Journal Evaluation in Education (JEE)
Vol. 7, No. 4, October 2026, pp. 785~806
ISSN: 2716-4160, DOI: 10.37251/jee.v7i4.3913

Research Article

Developing a Phyphox E-Module with Rule-Based Feedback for Science Process Skills in Rotational Dynamics

Riska Adelia[1], Tanti[1,*], Jerfi[1]
[1] Faculty of Tarbiyah and Teacher Training, UIN Sulthan Thaha Saifuddin Jambi, Jambi, Indonesia

Article Info

Article history:

Received Aug 24, 2026
Revised Sep 25, 2026
Accepted Oct 11, 2026
OnlineFirst Oct 20, 2026

Keywords:

Inquiry Skills
Physics E-Module
Practical Work
Rule-Based Feedback
Smartphone Sensors

ABSTRACT

Purpose of the study: Science process skills are required outcomes of Indonesia's Kurikulum Merdeka, yet teachers often teach rotational dynamics without hands-on experiments. This study developed a practicum e-module that combines Phyphox experiments with rule-based formative feedback linked to science process skill indicators, and evaluated its validity, practicality, and associated changes in students' scores.

Methodology: The ADDIE model guided development. The product was trialed with 32 Grade XI students at Senior High School 5 Sarolangun using a one-group pretest-posttest design. We analyzed validity and practicality data descriptively. Pretest and posttest scores from a 15-item science process skills test were analyzed using the Wilcoxon signed-rank test, normalized gain, and effect size.

Main Findings: The mean expert-validity score was 88.72%, and students rated the e-module practical (M = 4.13; 82.65%). Mean scores increased from 30.97 to 77.09 ($Z = -4.643$, $p < .001$), with a moderate normalized gain ($g = 0.67$) and a large within-group effect size ($r = 0.82$). The largest changes occurred in identifying variables, designing experiments, and analyzing data, whereas formulating hypotheses and drawing conclusions changed least.

Novelty/Originality of this study: The e-module is therefore a valid and practical resource for supporting experimental work where laboratory equipment is limited. Because the study lacked a comparison group, the observed change cannot be attributed to the e-module alone; controlled and longer-term trials are recommended.

This is an open access article under the CC BY license
© 2026 by the author(s)

Corresponding Author:
Tanti,
Faculty of Tarbiyah and Teacher Training, UIN Sulthan Thaha Saifuddin Jambi,
Jambi-Ma Bulian KM 16 Simpang Sungai Duren, Muaro Jambi, Muaro Jambi, 36361, Indonesia
Email: tanti@uinjambi.ac.id

1. INTRODUCTION

The Merdeka Kurikulum in Indonesia's education system requires students to master science process skills (SPS), but high school physics classes rarely carry out practical work. Two conditions sustain this situation: schools lack laboratory equipment, and teaching still centers on explaining formulas. SPS is both procedural and cognitive; without practicums, students lose the opportunity to control variables, collect

evidence, interpret data, and draw conclusions. Process skills can only be developed and assessed through tasks that truly involve students in the inquiry process [1]. Anggereni et al. [2] identified limited laboratory equipment as the main reason for the low frequency of experimental activities in physics learning. Moreover, Yunita [3] reports junior secondary students' science process skills at 39.44%, with the two weakest SPS dimensions in that study being variable identification and data interpretation. Thus, SPS remains a curriculum achievement that is difficult for students to achieve because classroom conditions do not provide the practical experience they need.

Rotational dynamics is a material that is very difficult to teach. Its main variables, namely angular velocity, angular acceleration, torque, and moment of inertia, are abstract and rarely directly felt in everyday experience. Measuring these variables generally requires photogates, rotational motion sensors, or data loggers that many high schools in Indonesia lack. Rimoldini and Singh [4] found that students across undergraduate levels struggled with torque, moment of inertia, and rolling, and that part of this struggle carried over from faulty reasoning about linear motion, such as expecting a steady torque to keep angular velocity steady. In the Indonesian context, Rafika and Syuhendri [5] reported that only 1.70% of 35 grade XI students understood rotational and rolling motion, while 58.30% held misconceptions across every concept tested, including moment of inertia, angular velocity, and angular acceleration. Therefore, rotational dynamics practicum in schools requires a measuring tool that is easily accessible, quantitative, and capable of visualizing abstract rotation quantities.

Phyphox offers a practical solution by converting sensors on regular smartphones into laboratory instruments that record real physical data. Unlike simulations that display model outputs programmed by developers, Phyphox measures an object's actual motion through an accelerometer, gyroscope, and other sensors. This distinction is epistemologically important, as SPS such as measuring, identifying variables, and interpreting data assume data that carries uncertainty and noise from real phenomena. Staacks et al. [6] developed Phyphox as a free application that provides access to raw sensor data, real-time graphs, and remote experimental control via a web browser. Its usefulness in the classroom has been demonstrated in measuring kinematic variables [7] and in practical guides for physics teachers [8]. A literature review by Imtinan and Kuswanto [9] also shows that Phyphox has been applied to a wide range of physics topics in experiment-based learning. Thus, Phyphox provides authentic empirical data, a prerequisite for developing SPS. Systematic reviews and comparative studies likewise identify smartphone sensors as accessible experimental tools, while emphasizing that their learning value depends on task design, guidance, and integration with physics concepts [10]-[16].

The use of smartphone sensors for rotation phenomena is emerging in the literature, but its scope remains limited. Because smartphone gyroscopes record angular velocities directly, rotational dynamics are one of the most natural applications for these devices. Nonetheless, most existing research focuses on demonstrating measurement techniques rather than on how learners learn through the measurements. Monteiro et al. [17] used Phyphox and a turn table to measure regular circular motion and relate centripetal acceleration to angular velocity. Wheatland et al. [18] utilized smartphones as a free-rotation laboratory to investigate the rotation of rigid objects against their main axes. Both studies primarily focused on the quality and physical interpretation of measurement results, and neither was designed as a structured practicum to develop SPS for high school students. Therefore, the application of Phyphox to rotational dynamics in SPS-oriented high school practicum is still rarely studied.

