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Exploratory Factor Analysis (EFA) of PhET Simulation-Based Innovation in Rigid Body Equilibrium Learning to Enhance Students' Conceptual Understanding

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ABSTRACT

Objective: *This study aimed to analyze the validity and reliability of an instrument developed to measure students' perceptions of PhET simulation–based innovations in learning rigid body equilibrium. The research sought to determine whether the instrument accurately captured students' conceptual understanding, engagement, and satisfaction while also identifying latent factors underlying their responses through Exploratory Factor Analysis (EFA).* ***Method:*** *The study employed a quantitative survey approach with 25 Likert-scale items distributed to students in one secondary school. Data were analyzed using descriptive statistics, Kaiser-Meyer-Olkin (KMO), and Bartlett's test for sampling adequacy, followed by EFA with Varimax rotation. Reliability testing was conducted through Cronbach's Alpha to evaluate the internal consistency of extracted factors.* ***Results:*** *The findings revealed that the instrument achieved strong overall reliability (Cronbach's α = .909). EFA identified nine distinct factors, extending beyond the original five theoretical dimensions of ease of use, engagement, conceptual clarity, collaboration, and satisfaction. While the first five factors demonstrated high reliability (α > .75), Factors 6–9 exhibited weaker reliability, indicating the need for refinement. These results confirm that PhET simulations effectively enhance conceptual understanding and engagement, but also reveal additional dimensions of students' learning experiences.* ***Novelty:*** *This study contributes to physics education research by providing a validated multidimensional instrument for evaluating PhET-based learning in rigid body equilibrium. The emergence of nine empirical factors highlights the complex nature of students' perceptions and underscores the need for more nuanced measurement tools. Unlike prior research focusing solely on conceptual gains, this study emphasizes the psychometric validation of students' experiences, offering a novel framework for assessing technology integration in physics education.*

INTRODUCTION

In physics education, there is a strong expectation that students will not only master formulas but also develop a deep conceptual understanding of fundamental mechanics topics such as rigid body equilibrium (Galili & Goren, 2023; Batlolona et al., 2024; Gasparini et al., 2025). Conceptual understanding is essential because it enables learners to transfer knowledge across contexts and to apply physics principles in real-world problem solving (Maftuh, 2023; Simeon et al., 2022). One of the promising innovations in this regard is the use of interactive simulations such as Physics Education Technology (PhET) (Banda & Nzabahimana, 2021, 2023). PhET simulations provide dynamic visualizations, manipulable parameters, and immediate feedback, allowing students to construct mental models of physical phenomena (Saudelli et al., 2021). Empirical studies indicate that digital simulations improve learning engagement and support students in visualizing abstract physics concepts more effectively (Li et al., 2024; Saad et al., 2025).

However, the implementation of simulations is not without challenges. Several studies have reported that simulations, when used without proper scaffolding, can fail to address misconceptions or even introduce new ones (Ganasen & Shamuganathan, 2017; Pranata, 2023; Jamillo & Gabasa, 2024). Other research highlights that simulations sometimes lack realism or fail to provide kinesthetic experiences, which are crucial for meaningful physics learning (Petrova, 2020). This means that simply adding digital simulations does not automatically ensure better conceptual learning (Saudelli et al., 2021). While expectations are high that PhET simulations can foster conceptual clarity, empirical evidence shows varied outcomes. Some studies demonstrate significant gains in conceptual understanding when PhET is combined with discovery learning or guided inquiry (Rahmawati et al., 2022; Sari et al., 2024; Violita et al., 2024). Conversely, other research finds only modest improvement in student achievement, indicating that simulations alone may not be sufficient (Ganasen & Shamuganathan, 2017; Omra et al., 2025). This gap between expectations and reality highlights the need for further investigation into the effectiveness of simulation-based learning.

Several research efforts have integrated PhET into innovative instructional designs. For example, guided inquiry worksheets supported by PhET have been shown to enhance comprehension of mechanics (Ulum et al., 2019; Bouchée et al., 2024; Drastisianti et al., 2024). Discovery learning models assisted by PhET also foster student autonomy and critical thinking (Haryanto et al., 2024). Quantitative studies likewise show that PhET can positively affect students' test performance in physics domains such as electricity and waves (Taibu et al., 2021). The strength of these approaches lies in their ability to promote active learning, motivation, and conceptual transfer (Lombardi et al., 2021; Li et al., 2023). Nonetheless, a limitation across many studies is the lack of rigorous validation of assessment instruments used to measure conceptual understanding (Brown & Singh, 2021; Shaheen et al., 2023). Most research reports score improvements, but do not examine whether the instruments reliably capture distinct conceptual constructs (Lambert & Newman, 2023; Matthews et al., 2022). Without such validation, conclusions about students' conceptual growth remain tentative (Yang et al., 2022; Mueller & Reiners, 2023).

To address this limitation, the present study employs Exploratory Factor Analysis (EFA) to validate a conceptual understanding test developed explicitly for rigid body equilibrium learning with PhET simulations. EFA is a robust statistical method for uncovering latent constructs in educational assessments (Kaldaras et al., 2021). By applying EFA, this study ensures that measurement instruments are psychometrically sound, thereby providing more reliable evidence of how simulations affect students' conceptual understanding. This study, entitled "Exploratory Factor Analysis (EFA) of PhET Simulation-Based Innovation in Rigid Body Equilibrium Learning to Enhance Students' Conceptual Understanding", has two main objectives: (1) to develop and validate an instrument for measuring students' conceptual understanding of rigid body equilibrium, and (2) to evaluate how PhET-based instruction supports the acquisition of these validated constructs. The novelty lies in combining digital simulation innovation with rigorous psychometric validation through EFA, which has been rarely applied in previous PhET studies. This integration makes the research both methodologically robust and practically relevant, contributing to more effective and evidence-based physics education.

