

STEM-Based Gear Activities for Enhancing Understanding and Satisfaction in a Thai Multi-Grade Engineering Class

Chinapat Mongkholsiriwattana ^{1,2}, Monamorn Precharattana ¹

¹Institute for Innovative Learning, Mahidol University,
Nakhon Pathom, 73170, Thailand

²Darunsikkhalai School for Innovative Learning, King Mongkut's
University of Technology Thonburi, Bangkok, 10140, Thailand

ABSTRACT

This study investigated the impact of a STEM-based hands-on gear activity on students' conceptual understanding and satisfaction in a multi-grade engineering class (Grades 8–12) at Darunsikkhalai School (DSIL). The gear set was designed to reduce reliance on external materials while supporting instruction on gear ratios and the Engineering Design Process (EDP). A 19-item two-tier diagnostic test measured students' knowledge. Scores for Grade 8–9 students increased from 11.82 (SD 4.08) to 17.18 (SD 7.54), while Grade 10–12 students improved from 18.72 (SD 6.36) to 24.94 (SD 8.53), results statistically significant ($p < .001$). Student satisfaction was assessed through a five-dimensional form, indicated improved satisfaction and deeper conceptual understanding. The findings suggest that integrating STEM instruction with hands-on activities can enhance learning, even in complex topics such as gear systems. This study contributes to curriculum innovation in STEM education within ASEAN contexts, underscoring value of responsive, resource-conscious teaching strategies.

Keywords: Hands-on learning, gear ratio, Satisfaction, STEM, Two-tier test

ARTICLE INFORMATION

Article History

Received: January 7, 2025

Revised: November 17, 2025

Accepted: November 18, 2025

Editor-in-Chief

Watsatree Diteeyont, PhD

Managing Editor

Marie Paz E. Morales, PhD

Guest Editor

Assoc. Prof. Dr. Duong Minh Quang

Co-Guest Editors

Dr. Nguyen Vu Thanh Tam

Introduction

In recent years, hands-on learning (also referred to as active and practical learning) has gained prominence in STEM classrooms for its ability to help students connect theoretical knowledge to real-world applications (Tep et al., 2024). While project-based learning can deepen conceptual understanding, it often lacks the tactile experiences necessary to develop technical skills, especially in interdisciplinary topics such as gear system design. Effective instruction in this area requires both conceptual grounding and practical engagement—an integration often missing in current school curricula.

One key issue is the absence of gear-related content in global physics textbooks at the high school level and the national curriculum. Although foundational concepts like Newton's laws of motion are covered, explicit instruction on gear systems is lacking. International textbooks show limitations; for example, Satyam (2024) discussed pulleys and shafts but omitted gears entirely. Meanwhile, gear content in university-level engineering texts, such as Jackson and Tarhini (2022), tends to be overly complex—relying on technical language and advanced formulas inappropriate for secondary-level students.

At the local level, Thailand has faced similar challenges, as evidenced by the limitations in high school physics books (Institute for the Promotion of Teaching Science and Technology, 2011). This gap leaves both teachers and students at a disadvantage. Teachers struggle to design lessons that meet students' interests and curriculum standards, particularly when resources are scarce or not age-appropriate. Students interested in gear mechanics often resort to informal learning

sources such as YouTube, where simplified gear demonstrations using LEGO or cardboard help convey concepts like torque and gear ratios. However, these informal materials are not systematically aligned with classroom instruction or national standards.

To address this gap, the present study introduces a STEM-based instructional model that integrates hands-on gear activities with Kolb's experiential learning cycle and the Engineering Design Process (EDP). The objective is to enhance students' conceptual understanding of gear ratios and improve their satisfaction through structured, curriculum-aligned activities. The effectiveness of the instructional design is assessed through students' learning outcomes and satisfaction.

Literature Review

Experiential Learning Theory

David Kolb (1984) defines direct experience as the foundation of Experiential Learning Theory (ELT), outlining a four-stage cycle: Concrete Experience (CE)—engaging in practice; Reflective Observation (RO) – reflecting for deeper understanding; Abstract Conceptualization (AC) – developing ideas; and Active Experimentation (AE) – testing theories in real situations.

ELT is widely applied in STEM, problem-based, and skill-based learning, promoting active, critical, and problem-solving engagement. Li et al. (2019) applied ELT in a mechanical engineering course and found improved student engagement and understanding; students better grasped principles through interaction with real transmission systems.

