suggest the kit's potential for broader application in both secondary and higher education.

Keywords: User Responses, Rasch Model, Solar Powered, Direct Current, experimental kit

1. Introduction

Research has demonstrated the potential of renewable energy sources like solar and wind to contribute significantly to global electricity demands, thereby reducing reliance on fossil fuels (Prema et al., 2022). This shift not only helps decrease greenhouse gas emissions but also fosters innovative approaches to education in the sciences, particularly physics, where understanding energy production and consumption is paramount (Rabbi et al., 2022). The promotion of renewable energy education in high school presents a myriad of challenges and opportunities. One significant challenge lies in the integration of complex technical concepts within existing curricula, which can overwhelm both educators and students (Oyekale et al., 2020). Despite the Indonesian government's acknowledgment of renewable energy's importance, there is a significant gap in human resources capable of advancing this sector. Many experts suggest that elevating educational standards on renewable energy technologies is imperative for fostering a knowledgeable workforce with the skills required for implementation (Esquivias et al., 2022; Hernandez & Prakoso, 2021). The existing education system appears insufficient to equip students with essential knowledge about renewable technologies, which discourages broader adoption and utilization within the community (Situmeang et al., 2022). Thus, it is vital to incorporate renewable energy concepts into educational curricula at all levels to bridge this gap and prepare future generations for challenges related to sustainable energy (Esquivias et al., 2022; Hernandez & Prakoso, 2021).

Hands-on, practical experience is widely recognized as an effective method for teaching scientific concepts, including those associated with renewable energy. Engaging students through practical activities allows them to apply theoretical knowledge in real-world contexts, thus deepening their understanding of complex topics (Tan et al., 2023). Furthermore, inquiry-based learning models, which incorporate hands-on activities, have been shown to foster critical thinking skills among students (Arisa et al., 2022). In the context of renewable energy, incorporating hands-on learning experiences plays a critical role in nurturing future generations of environmentally literate citizens able to address pressing energy challenges (De La Cruz-Lovera et al., 2019). The practical application of scientific concepts promotes an active engagement that is conducive to long-term retention and understanding, as students often remember more when they physically interact with the material (Syifa et al., 2023). Thus, integrating hands-on experiences in the curriculum is essential for effective science education, particularly in preparing students to tackle contemporary socio-scientific issues like climate change and energy sustainability (De La Torre et al., 2021)

Comparatively, countries such as China, Japan, and South Korea employ structured hands-on curricula revolving around STEM (Science, Technology, Engineering, and Mathematics) education. This approach aligns with innovative pedagogical frameworks that promote scientific inquiry and environmental stewardship (Santoso et al., 2023). In Southeast Asia, nations like Singapore, Thailand, and Malaysia also leverage hands-on methods extensively within their educational frameworks, focusing on renewable energy themes that resonate with local sustainability goals. In the Philippines, practical experience in renewable energy education is bolstered through community-based projects that encourage student engagement and awareness (Gamarra et al., 2021). Engaging various hands-on pedagogies across cultures highlights the

enhanced educational outcomes of inquiry-based and experiential learning, suggesting that such methods are cornerstone strategies for fostering a sustainable future across high school systems (Demircioglu et al., 2023; Santoso et al., 2023).\

Developing innovative teaching aids like the mini solar-powered DC circuit kit is a vital step in making renewable energy concepts more accessible and engaging for students. However, the true value of such tools can only be realized if their effectiveness and acceptance are systematically evaluated. Simply introducing new resources is not enough; educators need evidence that these aids genuinely enhance learning outcomes. This is why our study goes beyond development, focusing on robust evaluation using a carefully designed user response questionnaire. By applying Rasch analysis, we ensure that the feedback we gather is both reliable and valid across different groups of students. This approach allows us to identify not just how well the kit works, but also whether it is equally effective and accepted regardless of education status or gender. Systematic evaluation like this is essential for building trust in new educational tools and for guiding future improvements. Ultimately, our goal is to set a standard for how teaching innovations should be tested, ensuring that only the most effective and inclusive resources reach the classroom.

