

The impact of Symbolab software integration on mechanics comprehension in Applied Physics education for Civil Engineering undergraduates

Hoang Sy Minh Tuan

Thu Dau Mot University, 6 Tran Van On, Phu Loi ward, Ho Chi Minh City, 700000, Vietnam

ABSTRACT

This quasi-experimental study investigated the effectiveness of Symbolab software integration in enhancing mechanics comprehension among first-year civil engineering students at Thu Dau Mot University, Vietnam. Ninety participants were randomly assigned to experimental (n=45) and control groups (n=45). The experimental group received 8-week Symbolab-enhanced instruction covering kinematics, dynamics, and energy concepts, while the control group received traditional instruction. Post-test scores on a validated 25-item mechanics assessment revealed significantly higher performance in the experimental group ($M=78.5$, $SD=8.2$) than in the control group ($M=69.2$, $SD=10.5$), with a large effect size (Cohen's $d=0.98$, $t(88)=4.56$, $p<0.001$). Qualitative analysis of semi-structured student interviews revealed enhanced problem-solving confidence, improved visualization of abstract concepts, and increased engagement in mechanics learning. These findings provide compelling evidence that Symbolab integration significantly improves student comprehension of mechanics concepts in civil engineering education, suggesting that technology-enhanced pedagogical approaches warrant broader implementation in STEM curricula.

INTRODUCTION

Applied physics, particularly mechanics, forms the bedrock of civil engineering education, providing essential theoretical frameworks for structural analysis, material behavior, and construction methodologies (Fabian et al., 2018; White & Sabarwal, 2014). Civil engineers require a comprehensive understanding of statics, dynamics, and material mechanics to design safe infrastructure systems capable of withstanding various loading conditions and environmental stresses (Dhaniaputri et al., 2025; Faresta et al., 2024). The complexity of these concepts

often challenges first-year students, who must transition from abstract mathematical representations to practical engineering applications (Rataj et al., 2024).

Traditional physics instruction, characterized by lecture-based delivery and passive learning approaches, frequently fails both to engage students adequately and to develop the deep conceptual understanding necessary for engineering problem-solving (Samaila et al., 2021; Martínez, 2017). Research consistently demonstrates that students struggle with mechanics concepts when taught through conventional methods, particularly in visualizing force vectors, understanding motion relationships, and applying conservation principles (Mgeladze, 2025). These instructional limitations necessitate innovative pedagogical approaches that leverage technology to enhance student comprehension and engagement.

Incorporating educational technology into physics teaching is increasingly regarded as a promising way of tackling these pedagogical difficulties (Ahmad et al., 2024; Tunggyshbay et al., 2023). Digital tools offer unique advantages, including interactive visualization, step-by-step problem solving, immediate feedback, and personalized learning experiences that accommodate diverse learning styles (Babayeva et al., 2025). Among available educational technologies, Symbolab represents a sophisticated online mathematics and physics platform specifically designed to support complex problem-solving through detailed algorithmic solutions and interactive learning features. Symbolab (Fig. 1) distinguishes itself from basic calculators or general computational tools like Wolfram Alpha through its educational focus on step-by-step solution methodologies and physics-specific applications (Symbolab, 2024). Unlike PhET simulations, which are primarily designed for interactive conceptual demonstrations, Symbolab offers comprehensive problem-solving support across mechanics topics, including kinematics, dynamics, energy systems, and vector analysis (PhET Interactive Simulations,

*Corresponding author

Email Address: hoangsyminhtuan@tdmu.edu.vn

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2024). This pedagogical orientation directly addresses known learning barriers in mechanics comprehension, particularly students' difficulties with mathematical manipulation and conceptual application in physics contexts (Sweller, 2011).

Despite the growing recognition of educational technology's potential in physics instruction, limited empirical research has examined Symbolab's specific effectiveness in enhancing mechanics comprehension among civil engineering students. This study addresses this research gap by investigating how Symbolab integration influences student learning outcomes, problem-solving capabilities, and conceptual understanding in applied physics education.

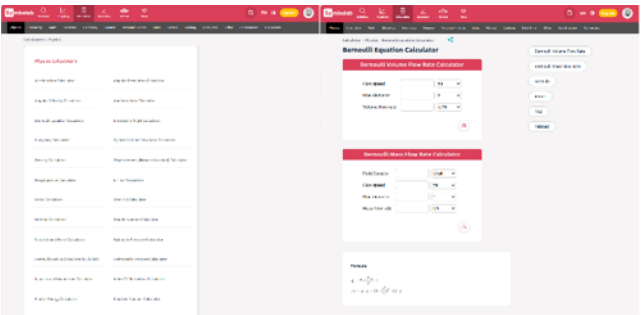


Figure 1: Symbolab's user interface, showing its physics calculator menu and a specific calculation window for Bernoulli's equation.