This alignment between EDP and ELT provides structural correspondence and enhances effectiveness. Through experiential engagement (CE), students face real engineering problems that stimulate curiosity. Reflective Observation (RO) gives students the opportunity to analyze failures and successes, fostering metacognitive growth essential for iterative design. Abstract Conceptualization (AC) helps students create engineering principles and designs that link theory with practice, and Active Experimentation (AE) plays the role of transforming those ideas into prototypes that can be tested and improved. Cycling through these stages promotes students to become adaptive experts who apply knowledge flexibly in novel contexts. Therefore, ELT increase EDP by embedding mechanisms of reflection, iteration, and conceptual transfer as continuous processes, enhancing cognitive understanding and engineering skills.

Bloom's Taxonomy Cognitive Domain

Bloom's Taxonomy, developed by Benjamin S. Bloom (1956), provides a structured framework for educational objectives across three domains: cognitive, affective, and psychomotor. Focusing on the cognitive domain, Bloom identified six learning levels from basic recall to higher-order thinking (Zhao et al., 2022). Anderson (2001) revised the taxonomy to emphasize active learning, renaming categories with verbs and reordering them as Remembering, Understanding, Application, Analysis, Evaluating, and Creating. In this study, a two-tier test investigated students' cognitive processing after the activities, focusing on all levels except "Remembering."

STEM Hands-on

The ASEAN Work Plan on Education (2021–2025) emphasizes enhancing education in

Southeast Asia, particularly through STEM initiatives. A key focus of this plan is promoting gender equality and empowering women in STEM. Lemus-Delgado and Cerda (2025) highlighted that increasing female participation is essential for regional development and inclusive education. Classroom design should include hands-on tool experiments that engage all students equally. Wahono et al. (2020) found that the effective implementation of STEM leads to better student learning outcomes.

However, the quality of STEM education often depends on access to teacher training and educational resources. Freeman et al. (2019) note that sharing effective STEM practices helps overcome challenges and provides valuable insights. Chou and Ravinet (2017) suggest that educational regionalism promotes cooperation, enabling countries to learn from one another's successes and failures. ASEAN cooperation is therefore essential for advancing STEM education in the region.

Many studies highlight the benefits of hands-on STEM learning for improving student engagement and satisfaction. Jovanović et al. (2019) introduced robot- and drone-based activities, enabling real-world experiences and technical learning for future STEM careers. Similarly, Tep et al. (2024) implemented an aviation project-based classroom where students worked with structural components and radio-controlled airplanes, demonstrating improvement in learning performance. Kanapathy and Azhari (2024) found that hands-on STEM learning positively affects students' knowledge and satisfaction.

Integrating models and frameworks into STEM education helps students grasp complex concepts. For example, Wang and Wang (2023)

used the Predict–Observe–Explain (POE) model in junior high energy education, leading to better understanding and promoting deeper learning. Hong et al. (2021) developed a STEAM classroom using Object-Related and Object-Free learning approaches, which improved students’ problem-solving and analytical skills while fostering self-efficacy and positive attitudes toward practical activities.

Using tangible objects in the classroom significantly enhances comprehension and highlights the importance of designing activities that support diverse intelligences. Prior hands-on STEM studies have focused on gear-based learning tools integrating mechanical concepts. Stump (2000) used a real multi-speed bicycle with chainrings and cogs to explain gear ratios and fractions by observing gear movement. Chambers et al. (2008) utilized LEGO Mindstorms to build and program robots, helping students grasp concepts such as power-speed and gear ratios. Chang et al. (2012) developed a virtual game laboratory for experimenting with simple and complex gear systems, allowing students to assemble and test virtual mechanisms for deeper insights. Slightam and Nagurka (2015) incorporated 3D-printed gears, where students designed, disassembled, and calculated ratios for mechanisms such as clocks. These activities promoted problem-solving, analytical thinking, and confidence in mechanical design.

Although various tools have been used to teach gear systems, allowing students to manipulate real materials enhances understanding and practical skills. This study introduces a practical approach using a laser cutting machine to create low-cost, durable plywood gears. Unlike LEGO, 3D printing, or virtual simulations, these gears are more accessible and reproducible, addressing

classroom constraints while improving engagement and offering both conceptual and practical benefits in STEM education.

Framework of the Study

Mongkholsiriwattana et al. (2023) proposed hands-on activity kits for a flipped robotics camp on gears. Students engaged with tangible materials and abstract concepts, bridging the gap between theory and practice through independent exploration.

Bozkurt (2021) implemented a five-step EDP emphasizing real-world problem solving: (1) identify a problem, (2) develop possible solutions, (3) select the best idea, (4) prototype and test, and (5) share and communicate. This model enhances creativity, communication, and problem-solving, while hands-on experimentation deepens understanding of engineering concepts. Real-life applications also reinforce students’ retention of science and math principles. Therefore, this study integrates the EDP into the STEM classroom and aligns it with ELT to promote experiential learning.