E-modules are a common way to structure practical work in Indonesian schools. They combine text, images, video, and interactive elements, allowing students to follow experimental procedures at their own pace. Their value, however, depends on whether they merely digitize printed worksheets or respond to what students actually do. Darmaji et al. [19] embedded a problem-solving approach in a basic physics practicum e-module oriented toward science process skills. Although research on e-modules is expanding, literature reviews show a predominant focus on higher-order thinking via interactive multimedia and Android platforms [20]. Digital literacy has indeed been linked to students' science process skills (SPS) and critical thinking [21]. However, practical-work e-modules rarely provide automated feedback during data recording, processing, and interpretation. Reviews of inquiry-based mobile learning further indicate that mobile resources are most productive when they organize purposeful investigation rather than merely digitizing content [22]-[25].

Automated feedback can close these gaps by responding to learners' work as it is generated. Timely and specific feedback allows learners to correct their procedures and interpretations before mistakes become entrenched. In practicums, this is possible because every SPS indicator, from reading graphs to formulating conclusions, can be assessed against explicit criteria. Meyer et al. [26] examined automated feedback on physics tasks generated with open-source generative artificial intelligence. A systematic review by Wang et al. [27] shows that AI-based feedback and assessment tools are mostly researched at the higher education level. Letteri and Vittorini [28] also examined AI-generated feedback in university-level data science education. Thus, existing research is dominated by generative models in higher education, leaving room for rule-based feedback designed per SPS indicator for high school practicum, which demands transparent and predictable feedback. Meta-analytic evidence also shows that feedback is most effective when it is specific, timely, and directed toward the learning process [29].

Based on these gaps, this study developed a practicum e-module that integrates Phyphox and rule-based feedback on the rotational dynamics material in class XI. This e-module combines real sensor data from Phyphox with feedback triggered by each SPS indicator when students complete the practicum. This design addresses the three identified gaps simultaneously, rather than separately. First, this study offers combinatorial novelty because, to the best of the author's knowledge, no product integrates Phyphox, rule-based feedback, and e-modules in a single learning resource. Second, this study offers content novelty by applying Phyphox to rotational dynamics, a material that is still rarely studied in Phyphox-based learning research. Third, this study offers contextual novelty by aligning with the Independent Curriculum and the high school/MA context in Indonesia, using the ADDIE development model [30]. The design follows established inquiry cycles and evidence that guided inquiry can support scientific reasoning, higher-order thinking, and laboratory performance [31]-[36]. Recent research also links smartphone-supported laboratory work with science process skills and student engagement [37]-[41]. Therefore, this study aims to develop the e-module, evaluate its validity and practicality, and describe the changes in students' SPS after its implementation.

2. RESEARCH METHOD

This study followed a research and development design structured by the ADDIE model, and the resulting product was trialled in a one-group pretest–posttest arrangement. ADDIE was selected because each of its five stages closes with a formative evaluation, so that revision can be made before the following stage begins [30]. The single-group arrangement follows from the setting rather than from preference, since only one grade XI class at the school met the equipment condition the trial imposed. In the analysis stage, learning needs were mapped through interviews, classroom observation, and a needs analysis questionnaire. The design stage set out the structure of the e-module, placing Canva-based conceptual material, Phyphox experiments on moment of inertia and angular velocity, and rule-based feedback within one sequence. The development stage realized that structure in Heyzine PDF Corporate Edition, configured the gyroscope and accelerometer routines in Phyphox, encoded the feedback rules, and submitted the product to three experts in physics content, instructional media, and assessment for review. The implementation stage brought the revised e-module into the classroom over five lessons, and the evaluation stage examined its validity, its practicality, and the change in students' science process skill scores. The overall ADDIE model procedure is presented in Figure 1.

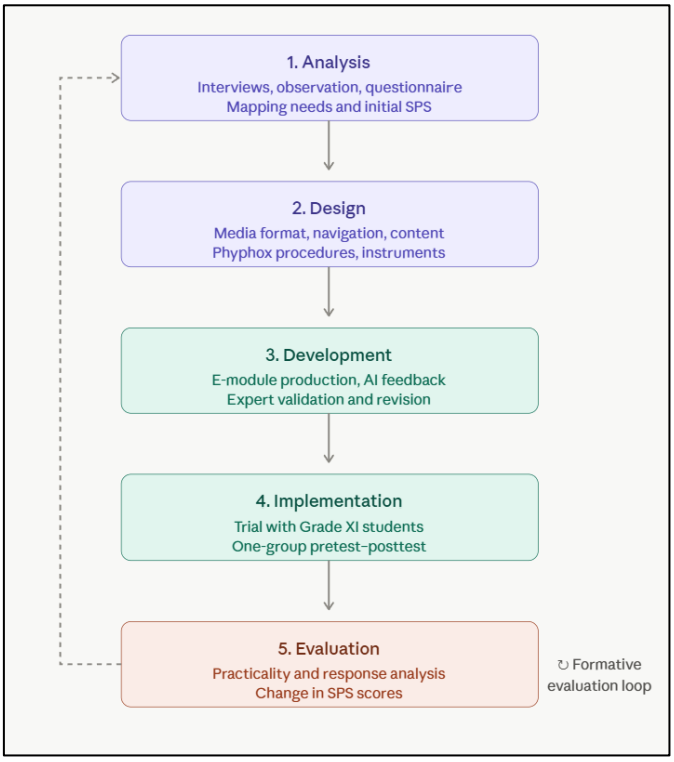


Figure 1. Research Procedure Based on the ADDIE Model

Figure 1 shows the development stages using the ADDIE model. First, in the analysis stage, we identified learning needs through interviews with ten students and two teachers, learning observations, and a needs-analysis questionnaire. This stage mapped students' difficulties in comprehending rotational motion material, the existing practicum conditions, and students' current mastery of SPS. The analysis showed that

students' main conceptual difficulties included separating rotational motion components, visualizing the angular velocity vector, and understanding moment of inertia. Second, in the design stage, we designed the e-module structure by integrating Canva-based conceptual material, Phyphox-based experiments for moment-of-inertia and angular-velocity practicums, and rule-based feedback to provide feedback to students. Third, in the development stage, we used Heyzine PDF Corporate Edition to design the e-module, configured Phyphox experiments on the gyroscope/accelerometer sensors, and developed a feedback algorithm based on a rule-based expert system. Next, during implementation, we conducted expert validation (physics material, instructional media, evaluation), followed by trials with 32 students. Finally, in the evaluation stage, we measured the product's validity, practicality, and effectiveness.

