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Design of an Axle Wheel Laboratory Tool Assisted by Phyphox to Enhance Students' Critical Thinking Skills

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Abstract
This research aims to develop a wheel-and-axle practicum apparatus assisted by the Phyphox sensor application to support the verification of mechanical advantage concepts and strengthen students' critical thinking skills in rotational dynamics learning. The study employed the Research and Development (R&D) method with the 4D model, limited to the development stage due to time constraints. Product validation involved four expert validators, consisting of a physics content expert, a learning media expert, a sensor technology expert, and a pedagogical expert. Validation data were analyzed using Aiken's V formula. The results indicate that the developed practicum tool meets the criteria of content accuracy, technical feasibility, safety, and pedagogical appropriateness. The overall Aiken's V coefficient was 0.91, categorized as highly valid. Experts noted that the integration of magnetic sensors with the Phyphox application enables real-time measurement of angular velocity, providing more precise experimental data compared with manual stopwatch-based methods. The tool effectively visualizes rotational dynamics concepts—such as torque, moment of inertia, and angular acceleration—making it a suitable medium for inquiry-based physics learning. Thus, the Phyphox-assisted wheel-and-axle apparatus is feasible for implementation in physics practicum activities and has the potential to enhance students' critical thinking skills.

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INTRODUCTION

Critical thinking skills are one of the essential 21st-century competencies that learners must possess, particularly in physics education, which demands analytical skills, logical reasoning and evidence-based evaluation García-Carmona, A. (2023). The National Research Council emphasises that science education should ideally provide students with opportunities to conduct scientific investigations, enabling them to interpret phenomena through the use of empirical evidence (National Research Council, 2000). In the context of physics, activities such as analysing experimental data, assessing the consistency of measurement results with theory, and constructing evidence-based arguments form the cornerstone of critical thinking Megowan-Romanowicz. (2010).

As the paradigm of the modern laboratory evolves, the use of mobile technology, such as smartphones, has opened new opportunities for conducting physics practicals in schools Hestenes 1992; and Wells, et.al (1995). The Phyphox app, developed by RWTH Aachen University, has become one of the most widely used platforms because it utilises a smartphone's internal sensors accelerometers, gyroscopes, magnetometers, and others—to conduct physics experiments accurately and efficiently. Findings by Sari et.al (2022) indicate that the use of Phyphox in secondary school practicals can enhance students' scientific process skills, including the ability to observe, interpret, and draw conclusions critically.

Recent research also reinforces the notion that smartphone-based devices can replace most conventional laboratory equipment, which is expensive and difficult for schools to access. Staacks et.al (2018) developed an accelerometer-based practical e-module and reported that it was highly valid and received positive student responses, making it suitable for use in formal education. Similar findings were reported by Raharja, et.al. (2024), who demonstrated that smartphone sensor-based experimental modules in mechanics proved practical, easy to use, and provided accurate measurement results.

A number of other studies have also demonstrated the great potential of Phyphox for applications in physics topics based on motion and dynamics. Putri et.al. (2025) successfully analysed harmonic motion using Phyphox with high accuracy, whilst Yasaroh et al. (2023) measured the moment of inertia of a hollow cylinder using smartphone sensors and obtained results consistent with classical physics theory. Furthermore, a methodological review by Sukariasih (2019) confirms that the use of smartphone sensors in school laboratories can enhance conceptual understanding, as students are directly involved in measurement and digital data analysis.

Globally, modern literature also indicates that smartphone-based laboratories support active engagement, deeper conceptual understanding, and improved critical thinking skills. Zhao (2025), in his comprehensive review, concludes that smartphone-based laboratories not only reduce barriers to accessing laboratory equipment but also enhance the quality of learning through real-time data, digital visualisation, and analytical integration that are not available with conventional equipment.