The mapping between EDP and ELT in this study is as follows:

1. Identifying the problem → CE: Hands-on problem engagement.
2. Developing possible solutions → RO: Analyze, reflect, and explore options.
3. Selecting the best idea → AC: Apply engineering principles plan.
4. Prototyping and testing → AE: Building and refining prototypes.
5. Sharing and communicating → All ELT: Feedback, reflection, and iterative improvement.

This integration demonstrates how EDP supports ELT by engaging students in a continuous learning cycle of experience, reflection, conceptualization, and application.

Physics Content Related to Gears

According to Mongkholsiriwattana et al. (2023), gear-related physics is not directly included in Thailand's high school curriculum. Relevant concepts appear under circular motion, mechanical advantage, and equilibrium, covering torque, moment, frequency, linear velocity, and angular velocity—essential for understanding gear ratios and applications.

Given this limitation, our study combines experiential learning with hands-on gear experiments to help students develop a deeper understanding of these core physics concepts.

Research Objectives

The study aims to:

1. Evaluate the effectiveness of STEM instruction based on Kolb's ELT and EDP, using hands-on gear activities, in enhancing students' understanding of gear ratios.
2. Assess students' satisfaction with STEM instruction incorporating hands-on gear activities across five dimensions: (a) lesson topic, (b) teacher's instruction, (c) classroom activities, (d) learning method, and (e) hands-on model.

Research Questions

To achieve these objectives, the study addresses the following questions:

1. To what extent does STEM instruction, grounded in Kolb's ELT and EDP, enhance students' understanding of gear ratios through hands-on gear activities, as measured by pre- and post-test?
2. How satisfied are students with the STEM instruction incorporating hands-on gear activities, evaluated across five dimensions:
 - a. appropriateness and clarity of the lesson topic,
 - b. supportiveness of the teacher,
 - c. engagement and relevance of classroom activities,
 - d. effectiveness of the learning method in promoting collaboration and knowledge sharing, and
 - e. usability and conceptual clarity of the hands-on model.

Participants

This study employed purposive sampling to recruit 35 students from Grades 8–12 at Darunsikhalai School for Innovative Learning (DSIL). According to William S. Gosset's principle (Student, 1908), a minimum of 30 participants is sufficient for statistical analysis. Participants were selected based on two criteria: prior experience with project-based learning and interest in STEM, particularly mechanical design. This ensured that students were capable of engaging in hands-on gear activities and benefitting from the integrated STEM instruction.

The final sample included 10 females (28.57%) and 25 males (71.43%), distributed as follows: 14 in Grade 8 (40.00%), 3 in Grade 9 (8.57%), 3 in Grade 10 (8.57%), 4 in Grade 11 (11.43%), and 11 in Grade 12 (31.43%). For analysis, students were grouped into Lower Secondary School (LSS: Grades 8–9, 48.57%) and Upper Secondary School (USS: Grades 10–12, 51.43%).

LSS students typically had limited exposure to formal physics, whereas USS students came from diverse curricular backgrounds. Some had explored gear systems independently through propulsion-related projects, providing relevant foundational knowledge.

Although purposive sampling enhances the study's focus and relevance, it limits generalizability to a broader population. Therefore, this research serves as an exploratory intervention examining how STEM-based hands-on learning affects student satisfaction and conceptual understanding in a specific context.

Methodology

This study employed a quasi-experimental, one-group pretest-posttest design to evaluate the effectiveness of the intervention in enhancing students' understanding of gear ratios and satisfaction with the learning experience.

Intervention Development

Two instructional components were developed to integrate gear concepts into STEM learning: (1) **Learning Gear Set** and (2) **STEM-Based Gear Activity Teaching Plan**.

The *Learning Gear Set*, designed with Rhinoceros-3D software, included laser-cut spur gears with 15–45 teeth (15, 20, 25, 30, 35, 40, and 45). Components were made from 3-mm plywood and featured a motor mount and speed control case, allowing students to assemble and manipulate real gear mechanisms.

The *STEM-Based Gear Activity Teaching Plan* was grounded in Kolb's ELT and EDP. The instructional plan integrated content from:

- Science: Identification of gear types (external, internal, spur) and gear train roles (driver, idler, driven).
- Technology: Utilization of the Learning Gear Set as a hands-on tool.
- Engineering: Application of a five-step ELT–EDP mapping for iterative problem-solving.
- Mathematics: Calculation of gear ratio, rotational speed, and mechanical advantage for real-world applications.

Research Procedure

This research followed a three-phase instructional process (Figure 1).

The instructional design was guided by a theoretical framework integrating Kolb's ELT and the EDP (Figure 2).