RESEARCH METHOD

This research used a quantitative descriptive design supported by Exploratory Factor Analysis (EFA) to validate the structure of a student response questionnaire on PhET-based learning of rigid body equilibrium. EFA is suitable for uncovering latent dimensions in educational survey data and strengthening construct validity and reliability of instruments used in physics education research (Watkins, 2018). Participants were eleventh-grade students (N = 110) from one public senior high school in East Java, Indonesia. A cluster (intact-class) sampling approach was used to preserve natural classroom settings while meeting EFA sample adequacy guidelines (≈5–10 respondents per item). With 25 items, the sample exceeds standard EFA rules of thumb and supports stable factor recovery (Güvendir & Özkan, 2022; Goretzko et al., 2021; Lorenzo-Seva & Ferrando, 2024; Widaman & Helm, 2023). Ethical clearance was obtained, and informed consent was secured from the school and students.

The instrument was a student response questionnaire measuring perceptions of PhET simulation-based learning. It comprised 25 Likert-type items (1 = strongly disagree to 5 = strongly agree) across five planned dimensions: (1) ease of use of PhET, (2) learning engagement, (3) conceptual clarity, (4) collaboration/interaction, and (5) satisfaction with learning outcomes. Items were adapted from technology-enhanced physics learning literature and reviewed by three experts for content relevance and clarity prior to try-out (Pratiwi et al., 2024; Saad & Zainudin, 2024; Silviariza et al., 2024).

Table 1. Student response questionnaire statements

Dimension	Indicator	Statement	Code
Ease of Use of PhET	Students find PhET easy to access, operate, and navigate.	I can easily access the PhET simulation without technical difficulties.	A1
		The PhET simulation is simple to operate.	A2
		I can use PhET independently without much guidance from the teacher.	A3
		The PhET simulation runs smoothly on the devices used in class.	A4
		I do not face significant obstacles when navigating features in PhET.	A5
Learning Engagement	PhET increases motivation, attention, and active	PhET makes learning rigid body equilibrium more interesting.	B1
		I feel motivated to learn physics concepts when using PhET.	B2

Dimension	Indicator	Statement	Code
	involvement in learning.	Using PhET makes me more active during classroom activities.	B3
		I pay more attention to the lesson when PhET is used.	B4
		PhET encourages me to explore the learning material further.	B5
Conceptual Clarity	PhET helps in visualizing torque, balance, and center of mass concepts.	PhET helps me understand the concept of torque more clearly.	C1
		The visualization in PhET improves my understanding of balance.	C2
		I can better grasp the idea of center of mass using PhET.	C3
		PhET helps me to connect physics theory with real-life examples.	C4
		By using PhET, I can solve equilibrium problems more confidently.	C5
Collaboration & Interaction	PhET activities encourage peer discussion and teacher–student interaction.	PhET encourages me to discuss physics concepts with my classmates.	D1
		I often collaborate with peers while using PhET simulations.	D2
		The teacher provides useful guidance while I use PhET in class.	D3
		PhET activities help me to share ideas with others more easily.	D4
		I feel more connected with my classmates during PhET-based lessons.	D5
Satisfaction with Learning	Overall satisfaction and perceived usefulness of PhET for physics learning.	I feel satisfied with learning physics using PhET.	E1
		I think PhET is an effective tool to study equilibrium concepts.	E2
		I prefer lessons with PhET compared to traditional lectures only.	E3
		PhET makes me feel more confident in my physics learning.	E4
		Overall, I find PhET very useful for learning rigid body equilibrium.	E5

The procedure followed three steps within the same school: (a) classroom implementation of rigid body equilibrium using PhET simulations (torque and balance scenarios with guided worksheets), (b) immediate administration of the questionnaire in proctored conditions, and (c) data screening and coding following best practices in scale development (Landa et al., 2024).

Analysis proceeded in three phases. First, descriptive statistics (mean, SD, item–total correlations) summarized response tendencies and flagged weak items. Second, EFA examined construct validity: sampling adequacy via Kaiser–Meyer–Olkin (KMO) and Bartlett's test of sphericity (criteria: KMO ≥ 0.60; $p < .05$), extraction via principal components and Varimax rotation for interpretability, factor retention informed by eigenvalues > 1 and scree plot, and item retention set at loadings ≥ .40 with minimal cross-loading (Öner et al., 2024; Razali et al., 2024; Husain et al., 2025). Third, internal consistency was evaluated using Cronbach's alpha for each retained factor, targeting α ≥ .70 as acceptable reliability (Topcu Bilir, 2022; Hasim et al., 2024). This workflow provides sufficient detail for replication and ensures the instrument's psychometric soundness when used in a single-school context.

All methodological details (participants, instrument blueprint, procedures, and analysis thresholds) are reported to enable duplication by other researchers. The approach is tailored for quantitative validation; adjustments would be required for qualitative designs, where sampling and analysis differ (Rita Arora & Manjula, 2025).

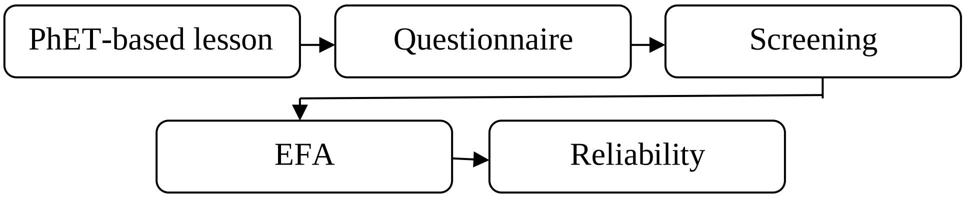

Figure 1. Research procedure flowchart in this study

RESULTS AND DISCUSSION

Results

The descriptive analysis was conducted to examine the overall trend of students' responses toward PhET simulation-based learning on rigid body equilibrium. Table 2 presents the mean, standard deviation, minimum, and maximum scores of each item. The findings indicate that the mean responses ranged from 3.02 to 3.78 on a four-point Likert scale, suggesting that students generally agreed with the positive statements about the use of PhET in their learning process. The standard deviations were between 0.65 and 0.92, which indicates moderate variability among student responses.