Four kinds of data were collected across the five stages. The data gathered in the analysis stage are qualitative and served to shape the design rather than to evaluate it. The remaining three are quantitative and carry the judgments of validity, practicality, and change in skill. Needs data came from interviews with ten students and two teachers, from observation of physics lessons, and from a needs analysis questionnaire, and pointed to three recurring difficulties: separating the components of rotational motion, visualizing the angular velocity vector, and interpreting moment of inertia. Validity data came from expert judgments recorded on a 29-item sheet with a five-point Likert scale ($\alpha = 0.89$). Practicality data came from a 42-item student response questionnaire ($\alpha = 0.91$) covering seven aspects: ease of use (5 items), display and design (5 items), material and learning (6 items), practical work with Phyphox (7 items), feedback (6 items), science process skills (7 items), and perceived benefit (6 items). Science process skill data came from a 15-item multiple-choice test addressing problem formulation, hypothesis generation, variable identification, experimental design, data analysis, and conclusion drawing (KR-20 = 0.82). The reliability coefficients were interpreted as evidence of acceptable internal consistency for research use [42].

Data analysis proceeded along three lines, one for each question the study asks. Validity and practicality were treated descriptively, since both rest on judgments recorded against fixed criteria rather than on comparison between groups. Change in science process skills was treated inferentially, though as a within-group change over time rather than as an effect attributable to the e-module alone. Validity was expressed as a percentage of the maximum validator score, read against four bands: above 80% very valid, 60–80% valid, 40–60% fairly valid, and below 40% invalid. Practicality was expressed as a mean questionnaire score, read as 4.20-5.00 very practical, 3.4–4.2 practical, 2.6–3.4 fairly practical, and below 2.60 not practical. Distribution of the pretest and posttest scores was examined with the Shapiro–Wilk test, and because normality did not hold, the Wilcoxon signed-rank test was applied at $\alpha = 0.05$, accompanied by the effect size $r = Z/\sqrt{N}$ with Lakens' [43] bands of 0.5, 0.3, and below. Normalized gain was computed as $g = (S_{post} - S_{pre}) / (S_{max} - S_{pre})$ and read against Hake's [44] bands of 0.7 and 0.3, both for the total score and for each science process skill indicator, with all computation carried out in SPSS 26.

3. RESULTS AND DISCUSSION

3.1. Product Development Results: Phyphox-Integrated E-Module

The needs analysis showed that rotational motion was taught only through theoretical concept and worked examples, with no practical component. Limited laboratory equipment contributed to this, and the lack of experiments left teachers without a way to see how well students comprehended the material and mastered science process skills during lessons. The interview transcript of ten students highlighted three ongoing difficulties: identifying the elements of rotational motion, forming a conceptual image of angular velocity vectors, and understanding moments of inertia. Interviews with two physics teachers also pointed to two further problems: detecting conceptual understanding and assessing students' abilities in the scientific process. In the self-evaluation survey, the students said that hypothesis formulation and experimental design were the areas in which they were least proficient (see Figure 2). Both aspects are addressed through experimentation, which the classroom has ignored in the past.

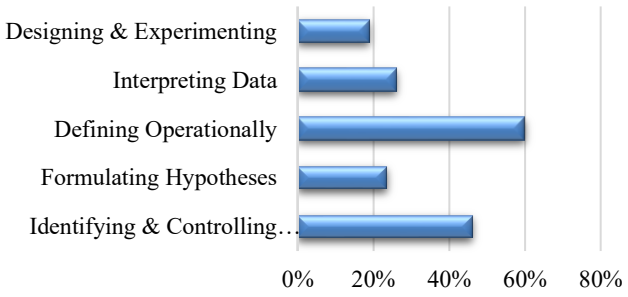


Figure 2. Students' SPS self-assessment result

Figure 2 shows an uneven profile of science process skills among students, with four of the five integrated indicators falling below 50%. This pattern suggests that students are relatively capable of handling the more definitional aspects of inquiry, but struggle with skills that require them to generate, test, and make sense of ideas independently. Such a profile is consistent with practicum activities that follow prescriptive procedures, in which students seldom formulate their own hypotheses, design their own investigations, or interpret authentic measurement data. Defining operationally recorded the highest achievement at approximately 60%, followed by identifying and controlling variables at approximately 46%. In contrast, interpreting data and formulating hypotheses reached only about 26% and 23%, respectively. The lowest achievement was found in designing and experimenting at approximately 19%, indicating that fewer than one in five students demonstrated this skill adequately. These gaps point to the need for practicum learning resources that provide structured opportunities to design experiments, collect real data, and receive indicator-specific feedback, which forms the basis for developing the e-module in this study.

The e-module was built to meet these requirements, and each of its specifications follows from them. It was designed in Canva and published as a flipbook in FlipPDF Professional, so that students could open it on smartphones or computers without installing additional software. The smartphone that displays the e-module also runs Phyphox, which removes the need for separate laboratory hardware. Learning activities follow the five phases of problem-based learning, and each phase is linked to the science process skills it calls on. The experiments use the gyroscope and accelerometer to record angular velocity in investigations of moment of inertia. Rule-based feedback is attached to the experimental tasks, and each rule responds to a science process skill indicator rather than the numerical answer. Figure 3 shows how these components are arranged across the e-module.