The Rasch Model is a fundamental component of modern educational measurement and psychometrics, providing a strong framework for assessing the effectiveness of tools such as questionnaires in collecting responses from various stakeholders, including students and teachers. By applying Rasch analysis, researchers can rigorously assess the reliability and validity of questionnaires, ensuring they accurately measure the intended constructs and function effectively across diverse population segments, including those in distance learning environments (Blouin & Smith, 2020). A key aspect of Rasch analysis is item fit/misfit analysis, which is essential for understanding how well each question performs within the assessment tool. Fit statistics are used to determine whether actual response patterns align with the expectations set by the Rasch model, guiding necessary modifications to enhance instrument accuracy (Fan et al., 2019).

Confirming the identified research gap, this study examines the instructional applicants of Solar Powered-DC Experimental kit on user responses. This research focus on 1) Does the User Responses Questionaire meets validity based on Rasch modeling?; 2) How user of SP-DC experimental kit responses on effectivity, relevance and endurance by using Rasch Model. By investigating these responses, this study contributes not only to equitable educational opportunities but also to the integrity of psychometric assessments (Hadžibajramović et al., 2022). Therefore, the use of the Rasch Model enriches the measurement process and underscores the importance of equity in educational assessment.

2. Methods

2.1 Research Design and Participants

This study Rasch Model to feasibility of a developed product- Solar Powered DC (SP-DC) Experimental Kit, based on evaluate user responses specific in effectiveness, relevance, and durability aspect. The research employed a quantitative methodology utilizing a questionnaire for data collection. Table 1 presents the participants demographic. This study encompassed 79 students from undergraduate and high school student, to find out whether this experimental kit is suitable

for use at which level of education. The participant fulfilling characteristics: (1) had learning basic physics in university or physics in high school level; (2) had directly used the SP-DC experimental kit. The arrangement of experimental kit is presented in Figure 1.

Table 1.
Sample Demographic

Background		n
Universitas Kristen Indonesia – science education and engineer major - Undergraduate Student		36
SMA N 11 Jakarta – The Xth grade Student		43
	N	79

2.2 Data Collection

Data collection is scheduled to occur between June 2022 and June 2023. An online questionnaire was disseminated through offline meeting and Classroom WhatsApp Group to participants. The objective was to test the validity of each item in User Responses Before the questionnaire distributed, participants, ust involved in hands-on activity in assembling the kit and measured the current and voltage of solar powered kit (Figure 2).

2.3 Instrument

This research instrument constructed of 14 item, inquired effectivity, relevance, and endurance of SP-DC experimental kit (Figure 1). This instrument is a closed- ended questionnaire. The item description presents in Table 2. Questionnaire and to assess feasibility of SP-DC experimental kit on effectivity, relevance and endurance. Rasch model was employ to asses fit validity or each item and the feasibility measurement of user responses.

2.4 Data Analysis

The user responses data were analyses by Rasch Modelling through Winstep software version 5.9.00. In this model, user responses answer is represented as ordinal data ranging from 1 to 5 score, which converted into interval data in log odd unit (logits). The validity of each item in user responses questionnaire is based on fit validity criteria. In Rasch measurement, Mean Square (MNSQ), Z-standardized fit statistic (ZSTD), and Point-Measure Correlation (PTMEA CORR) are commonly used as indicators to evaluate the extent to which observed response patterns align with model expectations (Bond & Fox, 2015).

The MNSQ statistic, which includes both infit (information-weighted) and outfit (outlier-sensitive) forms, quantifies the degree of discrepancy between observed and expected responses. The ZSTD statistic complements MNSQ by expressing these deviations in standardized units (z-scores), thereby indicating the statistical significance of the misfit. Ideally, ZSTD values hover around 0, with a practical range between −2.0 and +2.0 denoting acceptable fit (Wright & Linacre, 1994). Deviations beyond this range suggest that the observed response patterns significantly

diverge from model expectations, although researchers must interpret ZSTD cautiously in large samples, where even minor deviations can become statistically significant.