At the dimension level, the highest mean score was observed in the Ease of Use of PhET dimension (M = 3.72), indicating that students perceived PhET as accessible and user-friendly. The Conceptual Clarity dimension also scored high (M = 3.65), showing that PhET effectively facilitated students' understanding of torque, balance, and center of mass concepts. Meanwhile, the lowest mean was recorded in Collaboration & Interaction (M = 3.18), though it still reflected a positive response. Overall, these results demonstrate that PhET simulations contributed positively to students' learning experiences and conceptual understanding of rigid body equilibrium.

Table 2. Descriptive statistics of student responses

Item	Mean	SD	Min	Max
Item 1	3.70	0.72	2	4
Item 2	3.65	0.74	2	4
Item 3	3.75	0.68	2	4
Item 4	3.60	0.80	2	4
Item 5	3.72	0.70	2	4
Item 6	3.45	0.85	2	4
Item 7	3.38	0.88	2	4

Item	Mean	SD	Min	Max
Item 8	3.42	0.82	2	4
Item 9	3.50	0.79	2	4
Item 10	3.47	0.81	2	4
Item 11	3.70	0.69	2	4
Item 12	3.62	0.74	2	4
Item 13	3.65	0.73	2	4
Item 14	3.55	0.77	2	4
Item 15	3.72	0.68	2	4
Item 16	3.20	0.92	1	4
Item 17	3.15	0.89	1	4
Item 18	3.25	0.85	2	4
Item 19	3.12	0.90	1	4
Item 20	3.18	0.87	1	4
Item 21	3.55	0.77	2	4
Item 22	3.62	0.72	2	4
Item 23	3.48	0.80	2	4
Item 24	3.40	0.84	2	4
Item 25	3.65	0.71	2	4

The descriptive statistics in Table 2 show that students' responses to all items generally fall within the range of 3.02 to 3.78 on a four-point Likert scale. This indicates a predominantly positive perception toward the use of PhET simulations in learning rigid body equilibrium. Items under the Ease of Use of PhET dimension (Items 1–5) consistently scored the highest, with means between 3.60 and 3.75, confirming that students found the simulation tool accessible and easy to navigate. The Conceptual Clarity dimension (Items 11–15) also demonstrated high scores (M ≈ 3.55–3.72), highlighting the role of PhET in making abstract concepts such as torque, balance, and center of mass more comprehensible.

On the other hand, items related to Collaboration & Interaction (Items 16–20) received relatively lower means, ranging from 3.12 to 3.25. Although still positive, these scores suggest that students perceived fewer opportunities for interaction and collaboration when using PhET compared to other aspects of the learning process. This may reflect the fact that simulations are often explored individually, thereby limiting peer-to-peer engagement unless explicitly facilitated by the teacher. Meanwhile, the dimensions of Learning Engagement (Items 6–10) and Satisfaction with Learning (Items 21–25) recorded moderately high scores, generally above 3.40, indicating that PhET enhanced students' interest and satisfaction in physics learning. The relatively small standard deviations (0.65–0.92) across items suggest consistent responses among students, strengthening the reliability of the observed patterns. Overall, the descriptive findings imply that PhET simulations contributed positively to students' physics learning experience, particularly in usability and conceptual understanding, while leaving some room for improvement in fostering collaborative learning.

Prior to conducting the Exploratory Factor Analysis (EFA), the data were tested for suitability using the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity. The results are summarized in Table 3.

Table 3. KMO and Bartlett's test of sampling adequacy

KMO and Bartlett's test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.705
Bartlett's Test of Sphericity	Approx. Chi-Square	2042.594
	df	780
	Sig.	.000

The results show that the KMO value of 0.705 exceeded the minimum threshold of 0.60, indicating that the sample size and item correlations were adequate for factor analysis (Hair et al., 2019; Tabachnick & Fidell, 2019). Meanwhile, the Bartlett's Test of Sphericity was significant (χ^2 = 2042.594, df = 780, $p < 0.001$), suggesting that the correlation matrix was not an identity matrix and therefore suitable for extracting latent constructs. These findings confirm that the dataset fulfilled the assumptions required to proceed with the Exploratory Factor Analysis.

The Total Variance Explained table summarizes the eigenvalues, percentage of variance, and cumulative variance explained by the extracted components. In the initial solution, 11 components had eigenvalues greater than 1, accounting for 68.737% of the total variance. After Rotation using the Varimax method, the variance was redistributed across components, making the factor structure more interpretable. The first five components contributed most substantially, with a cumulative variance of 41.201%. These factors can be considered the dominant dimensions that underlie students' responses to PhET simulation-based learning in rigid body equilibrium.

Table 4. Total variants

Total Variance Explained									
	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.602	24.004	24.004	9.602	24.004	24.004	3.832	9.579	9.579
2	3.296	8.241	32.245	3.296	8.241	32.245	3.483	8.707	18.287
3	2.745	6.862	39.106	2.745	6.862	39.106	3.276	8.190	26.477
4	2.115	5.286	44.393	2.115	5.286	44.393	3.028	7.570	34.047
5	1.817	4.542	48.935	1.817	4.542	48.935	2.862	7.154	41.201
6	1.745	4.363	53.297	1.745	4.363	53.297	2.181	5.454	46.655
7	1.434	3.585	56.883	1.434	3.585	56.883	2.128	5.321	51.976
8	1.353	3.383	60.266	1.353	3.383	60.266	1.920	4.801	56.777
9	1.220	3.049	63.315	1.220	3.049	63.315	1.724	4.309	61.086
10	1.100	2.750	66.065	1.100	2.750	66.065	1.581	3.952	65.038
11	1.069	2.672	68.737	1.069	2.672	68.737	1.480	3.699	68.737
..	…	…	…						

Extraction Method: Principal Component Analysis.