Based on these findings, the need to design affordable, accurate, and accessible physics laboratory equipment has become increasingly important, particularly for topics in rotational dynamics that require high-precision experimental data. Many schools still face limitations in spindles and digital measurement devices, leading to teaching that is more often theoretical and verification-based. Therefore, this study has developed a Phyphox-assisted spindle wheel laboratory apparatus to measure parameters such as angular velocity and moment of inertia in real-time, enabling students to experience the actual scientific process: observing, collecting data, analysing, and drawing conclusions.

This innovation is expected not only to provide a practical solution to limitations in laboratory facilities but also to promote more investigative, interactive, and critical-thinking-oriented physics learning. By utilising smartphone technology, which is owned by almost all students, this practical apparatus offers an authentic, affordable laboratory experience that aligns with the direction of digital-based science learning transformation.

Given the background outlined above, this research is of high urgency and warrants development. The primary objective of this study is to develop and test the validity and effectiveness of the Phyphox magnetic sensor-based simple-axle wheel practical tool as a suitable medium for enhancing students' critical thinking skills in the subject of rotational dynamics.

METHOD

Product validation was carried out to assess the suitability of the Phyphox magnetic sensor-based wheel laboratory apparatus before it was tested with students. The validation process involved four expert validators: a physics expert, a learning media expert, a sensor technology expert, and a pedagogical expert. Each validator assessed the product based on four main aspects, namely: (1) content, covering the accuracy of concepts and relevance to learning outcomes; (2) design/media, covering safety, appeal, and ease of use of the apparatus.

The product validation instrument was designed as an assessment sheet completed by the experts using a four-point Likert scale, with the following rating categories: 1 = unsuitable, 2 = somewhat unsuitable, 3 = suitable, and 4 = highly suitable (Sugiyono, 2019). The validation data were then analysed using Aiken's V coefficient to determine the validity of each assessed aspect (Aiken, 1985). Aiken's V ranges from 0 to 1, with interpretation criteria of 0.00–0.40 indicating the 'inadequate' category, 0.41–0.70 'adequate', 0.71–0.90 'valid', and 0.91–1.00 'highly valid' (Azwar, 2012).

Based on the calculations, Aiken's V scores for each aspect were as follows: content aspect = 0.92, design/media aspect = 0.89. The overall average Aiken's V score was 0.90, which falls within the "highly valid" category. These results indicate that the Phyphox sensor-based wheel experiment apparatus developed has met the criteria for content, presentation, technical, and pedagogical suitability for use in learning. Several suggestions for improvement from the validators, such as adding a shaft guard for greater safety and simplifying measurement steps in the Phyphox application, have been incorporated prior to the limited trial phase.

RESULTS AND DISCUSSION

Product validation was conducted to assess the suitability of the Phyphox sensor-based spindle wheel laboratory apparatus as a physics teaching aid for rotational dynamics. The two main aspects validated were content and design/media, involving two expert validators: a physics lecturer and an educational media specialist. The assessment was carried out using a four-point Likert-scale validation sheet, with categories 1 (unsuitable), 2 (less suitable), 3 (suitable), and 4 (very suitable).

The validation data were then analysed using Aiken's V coefficient to assess inter-validator agreement regarding the suitability of each aspect (Aiken, 1985). Aiken's V ranges from 0 to 1, with the following interpretations: 0.00–0.40 = insufficiently valid, 0.41–0.70 = moderately valid, 0.71–0.90 = valid, and 0.91–1.00 = highly valid (Azwar, 2012).

Table 1. An example of a table.

No	Aspect assessed	Aiken's V	Category
1.	Subject Matter Expert	3,70	0,93
2.	Design/Media Expert	3,55	0,88
	Average	3,63	0,91

Based on Table 1, the average value of Aiken's V was found to be 0.91, which falls within the 'highly valid' category. In terms of content, the validators assessed that the tool was consistent with the concepts of rotational dynamics, particularly in explaining the relationships among torque, moment of inertia, and angular acceleration. The physical concepts visualised through the motion of the spindle-mounted wheel are consistent with Newton's Second Law of Motion for rotational motion, making it suitable for helping students understand the cause-and-effect relationship between force and motion (Wangi et al., 2022).