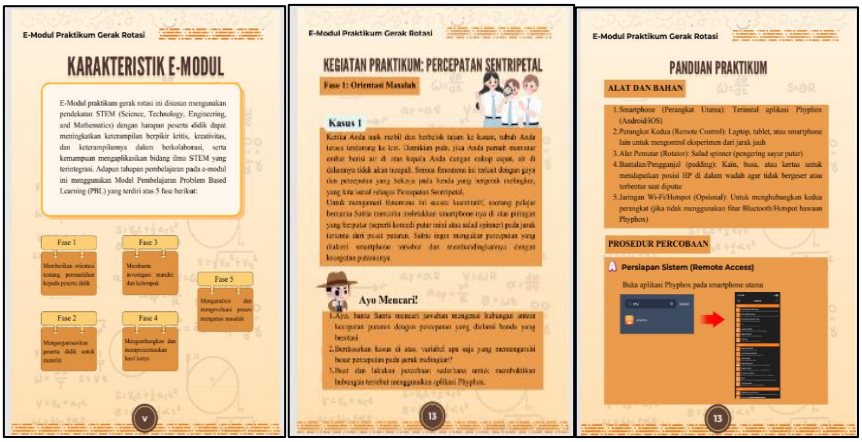


Figure 3. Characteristics of the Phyphox-integrated practicum e-module

Figure 3 shows the pedagogical framework used to develop the e-module. Problem-based learning was chosen because it begins with a problem that students cannot settle without collecting evidence. That starting point makes experimental work necessary rather than optional, which the needs analysis found missing. In the orientation phase, students meet a rotational phenomenon and formulate a problem and a hypothesis about it. In the organizing and investigating phases, they identify variables, plan the measurement, and record angular velocity with Phyphox. In the developing and presenting phase, they analyze their graphs and conclude. In the final phase, they evaluate the procedure they followed. Because each phase demands a named science process skill, the feedback rules could be written indicator by indicator.

3.2. Validity and Practicality Assessment

Experts rated the e-module as highly valid, with an overall score of 88.72%. Validity was established before any student used the product, so that the trial began with material that had already been checked and revised. Three validators assessed the e-module from different standpoints, which allowed a weakness in one aspect to be detected even when the others scored well. The content validator gave 88.60%, the media validator 90.00%, and the assessment validator 87.56%. Their arithmetic mean was 88.72%. All scores exceeded the 80% threshold for the very valid category. The e-module therefore met the validity criterion on content, media, and assessment grounds before implementation began.

Students rated the e-module practical, with an overall mean of 4.13 (82.65%) on the 42-item response questionnaire. The 32 students who used the e-module during the trial judged its practicality, as their experience determines whether it can work in a typical lesson. However, a single overall mean can conceal aspects students found difficult. The questionnaire therefore reports seven aspects separately, from ease of use to perceived benefit (Table 1). Ratings clustered at the upper end of the scale: 56.8% were 4, 28.2% were 5, and 15.0% were

3. No student rated any item 1 or 2. The e-module thus met the practicality criterion, and the aspect scores show where that judgment was strongest and weakest.

Table 1. Practicality Results of the E-Module per Aspect

Aspect	Number of Items	Mean	Percentage (%)	Category
Ease of Use	5	4.22	84.38	Very Practical
Display and Design	5	4.11	82.12	Practical
Material and Learning	6	4.20	84.06	Very Practical
Practicum and Phyphox	7	4.06	81.25	Practical
Rule-Based Feedback	6	4.18	83.65	Very Practical
Science Process Skills	7	4.06	81.16	Practical
Benefit and Effectiveness	6	4.13	82.60	Practical
Overall Mean	42	4.13	82.65	Practical

Table 1 shows that, of the seven aspects measured, three obtained the "Very Practical" category, namely ease of use (84.38%), material and learning (84.06%), and rule-based feedback (83.65%). The remaining four aspects fell into the "Practical" category, with percentages above 81%. The ease-of-use aspect received the highest score, indicating that the e-module interface is sufficiently intuitive and easy for students to operate. Meanwhile, the practicum-and-Phyphox aspect and the science-process-skills aspect obtained the lowest scores (4.06), indicating that some students still encountered difficulties with sensor calibration and required intensive guidance in the early phase. The distribution of responses shows that 56.8% gave a score of 4, 28.2% gave a score of 5, and 15.0% gave a score of 3, with none giving a response of 1 or 2. This finding is consistent with Wardani et al., (2023), who emphasized the importance of flexibility of access in e-modules. Overall, this positive response confirms that the developed e-module is accessible and resonant with the learning preferences of the digital generation.

3.3. Change in SPS Scores

Before scores were compared, the distribution of each set was examined to choose an appropriate test. A paired t-test assumes that both sets of scores are approximately normal, and a violation in either set is enough to rule it out. The Shapiro–Wilk test suits a sample of 32, which is why it was preferred to the Kolmogorov–Smirnov test also reported by SPSS. Pretest scores were normally distributed ($W = 0.945$, $p = .105$). Posttest scores were not ($W = 0.896$, $p = .005$), as Table 2 shows. The posttest distribution was negatively skewed, with scores concentrated toward the upper end of the scale (Table 3). The Wilcoxon signed-rank test was therefore used to compare pretest and posttest scores.

Table 2. Shapiro–Wilk Normality Test Results

Score	Shapiro-Wilk W	df	p	Interpretation
Pretest SPS	0.945	32	.105	Normal
Posttest SPS	0.896	32	.005	Non-normal

Table 3. Descriptive Statistics of Pretest and Posttest

Statistic	Pretest	Posttest
Mean	30.97	77.09
Standard deviation	14.72	19.81
Median	33.00	80.00
Minimum	7	40
Maximum	73	100
Interquartile range	20	37

Science process skill scores were markedly higher after the trial than before it. The mean rose from 30.97 to 77.09, a difference of 46.12 points on a 100-point scale. The median moved in the same direction, from 33 to 80, which matters because the posttest distribution was not normal. The lowest score rose from 7 to 40, and the highest from 73 to 100. The spread of scores also widened, with the standard deviation increasing from 14.72 to 19.81. Students therefore did not move as a block, and some gained considerably more than others. Whether the paired change exceeds what chance would produce was tested with the Wilcoxon signed-rank test (Table 4).