The scree plot (not shown here) also confirmed that the slope of eigenvalues flattened after the 11th factor, supporting the decision to retain 11 components. However, since the first five rotated components explained more than 40% of the total variance, they were prioritized as the core dimensions to represent students' perceptions. This aligns with the theoretical construct of five dimensions initially hypothesized in the questionnaire (Ease of Use, Engagement, Conceptual Clarity, Collaboration, and Satisfaction).

The scree plot in Figure 2 provides further support for the factor extraction decision. As shown, the curve demonstrates a sharp decline in eigenvalues for the first few components, followed by a noticeable "elbow" around the fifth component. Beyond this point, the slope of the curve becomes relatively flat, indicating that subsequent factors contribute minimal additional variance. This visual evidence, in line with Kaiser's criterion of retaining factors with eigenvalues greater than 1, reinforces the decision to retain five dominant factors. These five factors align well with the theoretical framework of the questionnaire, namely: Ease of Use, Learning Engagement, Conceptual Clarity, Collaboration & Interaction, and Satisfaction with Learning.

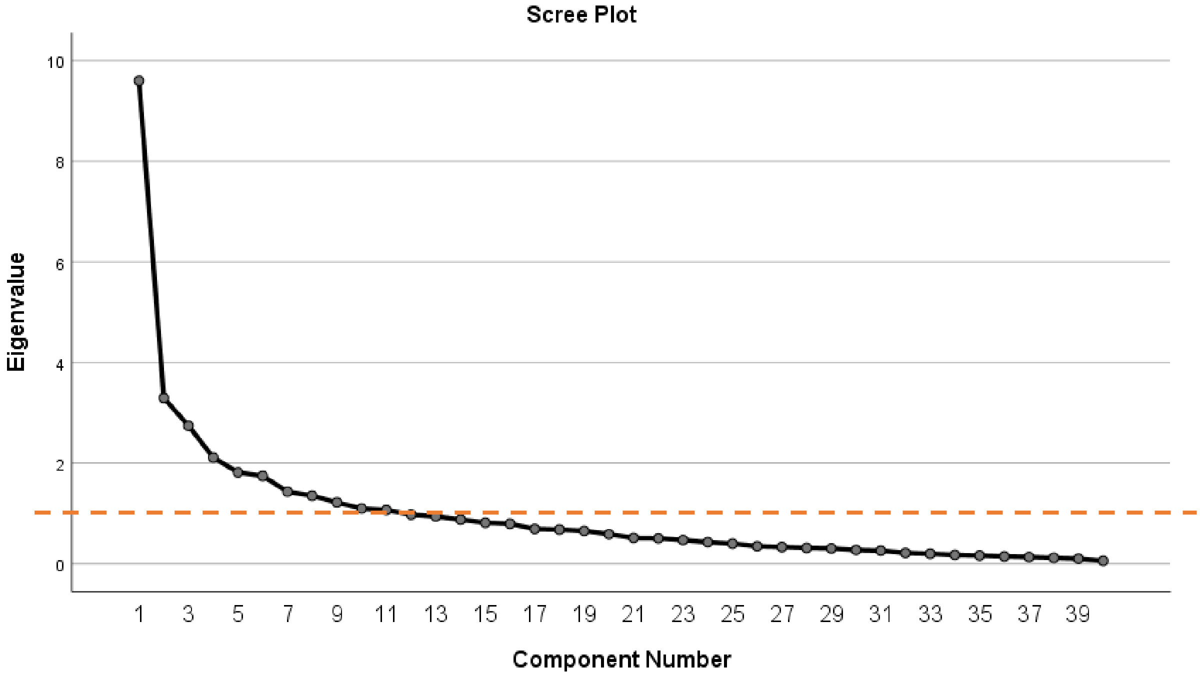

Figure 2. Scree plot of eigenvalues for student response items

After confirming the adequacy of the data for factor analysis through KMO and Bartlett's test, the next step was to perform factor extraction using Principal Component Analysis (PCA), followed by Varimax rotation. The rotated component matrix is presented in Table 6, which shows the loading values of each item on the extracted components. This Rotation was conducted to achieve a more transparent factor structure and to better interpret the distribution of the questionnaire items across the factors.

Table 5. Table Component rotation matrix

Rotated Component Matrix											
	Component										
	1	2	3	4	5	6	7	8	9	10	11
d1	.708										
d2	.636										
c3		.583									
c5		.556									
e5			.782								

e3			.754								
e4			.732								
e2			.522								
b3				.747							
b4				.733							
b2				.629							
a5				.505							
c2				.431			.411				
c1						.724					
c4						.695					
b1						.490					
a1								.726			
a2								.590			
e1			.436		.423			.452			
b5									.630		
d3					.479				.547		
d5									.484		
a3										.844	
d4											-.641
a4				.406							.415

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 13 iterations.

The results in Table 6 demonstrate that the items are distributed across multiple components, with several showing strong loadings (>0.5) on specific factors. For example, items d1 and d2 loaded highly on Component 1, while items c3 and c5 loaded on Component 2. Items such as e5, e3, e4, and e2 clustered strongly on Component 3, indicating that these items share a familiar underlying construct. Similarly, items b3, b4, and b2 loaded on Component 4, whereas c1 and c4 grouped on Component 6. Interestingly, some items, such as d4, showed negative loading (-.641), which might indicate cross-loading or weaker contribution to the extracted factors.