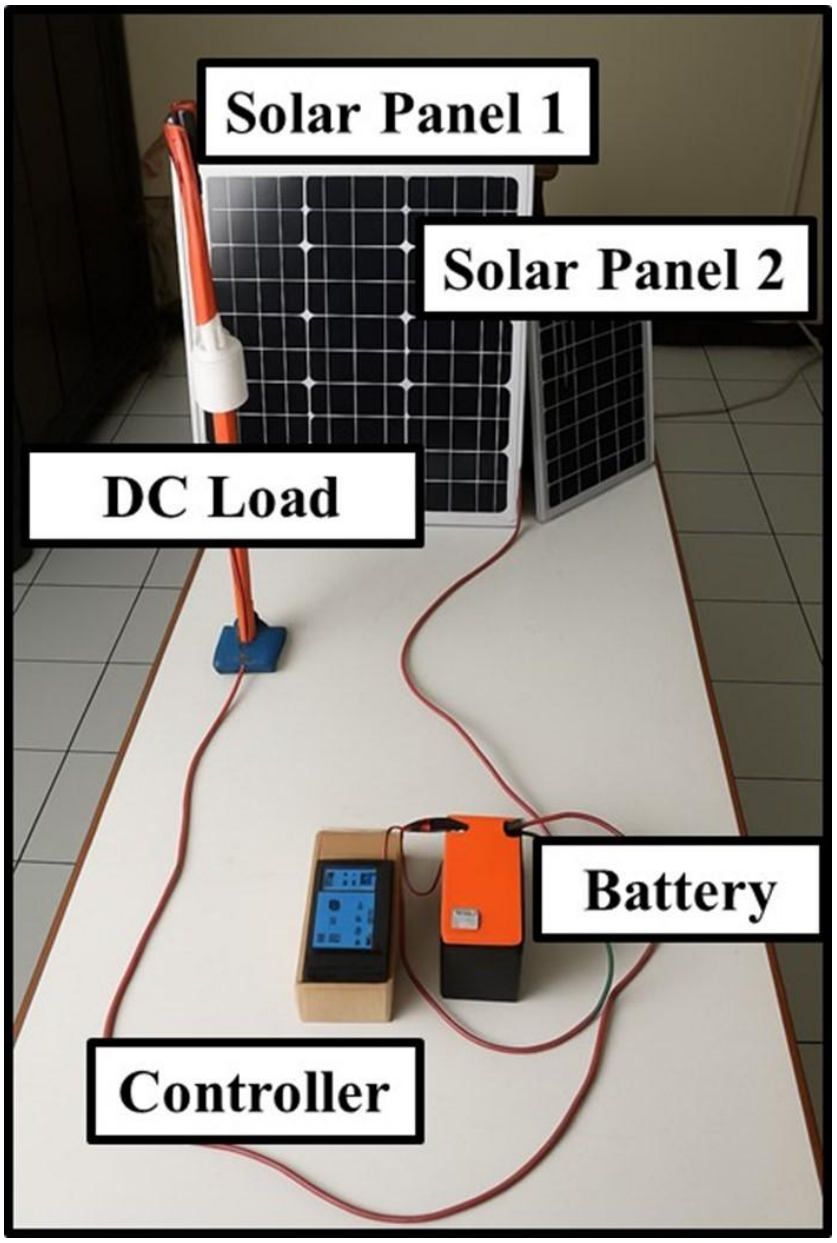

Figure 1.
Kit Arrangement

Figure 2.
Hands-On Activity On SP-DC Experimental Kit

The PTMEA CORR (Point-Measure Correlation) assesses the direction and strength of the relationship between an item's observed responses and the respondents' overall ability measures (in logits). Positive correlations indicate that higher-ability respondents are more likely to answer correctly, confirming that the item aligns with the intended construct. Conversely, negative correlations imply that the item may be flawed—potentially miskeyed, ambiguous, or measuring an unintended dimension. Acceptable PTMEA CORR values generally range between 0.3 and 0.8 (Boone, Staver, & Yale, 2014), where lower values suggest weak discrimination and higher values may indicate redundancy.