LITERATURE REVIEW

Technology Integration in Physics Education

Digital technologies have increasingly reshaped traditional instructional paradigms in physics education, offering dynamic approaches to presenting complex concepts that conventional methods struggle to convey effectively (Potkonjak et al., 2016; Heradio et al., 2016). Contemporary research emphasizes multiple technological tools, including simulations, virtual reality environments, augmented reality applications, and interactive software platforms in physics instruction (Cai et al., 2017). These technologies demonstrate the potential to significantly improve physics teaching through more immersive, engaging, and accessible educational experiences. Research has validated technology integration's positive effects on physics learning outcomes and student engagement (Wieman et al., 2008; Adams et al., 2008; Perkins et al., 2006). PhET Interactive Simulations have demonstrated significant improvements in student motivation and problem-solving abilities, proving equally or more effective than traditional educational resources (Adams et al., 2008). Studies examining PhET implementation report enhanced conceptual understanding, particularly in mechanics topics including motion analysis, force interactions, and energy transformations (Perkins et al., 2006). Virtual experiment platforms have gained prominence for overcoming traditional physics laboratory limitations, including inadequate equipment, environmental constraints, and safety concerns (de Jong et al., 2013). Research indicates virtual experiments enhance students' visual perception and conceptual comprehension in mechanics and electricity topics (Zacharia & Olympiou, 2011; Heradio et al., 2016).

Educational Software in Mathematics and Physics

Educational software designed for mathematics and physics instruction has demonstrated significant potential for enhancing student learning outcomes across diverse educational contexts (Cheung & Slavin, 2013). Research consistently indicates that specialized software applications can address specific learning challenges while providing personalized, interactive experiences that traditional large-class instruction typically cannot deliver at scale. Studies examining educational software effectiveness in mathematics education reveal substantial improvements in student

performance, particularly in complex problem-solving domains (Fabian et al., 2018). Software applications providing step-by-step solutions and interactive feedback have proven especially beneficial for students struggling with abstract mathematical concepts. These findings suggest considerable potential for similar applications in physics education contexts.

Symbolab in Educational Research

Symbolab, as a comprehensive online mathematics and physics platform, offers extensive functionality for equation solving, calculus operations, and physics problem analysis (Symbolab, 2024). Its step-by-step solution methodology represents a key pedagogical feature that distinguishes it from basic computational tools, providing detailed explanations that support student understanding of underlying mathematical and physical principles. The few empirical studies examining Symbolab's educational effectiveness have focused primarily on mathematics education contexts. Research by Paulin and Jean Baptiste (2023) investigated Symbolab calculator effectiveness in improving trigonometric equation solving among science and mathematics students. Their quasi-experimental study involving 112 participants demonstrated significant performance improvements in the experimental group ($M=20.52$, $SD=2.69$) compared to the control group ($M=13.72$, $SD=3.95$), with statistical significance ($t=35.65$, $p<0.001$). A Vietnamese study by Viet et al. (2018) explored Symbolab's role in cooperative linear algebra teaching, reporting improved student engagement and conceptual understanding through software-mediated learning activities. Despite these promising findings in mathematics education, limited research has examined Symbolab's specific effectiveness in physics instruction, particularly for mechanics comprehension among engineering students.

METHODOLOGY

Research Design

This study employed a quasi-experimental design with a pre-test/post-test control group framework to investigate Symbolab software integration's impact on mechanics comprehension among civil engineering students. A quasi-experimental approach was chosen because, in real classroom settings, assigning students at random to different teaching methods is often impractical (White & Sabarwal, 2014). This design facilitated a direct comparison of mechanics learning outcomes between students receiving Symbolab-enhanced instruction and those taught through traditional methods.

Participants and Sampling

The study population comprised first-year civil engineering students enrolled in Applied Physics courses at Thu Dau Mot University during the 2023-2024 academic year. Using systematic random sampling, 90 students were selected from a total population of 180 eligible participants. These 90 students were then randomly assigned to experimental ($n=45$) and control ($n=45$) groups via random number generation. Inclusion criteria required students to be enrolled in their first Applied Physics course with no prior exposure to Symbolab specifically.