Table 4. Distribution of Ranks for the Wilcoxon Test

Rank category or statistic	N or value	Mean rank	Sum of ranks
Negative ranks	3	3.83	11.50
Positive ranks	28	17.30	484.50
Ties	1	—	—
Total	32	—	—
Wilcoxon Z	-4.643	—	—
Two-tailed p	< .001	—	—

Table 4 shows that 87.5% of students had higher posttest scores, 9.4% had lower scores, and 3.1% had unchanged scores. The Wilcoxon result ($Z = -4.643$, $p < .001$) indicates a statistically significant within-group change. The magnitude of this change is summarized in Table 5.

Table 5. Indicators of Pretest-Posttest Change

Indicator	Value	Category
N-Gain	0.668	Moderate
Wilcoxon effect size (r)	0.82	Large
Mean score increase	46.12 points	—

$$\text{N-Gain} = \frac{(77.09-30.97)}{(100-30.97)} = 0.668$$

Table 5 shows a moderate mean N-Gain of 0.668 and a large Wilcoxon effect-size estimate of $r = 0.82$. These values describe the magnitude of the pretest-posttest change within the participating class. Because the study used a one-group design without a comparison condition, the statistics do not establish that the e-module alone caused the increase.

This study produced a Phyphox-based practicum e-module on rotational dynamics that experts rated very valid, and students rated practical. The trial also recorded a substantial change in students' science process skill scores, with a moderate normalized gain and a large effect size. This change, however, was not evenly distributed across the skill indicators. The largest changes occurred in identifying variables, designing experiments, and analyzing data, whereas formulating hypotheses and drawing conclusions changed the least. The practicality ratings showed a parallel pattern, as the two lowest-rated aspects were working with the sensor and exercising science process skills. The needs analysis had identified designing experiments and formulating hypotheses as the weakest skills before trial. The largest change therefore appeared in one of these two weak skills, designing experiments, and the smallest in the other, formulating hypotheses.

These results matter most in schools where laboratory equipment is scarce, as the needs analysis described. Kurikulum Merdeka expects students to carry out investigations, however many schools lack the equipment those investigations require A smartphone-based practicum narrows this gap because its built-in sensors turn a device most students already carry into a measuring instrument [45], [46]. Anggereni et al. [2] linked the low frequency of physics experiments to limited laboratory equipment. Yunita [3] found variable identification and data interpretation among the weakest science process skills, which are closely related to the skills that changed most in the present trial. In this study, experimental work returned to a unit taught without it, and it did so without new laboratory hardware. The e-module is therefore best read as a response to an infrastructure constraint, not as a replacement for laboratory work where laboratories exist.

The pattern of change follows what the Phyphox experiments require students to do. Identifying variables, designing an experiment, and analyzing data are exercised every time a student sets an object rotating and records its angular velocity. By contrast, formulating hypotheses and drawing conclusions require reasoning that goes beyond the measurement itself . Bao et al. [47] emphasize that scientific reasoning depends on coordinating evidence, variable control, and theory testing. Each measurement forces a decision about what to change, what to hold constant, and how to read the resulting graph. Because Phyphox records the motion of a physical object rather than generating output from a model, those decisions have visible consequences in the data. A poorly controlled trial produces an inconsistent graph, and the feedback rules then respond to the skill rather than the answer. Formulating hypotheses and drawing conclusions, by contrast, require reasoning that goes beyond the measurement itself. The e-module thus gave most practice to the skills tied to measurement and least to the skills tied to inference, and the distribution of change reflects that balance.

This interpretation fits the view that science process skills develop through use in genuine enquiry rather than through description. Harlen [1] argued that process skills cannot be separated from the content and context in which they are exercised. Holmes and Wieman [48] similarly argued that the ability to reason with data develops through repeated practice in making decisions from data, with feedback on these decisions. Phyphox records the motion of physical objects rather than generating model outputs. Procedural decisions thus leave visible traces in the data, distinguishing physical from virtual laboratories [36]. The rule-based feedback

responds to these traces at what Wisniewski et al. [29] called the process level, so a correct value obtained through an uncontrolled procedure still receives a response. This design differs from automated systems that evaluate the correctness of students' answers [26], [28]. The broader lesson is that science process skills are learned as things students do with real data, and inference-heavy skills therefore need more than one short unit to develop.

The findings extend earlier smartphone-sensor studies from measurement to skill development. Most previous work established that Phyphox measures accurately enough for teaching, or described classroom activities built around it. Few studies have examined what students learn to do when they place the sensor within a structured learning sequence. Monteiro et al. [17] measured uniform circular motion on a turntable with Phyphox, and Wheatland et al. [18] used a smartphone as a free-rotation laboratory, but neither study assessed science process skills. Darmaji et al. [19] developed a problem-solving e-module for basic physics practicum aimed at science process skills, without sensor-based measurement. The present study therefore joins two lines of work that have developed separately so far: sensor-based measurement and e-module design for science process skills. Studies of connected laboratory experiences and laboratory-support videos likewise suggest that technology contributes most when it is embedded in a coherent learning sequence [49], [50].

For teachers, these findings demonstrate that practical activities concerning rotational dynamics can be conducted using smartphones and structured e-modules. Rule-based feedback also provides a way to assess science process skills during instruction. Regarding curriculum implementation, the data indicate that the Kurikulum Merdeka expectations for investigative activities can be partially met by utilizing equipment students already possess. Future e-module development should incorporate design and reflection tasks to foster hypothesis formulation and conclusion drawing, given that scaffolded design activities accompanied by reflection have been shown to enhance scientific capabilities in physical laboratory settings [31]-[35]. While this e-module is currently ready for classroom use, a more extensive instructional sequence and controlled trials are required to determine its contribution to science process skills.