The threshold applicable to fit validity according to the Rasch model is as follows: The infit and outfit mean square (MNSQ) values for items and persons fall within the range of 0.5 to 1.5 logits, which is acceptable up to 1.6 if the PTMEA value is positive. Ideally, the value should be 1.0 logits; The infit-outfit ZSTD values for items and persons must be considered because the number of participants is less than 200. These values should fall within the range of -2.0 to 2.0 logits, with an ideal value of 0.0 logits; The PTMEA correlation values for each item in the instrument range from 0.4 to 0.85 logits. Meanwhile to describe user responses, this study use item measure (logit) and score value percentage distribution.

3. Result and Discussion

The evaluation of user responses to Solar-Powered DC (SP-DC) experimental kit occurance in three distinc phases. The first validity confirmed by item fit / misfit by Rasch analysis. Finally, an often-overlooked dimension is the description of user responses based on effectivity, relevance, and durability of SP-DC experimental kit.

3.1 Item Fit / misfit pada efectiveness, relevance, and endurance

Table 2 presents item fit/ misfit to confirmed fit validity of each iitem. The analysis of the data utilizing the Rasch model highlights the effectiveness, relevance, and endurance of teaching aids in a physics educational context. The effectiveness of assembly, use, portability, and storage of these aids were assessed with varying degrees of success. For instance, ease of assembly received an Infit MNSQ of 1.18 and an Outfit MNSQ of 1.27, indicating a somewhat less efficient usability experience. In contrast, ease of use scored lower, with an Infit MNSQ of 0.68, suggesting a more favorable reception where students found it easy to engage with the aids.

Relevancy was measured by the ability of the teaching aids to enhance understanding of key physics concepts, such as series and parallel circuits. The scores ranged from 0.81 to 1.11 across different aspects, with the highest score reflecting a relevant contribution to explaining AC and DC current, pointing to the importance of these aids in motivating students and supporting their comprehension.

Furthermore, endurance metrics indicated the durability of the teaching aids. Items such as the ease of operating the experimental kit and its functionality during educational activities received lower ratings, with Infit MNSQ scores of 0.72 and 0.73, respectively. This suggests that while the materials employed in the educational process are moderately effective, improvements could be beneficial for maximized student engagement and retention of concepts.

All items have a PTMEA CORR> 0.7, indicating that all items have a positive and strong correlation in terms of effectiveness, relevance, and endurance.

3.2 User Responses in Effectiveness Aspect

According to the threshold parameters used in the Rasch model which have been explained in the data analysis section, Figure 3 presents score value distribution of each item in effectiveness aspect. Most participants showed agreement with the statements regarding the item aspects, as indicated by the percentage of participants who mostly selected scales 4 and 5. This result indicates a positive trend in the aspect of effectivity. Users tend to choose statements 4 and 5 because the SP-DC kit is easy to assemble, use, move, and store. This hands-on approach not only enhances students' understanding of the subject matter but also encourages collaboration and critical thinking among peers, fostering a deeper connection to real-world applications.

Figure 4 presents item measure of each item for effectivity aspect. This figure shows all items on the fit effectiveness aspect according to the Rasch model. Item EFF4 has a measure point of 1.03, indicating that it is the most difficult item to agree upon. Meanwhile, item EFF3 shows the easiest item to agree upon, indicated by a measure point of -0.60. The measure points for items

EFF4 and EFF3 indicate that the scale on the effectiveness aspect has a balanced difficulty distribution.