Baseline demographic analysis revealed comparable groups with mean ages of 18.3 ($SD=0.7$) for the experimental group and 18.5 ($SD=0.8$) for the control group. Prior mathematics achievement scores showed no significant differences between groups (experimental: $M=7.2$, $SD=1.1$; control: $M=7.0$, $SD=1.2$; $t(88)=0.89$, $p=0.375$), confirming group equivalence at baseline. Pre-test mechanics assessment scores likewise showed no significant difference between the experimental group ($M=52.3$, $SD=8.8$) and the control group ($M=51.7$, $SD=9.2$), $t(88)=0.32$, $p=0.753$, Cohen's $d=0.07$, confirming baseline equivalence in mechanics knowledge prior to the intervention.

Ethical Considerations

This study received approval from Thu Dau Mot University's Institutional Review Board (IRB Protocol #2023-EDU-047). All participants provided written informed consent after receiving detailed explanations of study procedures, potential risks and benefits, and data confidentiality measures. Students were informed of their right to withdraw from the study at any time without academic penalty. Data collection and storage procedures adhered to institutional guidelines for educational research ethics.

Intervention Description

The intervention consisted of an 8-week instructional program covering three major mechanics topics: kinematics (weeks 1-3), dynamics (weeks 4-6), and energy systems (weeks 7-8). The experimental group received Symbolab-enhanced instruction integrated across multiple learning contexts, including classroom lectures, guided practice sessions, and homework assignments.

During lecture sessions, instructors demonstrated Symbolab's problem-solving capabilities through step-by-step solutions projected for the entire class. Students observed how complex mechanics problems could be decomposed into manageable steps with detailed explanations for each calculation. Guided practice sessions provided hands-on experience with Symbolab, where students worked individually and in small groups to solve assigned problems while receiving instructor support.

Homework assignments required experimental group students to use Symbolab for problem verification. Students were encouraged to compare their manual calculations with Symbolab solutions, identifying discrepancies and understanding error sources.

The control group received traditional instruction consisting of lecture-based content delivery, textbook problem-solving, and conventional homework assignments. Instructional content remained identical between groups, with the primary difference being the technological tools and pedagogical approaches employed.

Assessment Instrument

A 25-item mechanics assessment covering all three instructional modules was developed to evaluate student comprehension. The assessment included multiple-choice questions (15 items), short-answer problems (5 items), and extended-response applications (5 items) covering conceptual understanding, mathematical application, and real-world problem-solving.

Content validity was established through expert review by three physics education specialists and two civil engineering faculty members. Item difficulty and discrimination indices were calculated through pilot testing with 30 students from a comparable population not included in the main study. Cronbach's alpha reliability coefficient was 0.87, indicating acceptable internal consistency.

The assessment addressed specific mechanics concepts including: (1) Kinematic relationships and motion analysis (8 items); (2) Force systems and Newton's laws application (9 items); (3) Work, energy, and conservation principles (8 items).

Data Collection Procedures

Pre-test assessments were administered one week prior to intervention implementation to establish baseline comprehension levels. Post-test assessments were conducted immediately following the 8-week intervention period. Both assessments were administered under standardized conditions with identical time limits and testing environments.

Qualitative data were collected through semi-structured interviews with 20 experimental group participants (44% of experimental group) selected through stratified random sampling to ensure representation across performance levels. Interview protocols explored student perceptions of Symbolab's impact on learning, problem-solving confidence, and conceptual understanding. The interviews lasted 35–45 minutes on average and were conducted by two independent research assistants who were not involved in instruction or grading, in order to reduce social desirability bias. Student emotion levels (Fig. 2) were measured immediately after completing easy and difficult assignments using the short form of the Achievement Emotions Questionnaire (AEQ-S), rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Composite scores for each emotion were compared between groups using independent samples t-tests.

Data Analysis

Quantitative data analysis employed independent samples t-tests to compare post-test performance between experimental and control groups. Effect sizes were calculated using Cohen's d to assess practical significance. Qualitative interview data were analyzed using thematic analysis procedures, with two independent coders achieving 92% inter-rater agreement (Cohen's kappa = 0.84). Baseline equivalence was examined by comparing pre-test scores between groups using an independent samples t-test.

Statistical assumptions, including normality, homogeneity of variance, and independence, were verified prior to hypothesis testing. All analyses were conducted using SPSS version 28.0 with alpha level set at 0.05.