ELT emphasizes learning through experience, reflection, conceptualization, and experimentation, while EDP provides a structured approach to problem-solving—identifying challenges, developing and testing solutions, and sharing outcomes. Combining both models aimed to enhance students' understanding of mechanical systems and foster creativity, critical thinking, and

Figure 1

Research Procedure Flowchart

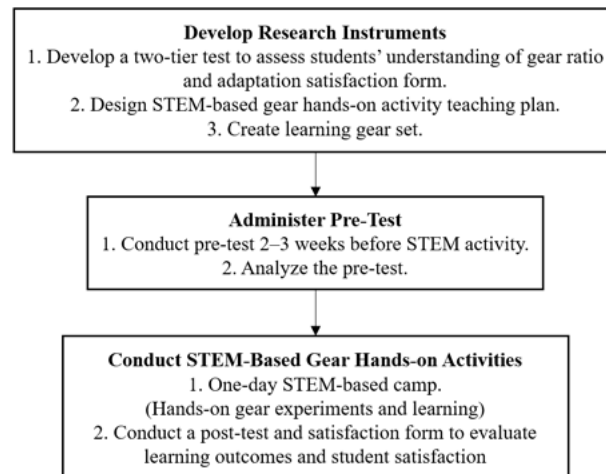


Figure 2

Diagrammatic Framework

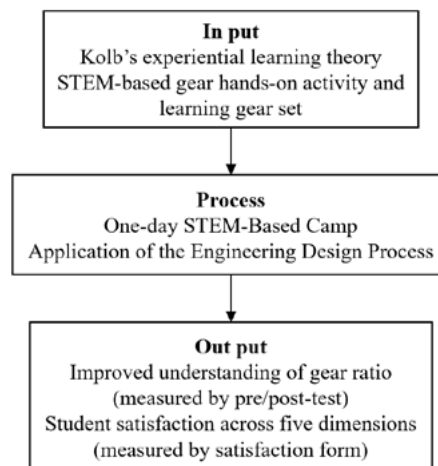


Table 1

Levels of Cognitive Domain in Gear Learning

Cognitive Level	Description
Understanding	Identification of idler gear function and direction of rotation.
Application	Explanation of multi-gear trains and implications of gear size.
Analysis	Comparison of gear configurations for specific tasks.
Evaluation	Selection of appropriate gear setups for defined problems.
Creation	Design of functional gear systems with missing or open-ended parameters.

satisfaction. This hybrid framework supported the development of both conceptual knowledge and practical skills in gear design.

Measurement Tools

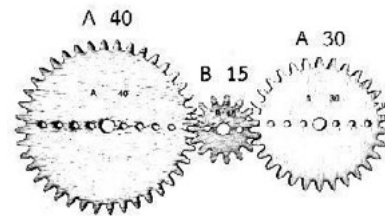
Student learning outcomes were measured using a 19-item two-tier multiple-choice diagnostic test on gear content, administered before and after the STEM camp. Two content experts (one with an MEd in Physics Education and another with a PhD and over 10 years of STEM curriculum experience) validated the test for content accuracy and cognitive alignment.

Reliability was examined using data from 36 students with similar backgrounds. Cronbach's $\alpha = .82$, indicating high internal consistency. The test assessed five levels of the cognitive domain, adapted from Bloom's revised taxonomy (see Table 1).

The two-tier test requires learners to answer in two steps: the first tier assesses content knowledge, and the second evaluates reasoning. It targets three key objectives: (1) understanding the function and rotation of idler gears in a gear train, (2) analyzing variables in simple and compound gear systems, and (3) applying gear train principles to real-world contexts.

Sample Test Format

Tier 1: Which of the following best describes the function of the middle gear (B 15) between gears A and C train?



- It is a driver gear, increasing high gear ratios.
- It is an idler gear, which changes the direction of the driver and the driven gears.
- It is an idler gear, which keeps the driver and driven gears in the same direction.
- It is a driven gear, significantly increasing the speed of the follower gear.

Tier 2: Because ...

- Gear A 40 rotates clockwise; therefore, gear B 15 rotates clockwise, and gear A 30 rotates counter-clockwise.
- Gear A 40 rotates clockwise; therefore, gear B 15 rotates

- counter-clockwise, whereas gear A 30 rotates clockwise.
- c. Gear A 40 rotates clockwise; therefore, gear B 15 rotates clockwise, and A 30 rotates clockwise.
 - d. Gear A 40 rotates clockwise, gear B 15 rotates counter-clockwise, and gear A 30 rotates counterclockwise.

After the STEM camp, students completed a satisfaction survey adapted from Wangdi et al. (2020), evaluating five dimensions of instructional quality: (1) lesson topic, (2) teacher's instruction, (3) classroom activities, (4) learning method, and (5) hands-on model. The survey used a 5-point Likert scale from "Strongly Disagree" (1) to "Strongly Agree" (5).