Three limitations qualify these conclusions. The trial used a one-group pretest–posttest design because only one grade XI class at the school met the equipment requirements. Without a comparison group, the change in scores cannot be separated from regular instruction, maturation, or familiarity with a test administered in the same form twice. The trial lasted five lessons, which is short for skills such as formulating hypotheses and drawing conclusions. The sample came from a single school, which limits how far the findings can be generalized. These constraints do not weaken the validity and practicality results, which rest on expert and user judgments rather than on comparison between groups. They do mean that the size of the change in science process skills should be read as descriptive until a controlled trial is conducted.

4. CONCLUSION

This study developed a practicum e-module on rotational dynamics that integrates Phyphox experiments with rule-based feedback tied to science process skill indicators. The e-module met the validity criterion, with an expert score of 88.72% in the very valid category. It also met the practicality criterion, with a student mean of 4.13 (82.65%) in the practical category. Ease of use, material and learning, and rule-based feedback were rated very practical, while practical work with Phyphox and science process skills received the lowest ratings. Mean science process skill scores rose from 30.97 to 77.09, a statistically significant change with a moderate normalized gain of 0.67 and a large effect size of 0.82. The change concentrated in identifying variables, designing experiments, and analysing data. The three research questions are thus answered: the e-module is valid, it is practical, and its use was accompanied by a substantial change in the skills most closely tied to measurement. The study contributes to physics education research in three ways. It combines Phyphox, rule-based feedback, and an e-module in a single instructional product, three elements that previous studies had treated separately. It applies Phyphox to rotational dynamics, a topic that smartphone-sensor activities have rarely addressed, by using the gyroscope to record angular velocity directly. It derives each feedback rule from a science process skill indicator, so that feedback responds to how students obtained a result and not only to the result itself. It also shows that sensor data from real physical motion, rather than simulation output, can be the material through which science process skills are practised. These contributions are particularly relevant to Indonesian schools where laboratory equipment is limited. The e-module thus offers a model for returning experimental work to physics lessons under ordinary classroom conditions. Further research should test the e-module against a comparison group, preferably in a randomized or quasi-experimental design. Such a design would allow the change in science process skills to be attributed to the e-module with more confidence than the present design permits. A trial lasting at least one semester would also show whether the skills are retained and transferred to other topics. Studies in several schools would indicate whether the results hold beyond a single class. The e-module itself should add tasks that give students more practice in formulating hypotheses and drawing conclusions. Analysis of the feedback records would show which rules students triggered most often

and at which step. These steps would turn a valid and practical product into one whose contribution to science process skills can be measured directly.

ACKNOWLEDGEMENTS

The authors express their gratitude to Senior High School 5 Sarolangun for granting permission to conduct the research at the school, as well as to all parties who assisted, and who provided encouragement and motivation to the researchers, enabling the completion of this research.

AUTHOR CONTRIBUTIONS

Riska Adelia contributed to conceptualization, methodology, investigation, data curation, visualization, and preparation of the original draft. Tanti contributed to validation, supervision, project administration, and review and editing. Jerfi contributed to validation, formal analysis, and review and editing. All authors read and approved the final manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all participants before data collection. Because the participants were Grade XI students, student assent and permission from parents or legal guardians were obtained where required by school policy. Participation was voluntary, and participant confidentiality was maintained. All images in this article have been authorized and are the property of the authors.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

REFERENCES

[1] T. Tanti, D. Darmaji, A. Astalini, D. A. Kurniawan, and M. Iqbal, "Analysis of user responses to the application of web-based assessment on character assessment," *Journal of education technology*, vol. 5, no. 3, pp. 356, 2021, doi: 10.23887/jet.v5 i3.33590.

[2] S. Anggereni, S. Suhardiman, and R. Amaliah, "Analisis ketersediaan peralatan, bahan ajar, administrasi laboratorium, keterlaksanaan kegiatan praktikum di laboratorium fisika [Analysis of the availability of equipment, teaching materials, and laboratory administration, as well as the implementation of practical activities in the physics laboratory]," *Jurnal Ilmiah Pendidikan Fisika*, vol. 5, no. 3, pp. 414-423, 2021, doi: 10.20527/jipf.v5i3.3925.

[3] N. Yunita and T. Nurita, "Analisis keterampilan proses sains siswa pada pembelajaran daring [Analysis of students' science process skills during online learning]," *Pensa E-Jurnal: Pendidikan Sains*, vol. 9, no. 3, pp. 378-385, 2021, doi: 10.26740/pensa.v9i3.41088.

[4] L. G. Rimoldini and C. Singh, "Student understanding of rotational and rolling motion concepts," *Physical Review Special Topics - Physics Education Research*, vol. 1, no. 1, Art. no. 010102, 2005, doi: 10.1103/PhysRevSTPER.1.010102.

[5] R. Rafika and S. Syuhendri, "Students' misconceptions on rotational and rolling motions," *Journal of Physics: Conference Series*, vol. 1816, Art. no. 012016, 2021, doi: 10.1088/1742-6596/1816/1/012016.

[6] S. Staacks, D. Dorsel, S. Hütz, F. Stallmach, T. Splith, H. Heinke, and C. Stampfer, "Collaborative smartphone experiments for large audiences with phyphox," European Journal of Physics, vol. 43, no. 5, Art. no. 055702, 2022, doi: 10.1088/1361-6404/ac7830.

[7] T. Pierratos and H. M. Polatoglou, "Utilizing the phyphox app for measuring kinematics variables with a smartphone," *Physics Education*, vol. 55, no. 2, , 2020, doi: 10.1088/1361-6552/ab6951.

[8] R. Carroll and J. Lincoln, "Phyphox app in the physics classroom," *The Physics Teacher*, vol. 58, no. 8, pp. 606-607, 2020, doi: 10.1119/10.0002393.