Table 2.
Item Fit/Misfit based on Rasch Modelling

Item	Item Descriptive	Infit MNSQ	Infit ZSTD	Outfit MNSQ	Outfit ZSTD	PTMA
EFF1	Ease of assembly	1,18	0,90	1,27	1,19	0.77
EFF2	Ease of use	0,68	-1,67	0,97	-0,05	0,81
EFF3	Ease of portability	1,20	0,96	1,03	0,21	0,73
EFF4	Ease of storage	1,03	0,22	1,23	1,05	0,79
REL1	Easier to understand physics concepts on the topic of series and parallel circuits, and types of electric current (AC and DC)	1.11	0,58	1,16	0,75	0,79
REL2	Increased motivation to learn physics with the presence of teaching aids as learning media	0,92	-0,32	1,07	0,33	0,79
REL3	Able to demonstrate physical phenomena	0,92	-0,34	0,82	-0,69	0,79
REL4	Necessary for teaching renewable energy	0,81	-0,93	0,69	-1,33	0,80
REL5	Necessary for teaching electric circuits	0,92	-0,32	0,76	-0,96	0,81
REL6	Able to explain AC and DC current	1,07	0,42	1,10	0,52	0,79
ENDU1	Not easily detached, broken, or damaged during use	1,16	0,82	1,28	1,26	0,77
ENDU2	Easy to operate the experimental kit	0,72	-1,44	0,63	-1,33	0,78
ENDU3	Teaching aids function well during use	0,73	-1,36	0,68	-1,11	0,77
ENDU4	Made of safe materials (low voltage)	0,86	-0,62	0,83	-0,61	0,78

Effectiveness pertains to how well the experimental kits achieve their intended educational outcomes. Various studies suggest that low-cost kits and innovative tools, such as those utilizing Arduino technology, have significantly impacted students' learning experiences and comprehension. For instance, research has shown that integrating Arduino controllers for physics experiments allows students to understand complex concepts like linear motion better, as they can

engage with data collection and analysis directly via their smartphones (Pratidhina et al., 2021); (Karakotsou & Zafiriadis, 2023); (Ouariach et al., 2020). This hands-on approach has been linked to enhancing cognitive skills essential for scientific inquiry, as students analyze and evaluate results in practical contexts (Ait Ben Ahmed et al., 2021; Rizki et al., 2024)

3.3 User Responses in Relevance Aspect

Figure 5 presents the distribution of score value for each item in relevance aspect. The distribution of respondents shows that the majority chose scales 4 and 5 for each item in the relevance aspect. For item REL 2, very few respondents selected scale 1. Furthermore, for items REL3, REL4, and REL5, only one-person selected scale 2 for each item. The assessment indicates a positive trend in the aspect of relevance. The activities shown in the image depict active engagement and practical learning outside the classroom.

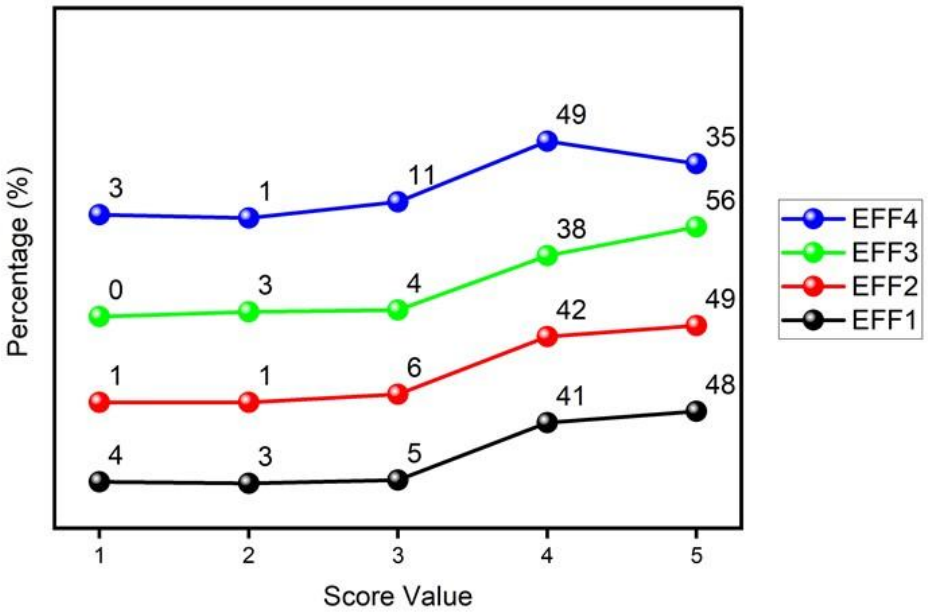

Figure 3.
Score Value (on %) for each item in Effectiveness Aspect

There are items that are the most difficult to approve (REL1) and the easiest to approve (REL2), with a sufficiently good range, so the scale on the relevance aspect is quite balanced. The items that received the highest and lowest approval ratings illustrate a variation in assessments or understanding related to this activity. A balance in the relevance scale indicates that participants feel engaged and have grasped the material being presented. This suggests that there may be differing levels of comprehension among participants, which could drive further discussion and exploration of the topics at hand. Ensuring that all participants are on the same page could enhance their learning experience and overall satisfaction with the activity.