Meanwhile, regarding the design/media aspect, the validators stated that the apparatus has a simple, stable, and safe design. The apparatus's configuration, featuring a magnetic sensor on the wheel, allows students to observe changes in angular velocity directly via a graph in the Phyphox application. Furthermore, the device's design utilises low-cost local materials, making it replicable in schools with limited laboratory facilities. However, several suggestions for improvement were offered, including smoothing the wheel's surface to reduce friction and adding additional supports to maintain the shaft's stability whilst rotating.

These validation results indicate that the developed practical apparatus has met the criteria for content and design validity, in accordance with Nieveen's (1999) principles of educational product development, namely that a good product must satisfy validity aspects before its practicality and effectiveness are tested. Consequently, the Phyphox sensor-based wheeled practical apparatus is deemed suitable for use in the pilot testing phase of the learning process.

Illustrations

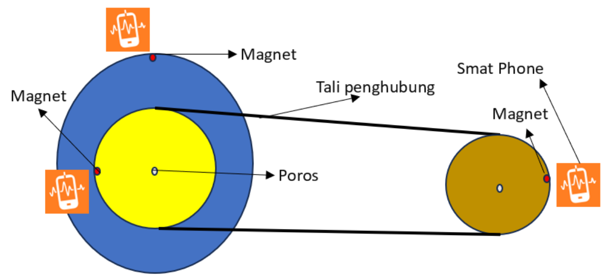

Figure 1. Design of a Spoked Wheel Laboratory Apparatus

Figure 2. Graphs Displayed by the Phypox Application on a Laptop

Discussion

The validation results show that the Phyphox-based rotating wheel laboratory apparatus developed meets the validity criteria for both content and design. In terms of content, the main advantage of this apparatus lies in its ability to transform abstract concepts of rotational dynamics into a concrete learning experience that students can observe directly. This visualisation helps students understand the relationship between theoretical concepts and real phenomena, whilst supporting inquiry-based learning that emphasises active engagement in observing, analysing, and drawing conclusions about physical concepts (Plomp & Nieveen, 2013).

From a design perspective, integrating magnetic sensors with the Phyphox application has been shown to improve the accuracy of time and angular velocity measurements compared to conventional manual stopwatches. This finding is consistent with the research by Fransiska et al. (2021); and Yasaroh et.al. (2021), who reported that Phyphox-based laboratory equipment can provide more precise real-time data and increase students' interest in laboratory activities.

Overall, the validation of the content and design aspects indicates that this product meets high-quality criteria for use in 21st-century physics education (Rohman et.al 2019), where the integration of technology serves as a vital means of developing students' critical thinking skills (Nieveen, 1999; Wangi et al., 2022).

CONCLUSION

This development research has produced a Phyphox sensor-based spindle wheel laboratory apparatus, validated through expert assessment of its content and design/media aspects. The validation results show an average Aiken's V score of 0.91, which falls into the 'highly valid' category, with a score of 0.93 for the content aspect and 0.88 for the design aspect. This indicates that the developed apparatus aligns with the concepts of rotational dynamics and features a simple, safe, and user-friendly design.

In terms of content, the apparatus can empirically visualise the concepts of torque, moment of inertia, and angular acceleration, thereby supporting inquiry-based learning and the development of students' critical thinking skills. Meanwhile, from a design perspective, the Phyphox-based sensor tool enables real-time angular velocity data collection, enhances measurement precision, and provides a more interactive laboratory experience.

Thus, it can be concluded that the Phyphox-based rotating wheel is a practical tool suitable as an innovative physics teaching aid for the topic of rotational dynamics. This product has the potential to strengthen student engagement in experiment-based learning whilst addressing the limitations of school laboratory facilities. Further research is recommended to test the practicality and effectiveness of this tool in real-world learning contexts, assessing its impact on students' critical thinking skills and learning outcomes.

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