[9] N. Imtinan and H. Kuswanto, "The use of Phyphox application in physics experiments: A literature review," *JIPF (Jurnal Ilmu Pendidikan Fisika)*, vol. 8, no. 2, pp. 183-191, 2023, doi: 10.26737/jipf.v8i2.4167.

[10] M. S. Ubben, F. E. Kremer, S. Heinicke, A. Marohn, and S. Heusler, "Smartphone usage in science education: A systematic literature review," *Education Sciences*, vol. 13, no. 4, Art. no. 345, 2023, doi: 10.3390/educsci13040345.

[11] J. Garzón and G. Lampropoulos, "Mobile learning for science education: Meta-analysis of K-12 research," Interactive Learning Environments, vol. 32, no. 10, pp. 6735-6750, 2024, doi: 10.1080/10494820.2023.2280973.

[12] M. J. N. Revano and R. P. Antonio, "From pocket to physics: Unlocking the potential of smartphone sensor experiments to enhance science learning," *Journal of Research on Technology in Education*, pp. 1-19, 2026, doi: 10.1080/15391523.2025.2598247.

[13] Y. Sirisathitkul and C. Sirisathitkul, "Smartphones as smart tools for science and engineering laboratory: A review," *Iraqi Journal of Science*, vol. 64, no. 5, pp. 2240-2249, 2023, doi: 10.24996/ijs.2023.64.5.12.

[14] K. Hochberg, J. Kuhn, and A. Müller, "Using smartphones as experimental tools - effects on interest, curiosity, and learning in physics education," *Journal of Science Education and Technology*, vol. 27, no. 5, pp. 385-403, 2018, doi: 10.1007/s10956-018-9731-7.
[15] K. Hochberg, S. Becker, M. Louis, P. Klein, and J. Kuhn, "Using smartphones as experimental tools - a follow-up: Cognitive effects by video analysis and reduction of cognitive load by multiple representations," *Journal of Science Education and Technology*, vol. 29, no. 2, pp. 303-317, 2020, doi: 10.1007/s10956-020-09816-w.
[16] A. Kaps and F. Stallmach, "Development and didactic analysis of smartphone-based experimental exercises for the smart physics lab," *Physics Education*, vol. 57, no. 4, Art. no. 045038, 2022, doi: 10.1088/1361-6552/ac68c0.
[17] M. Monteiro, C. Stari, C. Cabeza, and A. C. Marti, "Using mobile-device sensors to teach students error analysis," *American Journal of Physics*, vol. 89, no. 5, pp. 477-481, 2021, doi: 10.1119/10.0002906.
[18] T. Tanti, D. Deliza, and S. Hartina, "The effectiveness of using smartphones as mobile-mini labs in improving students' beliefs in physics," *JIPF (Jurnal Ilmu Pendidikan Fisika)*, vol. 9, no. 3, pp. 387-394, 2024, doi: 10.26737/jipf.v9i3.5185.
[19] D. Darmaji, A. Astalini, D. A. Kurniawan, H. Parasdila, I. Irdianti, S. Susbiyanto, K. Kuswanto, and M. Ikhlas, "E-module based problem solving in basic physics practicum for science process skills," *International Journal of Online and Biomedical Engineering*, vol. 15, no. 15, 2019, doi: 10.3991/ijoe.v15i15.10942.
[20] T. Tanti, A. Astalini, D. Darmaji, D. A. Kurniawan, and R. Fitriani, "Student perception review from gender: Electronic Moduls of Mathematical Physics," *JPI (Jurnal Pendidikan Indonesia)*, vol. 11, no. 1, pp. 125-132, 2022, doi: 10.23887/jpiundiksha.v11i1.35107.
[21] A. Astalini, D. Darmaji, D. A. Kurniawan, and M. Z. Azzahra, "Comparative analysis and the influence of science process skills on students' digital literacy on measurement materials," *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, vol. 13, no. 2, pp. 131-145, 2024, doi: 10.24042/jipfalbiruni.v13i2.22986.
[22] C. Liu, D. Zowghi, M. Kearney, and M. Bano, "Inquiry-based mobile learning in secondary school science education: A systematic review," *Journal of Computer Assisted Learning*, vol. 37, no. 1, pp. 1-23, 2021, doi: 10.1111/jcal.12505.
[23] H. Crompton, D. Burke, and Y.-C. Lin, "Mobile learning and student cognition: A systematic review of PK-12 research using Bloom's Taxonomy," *British Journal of Educational Technology*, vol. 50, no. 2, pp. 684-701, 2019, doi: 10.1111/bjet.12674.
[24] D. Parsons, A. Palalas, S. A. Nikou, and S. Rodulfo, "Mobile learning frameworks and pedagogy: A systematic review," *European Journal of Education*, vol. 59, no. 2, 2024, doi: 10.1111/ejed.12601.
[25] E. G. Galimova, O. V. Sergeeva, M. R. Zheltukhina, N. L. Sokolova, V. L. Zakharova, and N. N. Drobysheva, "Mobile learning in science education to improve higher-order thinking skills and communication skills: Scoping review," *Frontiers in Communication*, vol. 10, 2025, doi: 10.3389/fcomm.2025.1624012.
[26] A. Meyer, T. Bleckmann, and G. Friege, "Automatic feedback on physics tasks using open-source generative artificial intelligence," *International Journal of Science Education*, vol. 48, no. 15, pp. 2396-2421, 2025, doi: 10.1080/09500693.2025.2499220.
[27] W. Wang, Y. Wang, J. Chen, X. Wang, H. Zhang, C. Guo, and Y. Peng, "The effectiveness of AI-supported personalized feedback on students' learning outcomes and motivation: A meta-analysis," *Journal of Educational Computing Research*, vol. 64, no. 3, pp. 724-755, 2026, doi: 10.1177/07356331251410020.
[28] T. Tanti, W. Utami, D. Deliza, and M. Jahanifar, "Investigation in Vocation High School for Attitude and Motivation Students in Learning Physics Subject," *Journal Evaluation in Education (JEE)*, vol. 6, no. 2, pp. 479-490. 10.37251/jee.v6i2.1452.
[29] B. Wisniewski, K. Zierer, and J. Hattie, "The power of feedback revisited: A meta-analysis of educational feedback research," *Frontiers in Psychology*, vol. 10, Art. no. 3087, 2020, doi: 10.3389/fpsyg.2019.03087.
[30] R. M. Branch and İ. Varank, *Instructional Design: The ADDIE Approach*. New York, NY, USA: Springer, 2009.
[31] M. Pedaste et al., "Phases of inquiry-based learning: Definitions and the inquiry cycle," *Educational Research Review*, vol. 14, pp. 47-61, 2015, doi: 10.1016/j.edurev.2015.02.003.
[32] A. W. Lazonder and R. Harmsen, "Meta-analysis of inquiry-based learning," *Review of Educational Research*, vol. 86, no. 3, pp. 681-718, 2016, doi: 10.3102/0034654315627366.
[33] N. M. Dah, M. S. A. Mat Noor, M. Z. Kamarudin, and S. S. Syed Abdul Azziz, "The impacts of open inquiry on students' learning in science: A systematic literature review," *Educational Research Review*, vol. 43, Art. no. 100601, 2024, doi: 10.1016/j.edurev.2024.100601.
[34] T. T. S. Strat, E. K. Henriksen, and K. M. Jegstad, "Inquiry-based science education in science teacher education: A systematic review," *Studies in Science Education*, vol. 60, no. 2, pp. 191-249, 2024, doi: 10.1080/03057267.2023.2207148.
[35] R. P. Antonio and M. S. Prudente, "Effects of inquiry-based approaches on students' higher-order thinking skills in science: A meta-analysis," *International Journal of Education in Mathematics, Science and Technology*, vol. 12, no. 1, pp. 251-281, 2024, doi: 10.46328/ijemst.3216.
[36] S. J. Husnaini and S. Chen, "Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment," *Physical Review Physics Education Research*, vol. 15, no. 1, Art. no. 010119, 2019, doi: 10.1103/PhysRevPhysEducRes.15.010119.
[37] K. Kurniahtunnisa, B. R. Wola, F. Harahap, W. A. Tumewu, and Z. W. M. Warouw, "Research trends of science process skills in Indonesian science education journals," *Journal of Turkish Science Education*, vol. 21, no. 4, pp. 668-687, 2024, doi: 10.36681/tused.2024.036.
[38] N. Nurlaini, R. Asyhar, and T. Tanti, "Unlocking scientific potential: Using smartphones as mobile mini-labs to improve students' science process skills," *JIPF (Jurnal Ilmu Pendidikan Fisika)*, vol. 10, no. 1, pp. 175-181, 2025, doi: 10.26737/jipf.v10i1.6109.