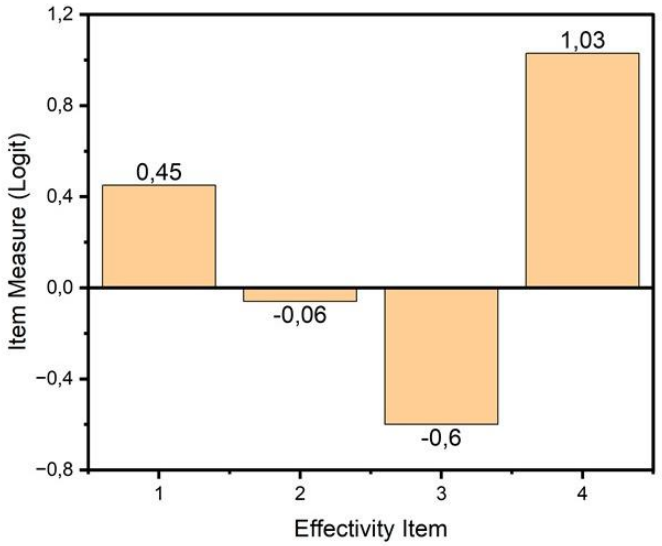

Figure 4.
Item Measure (in Logit) for each item in Effectivity Aspect

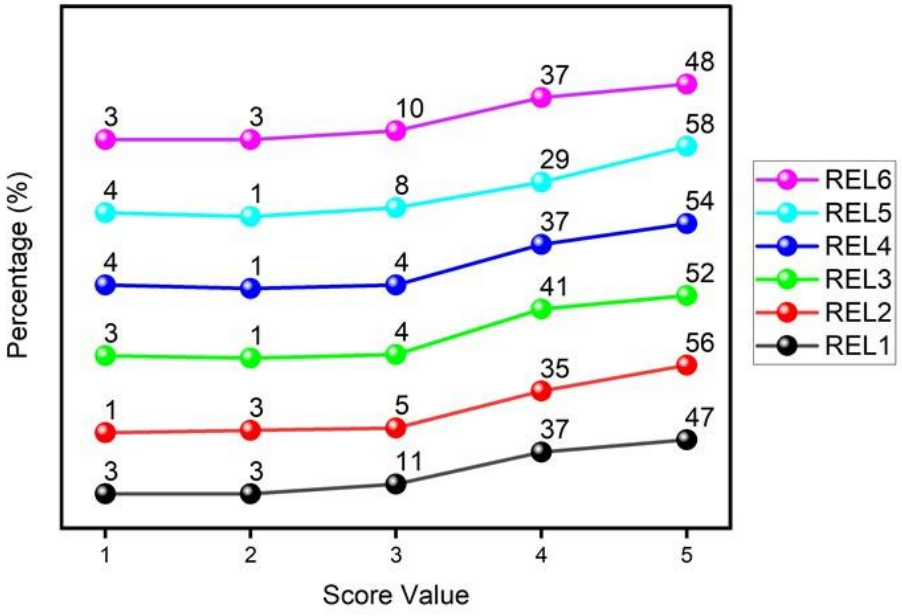

Figure 5.
Score Value (on %) for each item in Relevance Aspect

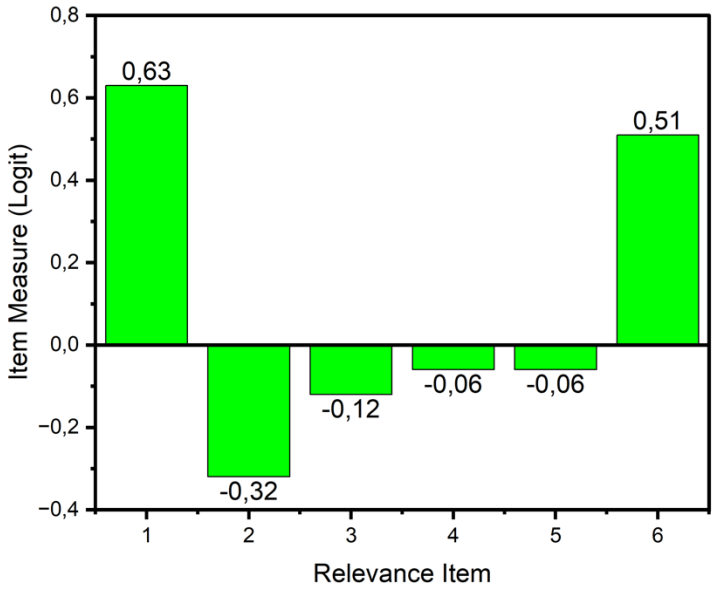

Figure 6.
Item Measure (in Logit) for each item in Relevance Aspect

Relevance analyzes how well the kits align with current educational standards and curricular goals. The growing trend of distance learning necessitates affordable and relevant experimental tools that can be seamlessly integrated into diverse teaching methodologies. Kits that utilize digital platforms and allow for inquiry-based learning have been shown to maintain student engagement by connecting theoretical knowledge to real-world physics applications(Arisa et al., 2022; Castaño et al., 2024). Moreover, studies highlight that relevance to students' lived experiences is instrumental in maintaining their interest in physics, which can be facilitated through interactive and problem-based learning frameworks (Sari et al., 2023; Vidak et al., 2022).

3.4. User Responses in Endurance Aspect

Figure 7 present the score value distribution in endurance aspect. The distribution of the majority response on scales 4 and 5 is quite even, although low scores are still utilized. This indicates that the assessment scale is fairly effective.

Figure 8 presents the item measure for each item in endurance aspect. This indicates that all items strongly contribute to the construct of the endurance aspect. It already has the easiest item to agree on (ENDU2) and the most difficult item to agree on (ENDU1) with a wide distribution, allowing for the detection of differences among respondents. The low level of ease of participants agreeing on item ENDU2 indicates that users agree that the SP-DC kit still needs improvement in terms of robustness. This indicates that participants are struggling with tool incompatibility in kit

materials which may be indicated by errors or cables coming loose from components. However, the SP-DC kit still demonstrates ease of operation in practical experience (ENDU 1). It doesn't require a high level of skill, making it suitable as a teaching aid even for secondary school students.