Ethical Considerations

This study was part of an extracurricular STEM camp supervised by the researcher. Participation was voluntary and based on students' interest. Parental and school approval was obtained prior to participation.

Students were informed about the study's objectives, procedures, and rights. All data were collected anonymously and used solely for research purposes, ensuring participants' privacy, safety, and academic welfare.

Data Analysis

Pre- and post-test data were analyzed using Microsoft Excel and R (R Core Team, 2021). Excel's Data Analysis ToolPak was used for a t-Test: Paired Two Sample for Means, while R handled descriptive statistics and assumption testing (Field et al., 2012).

Normality of paired differences was examined using the Shapiro–Wilk test (Shapiro & Wilk, 1965) and Q–Q plots. Results are presented in the Findings and Discussion section. Upon confirming normality, a paired-sample t-test was conducted to determine whether students' understanding of gear ratios improved significantly after the intervention.

As purposive sampling was employed, the analysis focused on within-group patterns rather than generalization. Descriptive statistics (mean and standard deviation) were also computed for pre- and post-test scores and satisfaction ratings.

Findings and Discussion

Assumption

The Shapiro–Wilk test results ($n = 17$), LSS pre-test ($W = 0.96$, $p = .61$) and LSS post-test ($W = 0.89$, $p = .06$). Test results ($n = 18$) of the USS pre-test ($W = 0.96$, $p = .57$) and USS post-test ($W = 0.97$, $p = .77$) indicated that the data were normally distributed ($p\text{-value} > .05$), which did not violate the paired-sample t-test assumption (see Table 2).

Table 2

The Shapiro–Wilk Test Results of Pre-Test and Post-Test for LSS and USS

Test	Mean	SD	Shapiro–Wilk	
			W	p
LSS: Pre-test	11.82	4.08	0.96	.61
LSS: Post-test	17.18	7.54	0.89	.05
USS: Pre-test	18.78	6.34	0.96	.57
USS: Post-test	26.56	5.86	0.97	.77

Q-Q plot of the pre-test and post-test confirmed the Shapiro-Wilk test results (Figures 3-6). The data points on both charts aligned perfectly along a straight line, confirming that the data were normally distributed.