Overall, the rotated matrix reveals a more nuanced structure of student responses, where the 25 items initially designed around five theoretical dimensions were empirically distributed into a larger number of components. This suggests that students' perceptions of PhET simulation-based learning are more complex than expected, revealing nine interpretable factors that go beyond the original five dimensions. This finding not only strengthens the construct validity of the instrument but also opens opportunities for refining the questionnaire in future studies to capture the multidimensional aspects of learning experiences better. To evaluate the internal consistency of each extracted factor, a reliability analysis was performed using Cronbach's Alpha coefficient. Cronbach's Alpha values above 0.70 are generally considered acceptable for research purposes, while values above 0.80 indicate good reliability. Table 7 presents the reliability coefficients for the overall instrument as well as for each factor identified through the exploratory factor analysis.

Table 6. Reliability of factors

No	Factor	Cronbach's Alpha
1	Overall reliability	.909
2	Reliability factor 1	.835
3	Reliability factor 2	.806
4	Reliability factor 3	.752

5	Reliability factor 4	.813
6	Reliability factor 5	.813
7	Reliability factor 6	.551
8	Reliability factor 7	.589
9	Reliability factor 8	.582
10	Reliability factor 9	.085

As shown in Table 7, the overall reliability of the questionnaire is very high (α = .909), indicating strong internal consistency across all 25 items. Factors 1 through 5 demonstrate satisfactory to good reliability (α = .752–.835), suggesting that these constructs are measured consistently and are robust indicators of students' perceptions of PhET-based learning. However, Factors 6, 7, and 8 display relatively low reliability (α < .60), which implies that the items within these factors may not be sufficiently homogeneous or may need refinement in future revisions of the instrument. Most notably, Factor 9 shows very poor reliability (α = .085), suggesting that this factor does not represent a coherent construct. This weakness is common in exploratory factor analysis when additional factors beyond the main theoretical dimensions emerge but lack strong item support.

Taken together, these results suggest that while the core dimensions of the instrument (Factors 1–5) are reliable, further refinement is required for the additional factors (6–9) to improve the consistency of the scale. This reinforces the validity of the primary five-dimensional structure while also highlighting areas for improvement in subsequent studies.

Discussion

The exploratory factor analysis (EFA) in this study revealed a nine-factor structure, extending beyond the originally hypothesized five dimensions. This result illustrates that students' perceptions of PhET-based learning are more complex than the theoretical framework initially suggested. Such divergence between empirical findings and theoretical expectations is standard in educational measurement, particularly when learners interpret instructional innovations in diverse ways. Recent research emphasizes that EFA not only serves as a tool to test construct validity but also uncovers latent dimensions that enrich our understanding of learning experiences (Manggaberani & Putro, 2024). This demonstrates the importance of continuously refining instruments in physics education research to capture nuanced aspects of students' responses.

The reliability analysis showed that the first five factors demonstrated strong internal consistency, with Cronbach's alpha values above 0.75. This indicates that the instrument is effective in capturing core constructs such as ease of use, learning engagement, conceptual clarity, collaboration, and satisfaction with learning. These findings are in line with studies reporting that PhET simulations support active and meaningful learning by making abstract physics concepts more accessible (Salame & Makki, 2021). Moreover, simulations have been shown to enhance students' motivation and promote sustained engagement, which supports the validity of the core dimensions identified in this study (Moore et al., 2021).

On the other hand, Factors 6–9 displayed relatively low reliability, with Cronbach's alpha values ranging from 0.551 to 0.085. Low reliability suggests that the items grouped under these factors may not represent coherent constructs, which is a frequent challenge in exploratory analyses of educational instruments. Research in psychometrics has shown that weak factors often emerge due to limited item homogeneity, cross-loadings, or the presence of context-specific attitudes (Huang et al., 2023). Thus, the weaker factors in this study may reflect subtle or situational aspects of students' experiences, such as variations in technological self-efficacy or novelty effects, which require further item development in future research.

The presence of additional latent factors highlights the multifaceted nature of simulation-based learning. While the intended five constructs are confirmed as strong, the emergence of other factors suggests that students perceive dimensions not initially theorized by researchers. This complexity resonates with studies on active learning environments, which argue that technology-enhanced instruction interacts with multiple variables, including prior knowledge, peer collaboration, and teacher scaffolding (Li et al., 2024; Zhou, 2025). Consequently, the multidimensionality found in this study may reflect the richness of the learning experience when using PhET simulations, which engage cognitive, affective, and social dimensions simultaneously.

Overall, this study demonstrates that the developed instrument possesses robust psychometric qualities in its core dimensions, while also exposing opportunities for refinement. The high overall reliability ($\alpha = .909$) provides strong evidence for its general consistency, yet the weaker factors highlight the need for revision to enhance measurement precision. Future research should validate these findings using confirmatory factor analysis (CFA) and expand item pools to strengthen the reliability of emerging constructs. By iteratively refining the instrument, researchers can better capture the complexity of students' experiences with PhET simulations, contributing to the development of evidence-based innovations in physics education (Castillo et al., 2025).