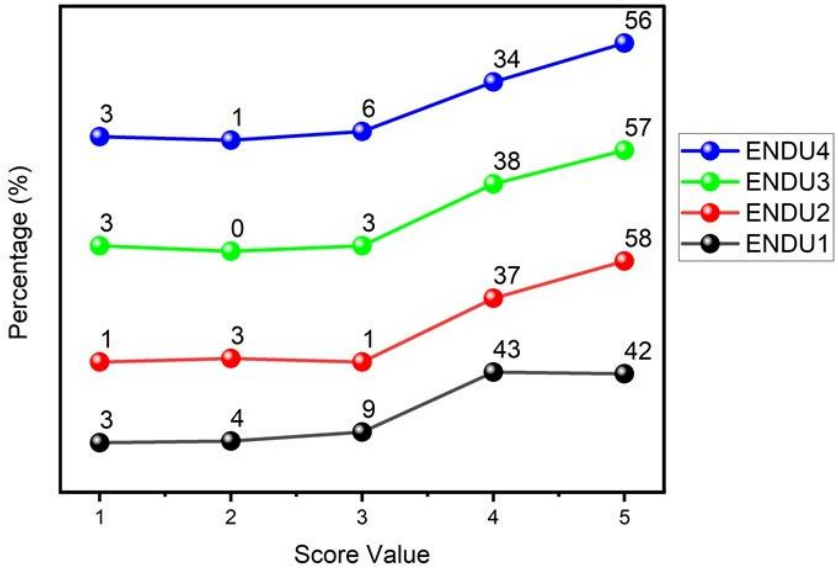

Figure 7.
Score Value (on %) for each item in Endurance Aspect

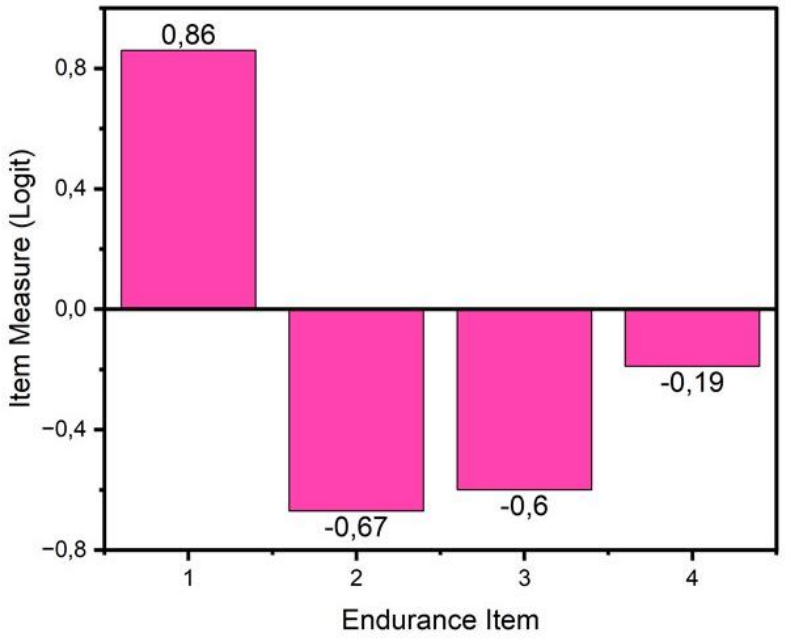

Figure 8.
Item Measure (in Logit) for each item in Endurance Aspect

Endurance is critical for evaluating the long-term usability and sustainability of educational kits. Research indicates that modular kits, such as those made with 3D printing, offer flexibility and adaptability, allowing for various experimental setups while remaining cost-effective (Haverkamp et al., 2022). Additionally, leveraging widespread technology, like smartphone applications, increases the longevity of these kits as they can be updated and enhanced over time (Martins, 2020; Roy et al., 2022). This aligns with educational goals, ensuring that tools remain in demand and effective over extended periods. However, the differences in responses between college students and high school students still need to be discussed in our next article.

4. Conclusion

This study evaluates the effectiveness, relevance, and endurance of a solar-powered direct-current (SP-DC) experimental kit for physics education using Rasch modeling. The Rasch-based validation confirmed that all 14 items met fit criteria— with infit and outfit MNSQ values between 0.5 and 1.5, ZSTD within ±2, and PTMA correlations above 0.7—demonstrating the questionnaire's reliable measurement of effectivity, relevance, and endurance.

In the effectivity domain, participants overwhelmingly endorsed the kit's ease of use, portability, storage, and assembly, with most ratings in the 4–5 range; the scale was well balanced, as "ease of storage" proved the most difficult item to agree on, while "portability" was the easiest. Relevance responses showed high agreement that the kit enhances understanding of current and

voltage on DC circuits and motivates learning, though items addressing conceptual clarity received slightly lower endorsements than those gauging motivational impact. Endurance ratings reflected strong confidence in the kit's durability and functionality—most participants selected top-end scores—yet structural integrity remained the most challenging aspect to endorse, whereas operational ease was the simplest. Taken together, these findings validate the SP-DC experimental kit as a feasible hands-on physics teaching tool that promotes engagement, peer collaboration, and deeper conceptual grasp, and they point to opportunities for targeted refinements in assembly guidance, storage design, and component robustness to further strengthen its effectiveness, relevance, and longevity.

These findings validate the SP-DC kit as a feasible, hands-on physics teaching tool that fosters engagement, collaboration, and deeper conceptual grasp. Targeted refinements in assembly guidance, storage design, and component robustness could further enhance its educational impact and longevity.

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