[39] A. R. Aththibby, H. Kuswanto, M. Mundilarto, and E. Prihandono, "Improving motivation and science process skills through a mobile laboratory-based learning model," *Cypriot Journal of Educational Sciences*, vol. 16, no. 5, pp. 2292-2299, 2021, doi: 10.18844/cjes.v16i5.6333.
[40] I. Wahyudi, V. A. Ashra, and E. Suyanto, "The effect of Phyphox application-assisted guided inquiry on students' creative-thinking ability," *Jurnal Pendidikan Matematika dan IPA*, vol. 13, no. 1, 2022, doi: 10.26418/jpmipa.v13i1.42590.
[41] E. Aregehagn, A. Lykknes, M. Febri, and M. Ayene, "The transformative effects of guided inquiry-based learning on scientific knowledge of vision," *African Journal of Research in Mathematics, Science and Technology Education*, vol. 26, no. 3, pp. 205-217, 2022, doi: 10.1080/18117295.2022.2135294.
[42] K. S. Taber, "The use of Cronbach's alpha when developing and reporting research instruments in science education," *Research in Science Education*, vol. 48, pp. 1273-1296, 2018, doi: 10.1007/s11165-016-9602-2.
[43] D. Lakens, "Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs," *Frontiers in Psychology*, vol. 4, Art. no. 863, 2013, doi: 10.3389/fpsyg.2013.00863.
[44] R. R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *American Journal of Physics*, vol. 66, no. 1, pp. 64-74, 1998, doi: 10.1119/1.18809.
[45] A. Gasparini, F. Stern, M. Delaval, and A. Müller, "Using smartphones and tablets as experimental tools in the physics classroom: Effects on learning and motivation," *Physical Review Physics Education Research*, vol. 22, no. 1, Art. no. 010129, 2026.
[46] S. Staacks, S. Hütz, H. Heinke, and C. Stampfer, "Advanced tools for smartphone-based experiments: phyphox," Physics Education, vol. 53, no. 4, Art. no. 045009, 2018.
[47] L. Bao, K. M. Koenig, Y. Xiao, J. C. Fritchman, S. Zhou, and C. Chen, "Theoretical model and quantitative assessment of scientific thinking and reasoning," *Physical Review Physics Education Research*, vol. 18, no. 1, Art. no. 010115, 2022, doi: 10.1103/PhysRevPhysEducRes.18.010115.
[48] N. G. Holmes and C. E. Wieman, "Introductory physics labs: We can do better," *Physics Today*, vol. 71, no. 1, pp. 38-45, 2018.
[49] A. Molz, J. Kühn, and A. Müller, "Effectiveness of science outreach labs with and without connection to classroom learning: Affective and cognitive outcomes," *Physical Review Physics Education Research*, vol. 18, no. 2, Art. no. 020144, 2022, doi: 10.1103/PhysRevPhysEducRes.18.020144.
[50] S.-Y. Lin, J. M. Aiken, D. T. Seaton, S. S. Douglas, E. F. Greco, B. D. Thoms, and M. F. Schatz, "Exploring physics students' engagement with online instructional videos in an introductory mechanics course," *Physical Review Physics Education Research*, vol. 13, no. 2, Art. no. 020138, 2017, doi: 10.1103/PhysRevPhysEducRes.13.020138.