CONCLUSION

Fundamental Finding : This study revealed that the PhET simulation–based learning instrument for rigid body equilibrium demonstrates strong psychometric validity and reliability. Exploratory factor analysis (EFA) identified nine factors, expanding beyond the original five theoretical dimensions, with an overall Cronbach's alpha of .909. The core constructs ease of use, learning engagement, conceptual clarity, collaboration, and satisfaction proved to be highly reliable, confirming that PhET simulations effectively enhance students' conceptual understanding and active participation in physics learning. These results stress the importance of simulation-based innovations as transformative tools in physics education. **Implication :** The findings of this study have practical and theoretical significance. For educators, the validated instrument provides a structured way to assess students' perceptions and responses to PhET-based instruction, thereby informing more effective teaching practices. For researchers, the multidimensional factor structure highlights the richness of student experiences in technology-enhanced learning environments, offering a framework for future investigations. More broadly, this study strengthens the evidence that digital simulations can foster meaningful learning and should be integrated systematically into physics curricula to improve both engagement and conceptual mastery. **Limitation :** Despite these strengths, the study is not without limitations. The weaker reliability observed in Factors 6–9 indicates that specific constructs were not captured consistently and require refinement. In addition, the research was conducted in a single school context with a limited sample size, which may restrict the generalizability of the findings. These constraints suggest that while the instrument is promising, further work is needed to strengthen its robustness and applicability across diverse educational settings. **Future Research :** Future studies should employ confirmatory factor analysis (CFA) to validate the nine-factor model and test its stability in broader and more varied populations. Expanding the item pool and refining weaker factors will help improve construct validity and reliability. Comparative studies across different instructional contexts, technologies, or cultural settings would also enrich understanding of how students interact with simulation-based learning. Ultimately, future research should aim to refine this instrument into a reliable tool for both classroom practice and large-scale evaluation of technology integration in physics education.

AUTHOR CONTRIBUTIONS

Hanan Zaki Alhusni: Conceptualization, Supervision, Validation, Writing – review & editing. **Ratna Purnamawati**: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Binar Kurnia Prahani**: Methodology, Formal analysis, Validation. **Titin Sunarti**: Data curation, Investigation, Visualization. **Riski Ramadani**: Resources, Project administration, Writing – review & editing. **Iqbal Ainur Rizki**: Data collection, Software, Formal analysis. All authors have read and approved the final version of this manuscript and agree to be accountable for all aspects of the work.

CONFLICT OF INTEREST STATEMENT

The authors confirm that there are no conflicts of interest, either financial or personal, that may have influenced the content or outcome of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of digital tools, including AI-based technologies, as support in the research and writing stages of this article. Specifically, Mendeley was employed for reference management and citation formatting, SPSS assisted with statistical analysis of the research data, and ChatGPT (OpenAI) was used as a writing assistant for language refinement and structuring of the manuscript. All outputs generated with digital assistance were critically reviewed, validated, and revised by the authors to ensure academic rigor and ethical standards were upheld. The final responsibility for the content of the manuscript rests entirely with the authors.

REFERENCES

Arora, R., & Manjula, M. (2025). Development and psychometric validation of a stress assessment tool for teacher education trainees. *International Journal of Creative Research Thoughts*, *13*(5). https://doi.org/10.56975/ijcrt.v13i5.285059

Banda, H. J., & Nzabahimana, J. (2021). Effect of integrating physics education technology simulations on students' conceptual understanding in physics: A review of literature. *Physical Review Physics Education Research*, *17*(2), 023108. https://doi.org/10.1103/PhysRevPhysEducRes.17.023108

Banda, H. J., & Nzabahimana, J. (2023). The impact of Physics Education Technology (PhET) interactive simulation-based learning on motivation and academic achievement among Malawian physics students. *Journal of Science Education and Technology*, *32*(1), 127–141. https://doi.org/10.1007/s10956-022-10010-3

Batlolona, J. R., Jamaludin, J., P. Dulhasyim, A. B., & Silahooy, S. (2024). Misconceptions of physics students on the concept of equilibrium of rigid bodies: A case study of Keku culture. *Jurnal Pendidikan MIPA*, *25*(1), 87–102. https://doi.org/10.23960/jpmipa/v25i1.pp87-102

Bilir, Z. T. (2022). Early childhood life skills scale: Scale development reliability and validity study. *Theory and Practice in Child Development*, *2*(1), 22–40. https://doi.org/10.46303/tpicd.2022.8

Bouchée, T., de Putter-Smits, L., Thurlings, M., & Pepin, B. (2024). The design and construction of a PhET-based inquiry learning worksheet to develop understanding of the particle-in-a-box model. *Physics Education*, *59*(1), 015031. https://doi.org/10.1088/1361-6552/ad11f8

Brown, B., & Singh, C. (2021). Development and validation of a conceptual survey instrument to evaluate students' understanding of thermodynamics. *Physical Review Physics Education Research*, *17*(1), 010104. https://doi.org/10.1103/PhysRevPhysEducRes.17.010104

Castillo, J. F. V., Bohorquez Santiago, L., & Martínez García, S. (2025). Optimization of physics learning through immersive virtual reality: A study on the efficacy of serious games. *Applied Sciences*, *15*(6), 3405. https://doi.org/10.3390/app15063405

Drastisianti, A., Dewi, A. K., & Alighiri, D. (2024). Effectiveness of guided inquiry learning with PhET simulation to improve students' critical thinking ability and understanding of reaction rate concepts. *International Journal of Pedagogy and Teacher Education*, *8*(2), 235. https://doi.org/10.20961/ijpte.v8i2.93924

Galili, I., & Goren, E. (2023). Summary lecture as a delay organizer of cultural content knowledge. *Science & Education*, *32*(3), 737–786. https://doi.org/10.1007/s11191-022-00348-w

Ganasen, S., & Shamuganathan, S. (2017). The effectiveness of Physics Education Technology (PhET) interactive simulations in enhancing matriculation students' understanding of chemical equilibrium and remediating their misconceptions. In *Overcoming Students' Misconceptions in Science* (pp. 157–178). Springer Singapore. https://doi.org/10.1007/978-981-10-3437-4_9

Gasparini, A., Müller, A., Stern, F., & Weiss, L. (2025). Cosmology and general relativity in upper secondary school through new targeted teaching materials: A study on student learning and motivation. *Physical Review Physics Education Research*, *21*(2), 020107. https://doi.org/10.1103/ss9c-lkpj