Figure 3

LSS: Pre-test Q-Q plot

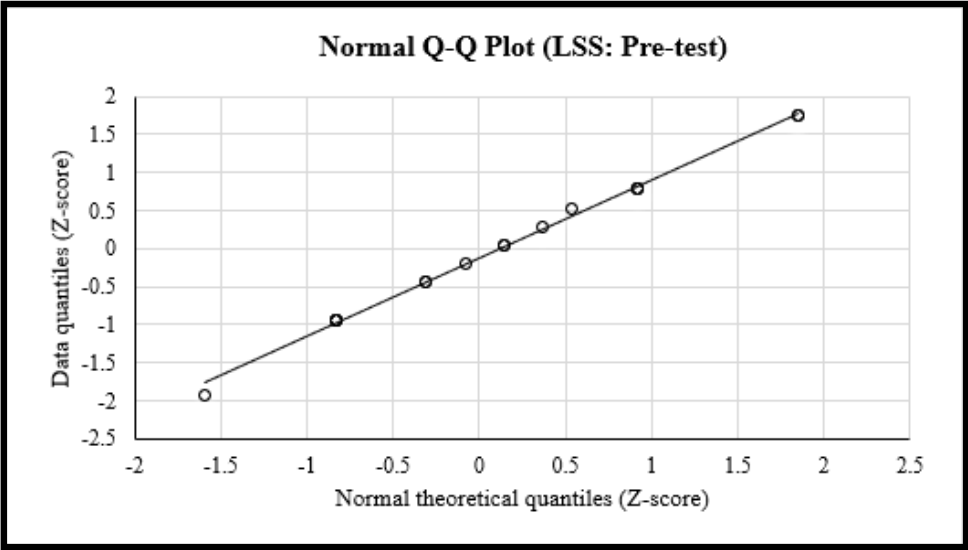


Figure 4

LSS: Post-test Q-Q plot

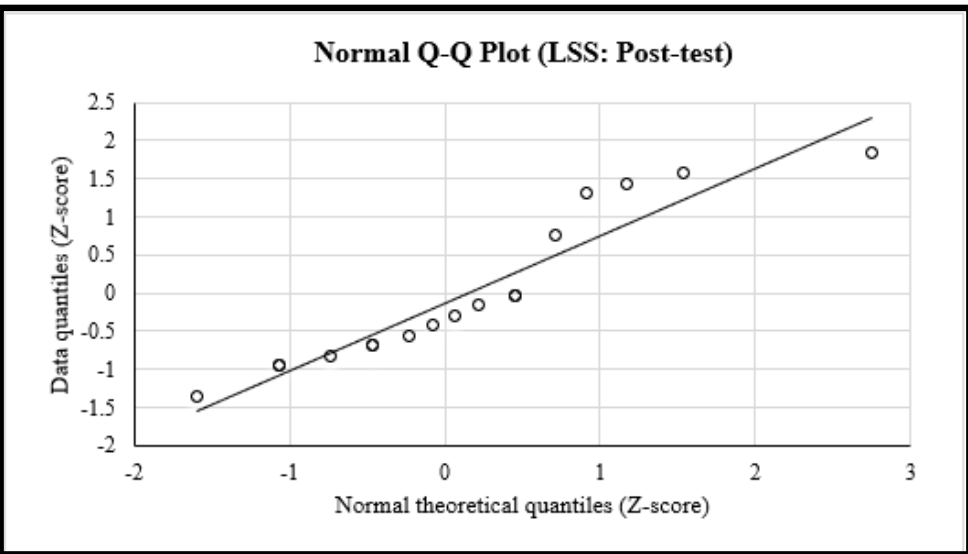


Figure 5

USS: Pre-test Q-Q plot

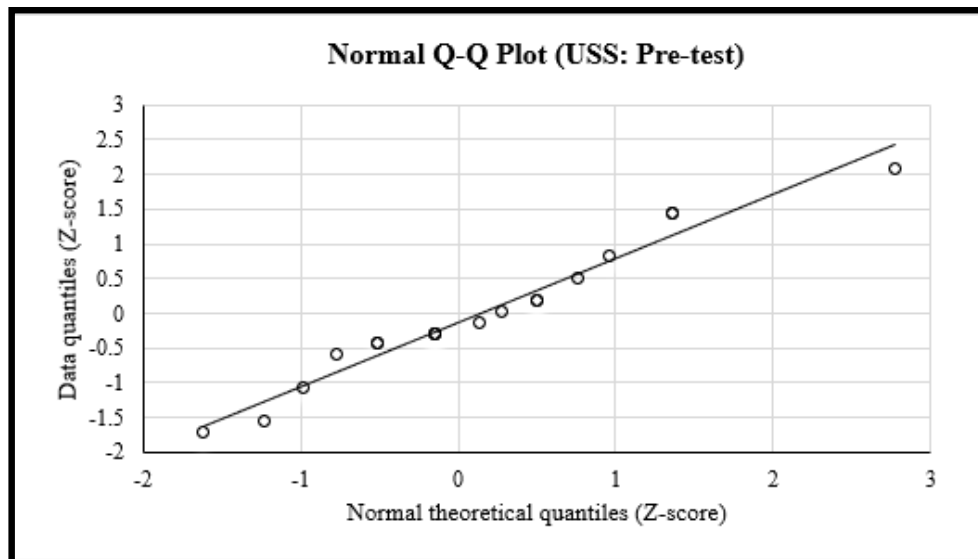


Figure 6

USS: Post-test Q-Q plot

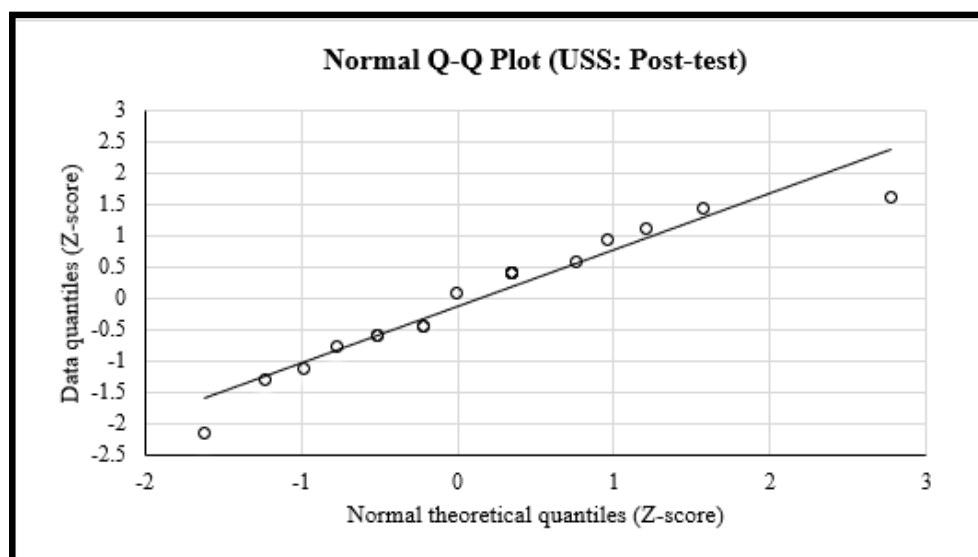


Table 3

Paired Sample t-Test Result

Comparison	Pre-test		Post-test		t	df	p-value
	Mean	SD	Mean	SD			
LSS (n=17)	11.82	4.08	17.18	7.54	3.36	16	< .001
USS (n=18)	18.78	6.34	26.56	5.86	5.09	17	< .001