RESULTS

Quantitative Outcomes

The independent samples t-test revealed statistically significant differences in post-intervention mechanics comprehension between experimental and control groups (Table 1). The experimental group achieved significantly higher mean scores ($M=78.5$, $SD=8.2$) compared to the control group ($M=69.2$, $SD=10.5$), $t(88)=4.56$, $p<0.001$. Cohen's $d=0.98$ indicated a large effect size, suggesting both statistical and practical significance and indicating that Symbolab integration produced substantial improvements in student learning outcomes.

Table 1: Descriptive Statistics and T-Test Results for Mechanics Assessment

Group	N	Mean	SD	t-statistic	df	p-value	Cohen's d
Experimental (Symbolab)	45	78.5	8.2	4.56	88	<0.001	0.98
Control (Traditional)	45	69.2	10.5				

Analysis of performance by topic area revealed differential effects of Symbolab integration. The largest improvements occurred in kinematics (experimental: $M=26.8$, $SD=3.1$; control: $M=22.4$, $SD=4.2$) and dynamics (experimental: $M=27.2$, $SD=3.5$; control:

$M=23.1$, $SD=4.8$), while energy systems showed more modest differences (experimental: $M=24.5$, $SD=3.8$; control: $M=23.7$, $SD=4.1$). These topic-level comparisons are descriptive only.

Qualitative Findings

Thematic analysis of interview data identified four major themes regarding Symbolab's impact on mechanics learning:

Enhanced Problem-Solving Confidence: Students reported increased confidence in approaching complex mechanics problems after observing Symbolab's systematic solution strategies. Representative quote: "Seeing how Symbolab breaks down problems into steps helped me understand that I don't need to solve everything at once. I can take it step by step."

Improved Conceptual Visualization: Participants described a better understanding of abstract physics concepts through Symbolab's detailed explanations and mathematical representations. One student noted: "The way Symbolab shows each calculation step made it clearer how the equations connect to the physical situations."

Increased Engagement and Motivation: Multiple students reported greater interest in physics learning through technology integration. As one participant explained: "Using Symbolab made physics more interesting because I could check my work immediately and understand my mistakes."

Self-Directed Learning Support: Students appreciated Symbolab's availability for independent study and homework verification. A representative comment: "I could practice more problems at home because Symbolab helped me check if I was doing things correctly."

Figure 2 presents student emotion levels during easy and difficult problem-solving assignments, showing higher positive emotions and reduced anxiety in the experimental group compared to the control group.

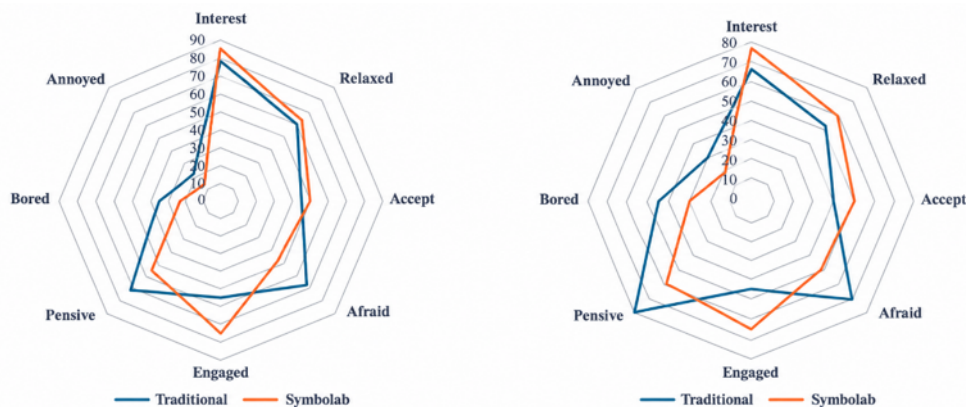


Figure 2: Student emotion levels while completing easy (a) and difficult (b) assignments.

DISCUSSION

The findings demonstrate that Symbolab software integration significantly enhanced mechanics comprehension among civil engineering students. This is supported by both the statistically significant group differences and the large effect size. The large effect size (Cohen's $d=0.98$) indicates that the intervention produced meaningful improvements in student learning outcomes that extend beyond mere statistical significance.

Several factors likely contributed to the observed performance improvements in the experimental group. Symbolab's step-by-step solution methodology provided scaffolded learning experiences that supported students' gradual development of problem-solving expertise. This approach aligns with cognitive load theory, which suggests that complex learning tasks benefit from decomposition into manageable components (Sweller, 2011; Rataj et al., 2024). The software's immediate feedback capabilities enabled students to identify and correct misconceptions promptly, preventing the consolidation of incorrect understanding that often occurs in traditional instruction (Samaila et al., 2021). This automated (rather than instructor-generated) formative assessment function supported self-regulated learning by allowing students to monitor their comprehension and adjust their study strategies accordingly. Comparing manual calculations with Symbolab solutions likely also promoted metacognitive awareness and self-regulated learning strategies. Symbolab's visualization features likely enhanced students' ability to connect abstract mathematical representations with physical phenomena, addressing a common challenge in physics education (Martínez, 2017). The software's graphical outputs and detailed calculations provided multiple representations of physics concepts, supporting diverse learning preferences and cognitive processing styles.