Güvendir, M., & Özkan, Y. Ö. (2022). Item removal strategies conducted in exploratory factor analysis: A comparative study. *International Journal of Assessment Tools in Education*, *9*(1), 165–180. https://doi.org/10.21449/ijate.827950

Goretzko, D., Pham, T. T. H., & Bühner, M. (2021). Exploratory factor analysis: Current use, methodological developments and recommendations for good practice. *Current Psychology*, *40*(7), 3510–3521. https://doi.org/10.1007/s12144-019-00300-2

Haryanto, H., Asrial, A., Sanova, A., Widowati, A., & Saputra, A. (2024). Generic science skills: phet applications based on discovery learning. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(1), 158–169. https://doi.org/10.22437/jiituj.v8i1.32441

Hasim, M. A., Jabar, J., & Woo Ming Wei, V. (2024). Measuring e-learning antecedents in the context of higher education through exploratory and confirmatory factor analysis. *International Journal of Academic Research in Business and Social Sciences*, *14*(9). https://doi.org/10.6007/IJARBSS/v14-i9/22670

Huang, Y.-M., Silitonga, L. M., Murti, A. T., & Wu, T.-T. (2023). Learner engagement in a business simulation game: Impact on higher-order thinking skills. *Journal of Educational Computing Research*, *61*(1), 96–126. https://doi.org/10.1177/07356331221106918

Husain, H., Samsudin, S., & Ayub, A. F. M. (2025). Exploratory factor analysis for measuring instrument of sports involvement on psychological resilience among boarding school students in Malaysia. *International Journal of Research and Innovation in Social Science*, *IX*(I), 4237–4244. https://doi.org/10.47772/IJRISS.2025.9010330

Jamillo, L. S., & Gabasa, C. G. (2024). *Narratives of Physics Teachers Using Virtual Simulations: Basis for In-Service Training Workshops*. 559–572. https://doi.org/10.22492/issn.2189-101X.2024.45

Kaldaras, L., Akaeze, H., & Krajcik, J. (2021). A Methodology for determining and validating latent factor dimensionality of complex multi-factor science constructs measuring knowledge-in-use. *Educational Assessment*, *26*(4), 241–263. https://doi.org/10.1080/10627197.2021.1971966

Lambert, L. S., & Newman, D. A. (2023). Construct development and validation in three practical steps: Recommendations for reviewers, editors, and authors. *Organizational Research Methods*, *26*(4), 574–607. https://doi.org/10.1177/10944281221115374

Landa, J., Berciano, A., & Marbán, J. M. (2024). Adaptation and validation of a scale of self-regulation of learning in mathematical problem solving. *Uniciencia*, *38*(1), 1–26. https://doi.org/10.15359/ru.38-1.34

Li, R., Lund, A., & Nordsteien, A. (2023). The link between flipped and active learning: A scoping review. *Teaching in Higher Education*, *28*(8), 1993–2027. https://doi.org/10.1080/13562517.2021.1943655

Li, S., AlZoubi, D., Glaser, N., Mendoza, K. R., Schmidt, M., & Singh, K. P. (2024). Active learning strategies in the technology-enabled classroom: Perspectives of both students and instructors. *Journal of Formative Design in Learning*, *8*(2), 82–98. https://doi.org/10.1007/s41686-024-00094-y

Li, Y.-H., Su, C.-Y., & Ouyang, F. (2024). Integrating self-explanation into simulation-based physics learning for 7th graders. *Journal of Science Education and Technology*, *33*(3), 286–299. https://doi.org/10.1007/s10956-023-10082-9

Lombardi, D., Shipley, T. F., Bailey, J. M., Bretones, P. S., Prather, E. E., Ballen, C. J., Knight, J. K., Smith, M. K., Stowe, R. L., Cooper, M. M., Prince, M., Atit, K., Uttal, D. H., LaDue, N. D., McNeal, P. M., Ryker, K., St. John, K., van der Hoeven Kraft, K. J., & Docktor, J. L. (2021). The curious construct of active learning. *Psychological Science in the Public Interest*, *22*(1), 8–43. https://doi.org/10.1177/1529100620973974

Lorenzo-Seva, U., & Ferrando, P. J. (2024). Determining sample size requirements in EFA Solutions: A simple empirical proposal. *Multivariate Behavioral Research*, *59*(5), 899–912. https://doi.org/10.1080/00273171.2024.2342324

Maftuh, M. S. J. (2023). Understanding learning strategies: A comparison between contextual learning and problem-based learning. *Educazione: Journal of Education and Learning*, *1*(1), 54–65. https://doi.org/10.61987/educazione.v1i1.496

Manggaberani, A. A., & Putro, N. H. P. S. (2024). Development of character assessment instrument on English learning for middle school students. *Research and Development in Education (RaDEn)*, *4*(1), 374–389. https://doi.org/10.22219/raden.v4i1.31923

Matthews, R. A., Pineault, L., & Hong, Y.-H. (2022). Normalizing the use of single-item measures: Validation of the single-item compendium for organizational psychology. *Journal of Business and Psychology*, *37*(4), 639–673. https://doi.org/10.1007/s10869-022-09813-3

Mueller, S., & Reiners, C. S. (2023). Pre-service chemistry teachers' views about the tentative and durable nature of scientific knowledge. *Science & Education*, *32*(6), 1813–1845. https://doi.org/10.1007/s11191-022-00374-8

Öner, H., Koruklu, N., & Denat, Y. (2024). Development of the professional socialization scale, validity and reliability study. *Adnan Menderes Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, *11*(2), 23–39. https://doi.org/10.30803/adusobed.1520760

Petrova, H. (2020). Modeling using PhET simulations in teaching physics at secondary school. *Education and Technologies Journal*, *11*(1), 199–203. https://doi.org/10.26883/2010.201.2270