Learning Outcome Results

The STEM-based gear activities significantly improved students' understanding of gear ratios in both LSS and USS (Table 3), the mean post-test score for LSS increased from 11.82 to 17.18 ($p < .001$), while the USS mean score rose from 18.78 to 26.56 ($p < .001$). These results demonstrate a statistically significant enhancement in conceptual understanding, confirming that hands-on STEM instruction effectively supports comprehension of complex physics concepts.

LSS students, who had limited prior exposure to gear mechanics and mainly focused on basic physics topics such as Newton's laws, benefited from the hands-on experience that connected abstract concepts to real-world applications. Conversely, USS students—already familiar with gear systems—used the same activities to strengthen theoretical understanding through practical application, illustrating the adaptability of STEM-based learning across different academic levels.

Satisfaction Results

The satisfaction survey (see Appendix Table) revealed both strengths and areas for improvement. Both LSS and USS found the lesson topic engaging but differed in perceived clarity. LSS rated the topic at 2.83, showing

high interest (3.56) but low comprehensibility (2.00), while USS gave higher overall ratings (3.92) with strong interest (4.41) but similar comprehension challenges. These results suggest that although the content was engaging, adjustments are needed to match varied academic levels.

Teacher instruction received positive feedback, particularly for respecting student perspectives and facilitating learning. LSS rated this dimension 3.50 (highest sub-score 3.94 for respect), while USS rated it 4.18. Both groups suggested simplifying the teacher's language for clarity, especially for younger students.

Both groups valued active participation and the integration of cognitive, physical, and emotional skills in classroom activities (LSS 3.26; USS 3.73). However, LSS reported greater difficulty understanding certain concepts, indicating a need for additional scaffolding.

Collaboration and knowledge sharing were rated positively (LSS 3.28; USS 3.91). While LSS appreciated group encouragement (3.50), they struggled more with activity flow, highlighting the need for clearer guidance.

Satisfaction with the hands-on model was high for both groups. LSS rated it 3.81 (with 3.89 for safety and novelty), and USS 4.19

(overall) with 4.18 for user-friendliness and 4.35 for conceptual clarity. The model effectively linked theory with real-world problem-solving, particularly at the Apply and Analyze levels of Bloom's taxonomy, though minor adjustments may better support LSS learners.

Discussion

The findings support the effectiveness of integrating Kolb's ELT with EDP in STEM instruction. The Gear Learning Set fostered satisfaction and engagement across all EDP stages (problem identification, ideation, testing, and evaluation) promoting the internalization of mechanical principles and transferable problem-solving skills.

The two-tier diagnostic test aligned with Bloom's taxonomy, assessing both conceptual understanding and reasoning. Tier 1 measured knowledge of gear types and rotational directions, while Tier 2 evaluated students' justifications based on physics principles. Post-test gains in both tiers reflected deeper conceptual reasoning, as more students could explain gear interactions and justify design choices, demonstrating higher-order thinking.

These outcomes align with ELT, where students engaged through Concrete Experience (manipulating gear models), Reflective Observation (analyzing interactions), Abstract Conceptualization (relating to torque and gear ratio), and Active Experimentation (testing designs). Simultaneously, the EDP guided learners through defining problems, constructing prototypes, testing, and iterating—cultivating creativity and critical thinking. Integrating the two-tier test with ELT–EDP provided a holistic evaluation of knowledge,

reasoning, and practical application.

Although satisfaction was generally high, LSS students showed lower comprehension than USS, likely due to abstract content and the one-day format limiting reflection. Future implementations should extend instructional time, differentiate content, and include preparatory materials via a flipped classroom model.

The results echo prior studies (Jovanović et al., 2019; Tep et al., 2024; Kanapathy & Azhari, 2024; Wahono et al., 2020), which confirm that real-world, hands-on approaches enhance satisfaction and understanding while addressing resource disparities. The Gear Learning Set filled a curricular gap by providing accessible, project-based experiences. Similarly, Hong et al. (2021) reported that STEAM hands-on tools improve problem-solving and analytical thinking, underscoring the value of concrete learning designs for diverse learners.