The differential effects observed across topic areas suggest that Symbolab's benefits may be most pronounced for topics requiring extensive mathematical manipulation, such as kinematics and dynamics. Energy systems, which involve more conceptual understanding than computational complexity, showed smaller improvements, indicating that technology integration should be strategically aligned with specific learning objectives.

Qualitative findings corroborate quantitative results by revealing students' positive perceptions of Symbolab's impact on their learning experiences. The themes of enhanced confidence, improved visualization, increased engagement, and self-directed learning support align with established theories of technology-enhanced education and motivation in STEM learning (Mgeladze, 2025; Ahmad et al., 2024).

Implications for Physics Education

These results have significant implications for physics education in engineering contexts. The substantial learning gains associated with Symbolab integration suggest that educational technology can effectively address traditional challenges in physics instruction when implemented thoughtfully and systematically.

The findings support a broader movement toward technology-enhanced pedagogical approaches in STEM education, particularly for courses requiring complex mathematical problem-solving skills. Symbolab's effectiveness in mechanics instruction may extend to other physics topics and mathematical domains, warranting controlled studies across other physics topics such as thermodynamics and electromagnetism.

For educators, these results indicate that software integration should focus on pedagogical enhancement rather than the adoption of technology for its own sake. Symbolab's success appeared to result from its alignment with fundamental learning

principles, including scaffolding, immediate feedback, and multiple representation formats.

Limitations and Future Research

Several limitations should be considered when interpreting these findings. The study was conducted at a single institution with a relatively homogeneous student population, potentially limiting generalizability to other educational contexts or student demographics. The 8-week intervention period, while sufficient to detect significant effects, may not capture long-term retention or transfer of learning outcomes.

The quasi-experimental design, though appropriate for educational settings, cannot eliminate all potential confounding variables that might influence student performance. Additionally, the study focused specifically on mechanics topics within applied physics, and results may not generalize to other physics domains or STEM subjects. Further limitations include potential instructor bias, given that the author may also have served as the instructor; residual social desirability bias in the interviews and self-reported emotion ratings, despite the use of independent research assistants as interviewers; and the use of independent samples t-tests without adjustment for pre-test scores (e.g., ANCOVA).

Future research should examine Symbolab's effectiveness across diverse educational contexts, student populations, and physics topics to establish broader applicability. Longitudinal studies investigating long-term retention and transfer effects would provide valuable insights into the durability of technology-enhanced learning outcomes.

Comparative studies examining Symbolab's effectiveness relative to other educational technologies would inform evidence-based decisions about optimal technology selection for specific learning objectives (Adams et al., 2008; Perkins et al., 2006).

CONCLUSION

This quasi-experimental study provides compelling evidence that Symbolab software integration significantly enhances mechanics comprehension among first-year civil engineering students. The substantial effect size (Cohen's $d=0.98$) and consistent qualitative findings support the conclusion that technology-enhanced instruction can effectively address traditional challenges in physics education.

The results demonstrate that educational technology, when aligned with sound pedagogical principles, can produce meaningful improvements in student learning outcomes. Symbolab's step-by-step solution methodology, immediate feedback capabilities, and visualization features addressed key barriers to mechanics comprehension while supporting diverse learning preferences and self-regulated learning strategies.

These findings support broader implementation of evidence-based technology integration in STEM education, particularly in courses requiring complex problem-solving skills. However, successful implementation requires thoughtful planning, appropriate instructor training, and strategic alignment with specific learning objectives.

The study contributes to growing evidence supporting technology-enhanced physics education while highlighting the need for continued research examining optimal implementation strategies, long-term effects, and broader applicability across diverse educational contexts. As educational institutions continue integrating digital technologies, these findings provide valuable guidance for evidence-based decision-making in physics curriculum development and instructional design, and they

encourage institutions in Vietnam and Southeast Asia to pilot Symbolab integration in applied physics courses.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

H.S.M.T. conceptualized the study, designed the methodology, implemented the intervention, collected and analyzed the data, and wrote and revised the manuscript. The author has read and approved the final version.

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