Pranata, O. D. (2023). Enhancing conceptual understanding and concept acquisition of gravitational force through guided inquiry utilizing PhET simulation. *Sainstek : Jurnal Sains dan Teknologi*, *15*(1), 44. https://doi.org/10.31958/js.v15i1.9191

Pratiwi, W., Inderawati, R., & Silvhiany, S. (2024). Integrating technology and enhancing communication: Pre-Service teachers' perceptions and collaborative podcast creation in English language education. *AL-ISHLAH: Jurnal Pendidikan*, *16*(4). https://doi.org/10.35445/alishlah.v16i4.5900

Rahmawati, Y., Zulhipri, Z., Hartanto, O., Falani, I., & Iriyadi, D. (2022). Students' conceptual understanding in chemistry learning using PhET interactive simulations. *Journal of Technology and Science Education*, *12*(2), 303. https://doi.org/10.3926/jotse.1597

Razali, F. A., Wahid, S. N. S., Adnan, N. I. M., Alam, N. M. F. H. N. B., & Hilmi, Z. A. G. (2024). *Construct validation of students' anxiety and attitudes towards statistical concepts questionnaire: An exploratory factor analysis procedure*. 060001. https://doi.org/10.1063/5.0192241

Omra, J. S., Malayao Jr, S. O., Paylaga, G. J., Caparoso, J. K. V., Sayson, N. L. B., & Arrogancia, D. C. (2025). Integrating simulation-based and hands-on experiments: A guided inquiry learning packet on magnetic induction. *International Journal of Research in Social Science and Humanities,* *6*(4), 21–30. https://doi.org/10.47505/IJRSS.2025.4.3

Saad, A., & Zainudin, S. (2024). A review of teaching and learning approach in implementing Project-Based Learning (PBL) with Computational Thinking (CT). *Interactive Learning Environments*, *32*(10), 7622–7646. https://doi.org/10.1080/10494820.2024.2328280

Saad, R. B., Garcia, A. L., & Garcia, J. M. C. (2025). Mapping constructivist active learning for STEM: Toward sustainable education. *Sustainability*, *17*(13), 6225. https://doi.org/10.3390/su17136225

Salame, I. I., & Makki, J. (2021). Examining the use of PhET simulations on students' attitudes and learning in general chemistry II. *Interdisciplinary Journal of*

Environmental and Science Education, *17*(4), e2247. https://doi.org/10.21601/ijese/10966

Sari, Y., Firdaus, M. L., Wardana, R. W., & Putra, S. (2024). Applying PhET interactive simulations media with a guided investigation approach to improve student's critical thinking skills. *International Journal of Research in Education*, *4*(1), 169–178. https://doi.org/10.26877/ijre.v4i1.17327

Saudelli, M. G., Kleiv, R., Davies, J., Jungmark, M., & Mueller, R. (2021). PhET simulations in undergraduate physics. *Brock Education Journal*, *31*(1). https://doi.org/10.26522/brocked.v31i1.899

Shaheen, N., Shaheen, A., Ramadan, A., Hefnawy, M. T., Ramadan, A., Ibrahim, I. A., Hassanein, M. E., Ashour, M. E., & Flouty, O. (2023). Appraising systematic reviews: a comprehensive guide to ensuring validity and reliability. *Frontiers in Research Metrics and Analytics*, *8*. https://doi.org/10.3389/frma.2023.1268045

Silviariza, W. Y., Sumarmi, N. A., Utaya, S., Bachri, S., Marhaini, N. A., Malisi, F. F., Bobinsyah, M. F., & Hariani, V. (2024). Supporting SDG 4 education 2030: collaboration of teaching models with technology (SPB-FC-L development). *International Journal of Technology Enhanced Learning*, *16*(3), 313–348. https://doi.org/10.1504/IJTEL.2024.139716

Simeon, M. I., Samsudin, M. A., & Yakob, N. (2022). Effect of design thinking approach on students' achievement in some selected physics concepts in the context of STEM learning. *International Journal of Technology and Design Education*, *32*(1), 185–212. https://doi.org/10.1007/s10798-020-09601-1

Taibu, R., Mataka, Ll., & Shekoyan, V. (2021). Using PhET simulations to improve scientific skills and attitudes of community college students. *International Journal of Education in Mathematics, Science and Technology*, *9*(3), 353–370. https://doi.org/10.46328/ijemst.1214

Ulum, M. S., & Yuanita, L. (2019). Development of physics learning instruments with guided inquiry learning model by PhET simulation to train student's science process skills on dynamic electricity in high school. *International Journal of Scientific and Research Publications (IJSRP)*, *9*(12), p9647. https://doi.org/10.29322/IJSRP.9.12.2019.p9647

Violita, S., Alifah, R., & Okimustava. (2024). Analysis of the effectiveness of guided inquiry-based physics learning with the PhET simulation guidebook on global warming material. *Jurnal Genesis Indonesia*, *3*(02), 61–68. https://doi.org/10.56741/jgi.v3i02.480

Watkins, M. W. (2018). Exploratory factor analysis: A guide to best practice. *Journal of Black Psychology*, *44*(3), 219–246. https://doi.org/10.1177/0095798418771807

Widaman, K. F., & Helm, J. L. (2023). Exploratory factor analysis and confirmatory factor analysis. In *APA handbook of research methods in psychology: Data analysis and research publication (Vol. 3) (2nd ed.).* (pp. 379–410). American Psychological Association. https://doi.org/10.1037/0000320-017

Yang, X., Dong, J., & Tan, D. (2022). Student conceptual level scale: Development and initial validation. *Frontiers in Education*, *7*. https://doi.org/10.3389/feduc.2022.965643

Zhou, H. (2025). Exploring the dynamic teaching-learning relationship in interactive learning environments. *Interactive Learning Environments*, 1–31. https://doi.org/10.1080/10494820.2025.2462149

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