The Gear Learning Set effectively supported visualization of complex physics concepts, consistent with findings by Stump (2000), Chambers et al. (2008), and Slightam & Nagurka (2015) that hands-on materials such as LEGO or 3D-printed gears enhance comprehension. Through experiential learning, students developed both foundational knowledge and real-world problem-solving skills, embodying Kolb's four learning stages. Integrating ELT with EDP, as supported by Bozkurt (2021), thus strengthens engineering competence through structured, iterative learning.

Implications

This study holds significant implications for teacher education by promoting the integration of STEM-based hands-on gear activities with project-based learning. Enabling students to select their own projects, address their individual needs, and deepen their understanding is essential. This approach should be further supported through teacher training focused on the effective use of hands-on kits and flipped classroom strategies to optimize instructional time. Two-tier multiple-choice assessments provide deeper insights into students' conceptual understanding and misconceptions.

From a policy perspective, this study supports strengthening physics education within ASEAN, where gear mechanics are largely absent from high school curricula. This aligns with the ASEAN Education Work Plan (2021–2025), which promotes STEM and gender equality. Lemus-Delgado and Cerda (2025) emphasized increasing female participation in STEM for regional growth, while Chou and Ravinet (2017) highlighted ASEAN collaboration as a driver for educational improvement. Integrating hands-on learning across curricula enhances inclusivity and instructional effectiveness. Frameworks such as Predict–Observe–Explain (Wang & Wang, 2023) could also bridge conceptual gaps in mechanical topics, simplifying complex content and supporting foundational learning for both teachers and students. These findings can further inform teacher training programs aimed at organizing experiential STEM activities aligned with industry and higher education expectations.

Conclusion

This study evaluated the effectiveness of STEM-based hands-on gear activities in enhancing students' understanding of gear ratios and assessed students' satisfaction following the activities. The emphasis was placed on integrating practical gear exercises into the physics curriculum to support conceptual learning in mechanics.

For the first objective, both lower secondary (LSS) and upper secondary (USS) students showed significant post-test improvements, indicating that experiential learning effectively strengthened comprehension of gear ratios regardless of prior knowledge. Regarding the second objective, both groups reported high satisfaction (average scores between 3 and 4), describing the activities as engaging, collaborative, and helpful for understanding abstract concepts, though LSS noted some difficulty with the complexity of the content.

Overall, the study demonstrates the potential of low-cost, tangible tools—such as the Gear Learning Set—to enhance physics instruction and address curriculum gaps, particularly in regions like ASEAN where gear-related topics are limited. The model provides a scalable framework for promoting educational equity and innovation in STEM learning.

Limitation

This study involved a small sample of 35 students from a single innovative school, limiting the generalizability of the findings. The one-group pretest–posttest design restricted comparisons with other instructional approaches, and long-term retention or the influence of mathematical proficiency were not examined.

Future research should include larger, more diverse samples across multiple schools and incorporate comparative analyses—such as quasi-experimental designs or comparisons with traditional instruction—to strengthen causal interpretations and deepen understanding of effectiveness of hands-on STEM instruction.



Statements and Declarations

The authors declare no competing interests, and no external funding was received for this research. AI tools were used solely for language refinement; all intellectual contributions, research design, data analysis, and interpretations were conducted by the authors. The authors express their gratitude to the principal of DSIL for providing the space to design the engineering classroom, contributing to the success of this research. This study was conducted under ethical guidelines.

References

- Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives: Complete edition*. Addison Wesley Longman. <https://eduq.info/xmlui/handle/11515/18824>
- Bozkurt, A. E., & Tan, S. (2021). Concepts of creativity in design based learning in STEM education. *International Journal of Technology and Design Education*, 31(3), 503–529. <https://doi.org/10.1007/s10798-020-09569-y>
- Chambers, J. M., Carbonaro, M., & Murray, H. (2008). Developing conceptual understanding of mechanical advantage through the use of Lego robotic technology. *Australasian Journal of Educational Technology*, 24(4). <https://doi.org/10.14742/ajet.1199>
- Chang, Y., Aziz, E. S., Esche, S. K., & Chassapis, C. (2012). A game-based laboratory for gear design. *Computers in Education Journal*, 22(1), 21–31.
- Chou, M. H., & Ravinet, P. (2017). Higher education regionalism in Europe and Southeast Asia: Comparing policy ideas. *Policy and Society*, 36(1), 143–159. <https://doi.org/10.1080/14494035.2017.1278874>
- Field, A., Miles, J., & Field, Z. (2012). *Discovering statistics using R*. Sage Publications. <https://www.torrossa.com/en/resources/an/4913501>
- Freeman, B., Marginson, S., & Tytler, R. (2019). An international view of STEM education. In *STEM education 2.0* (pp. 350–363). Brill. https://doi.org/10.1163/9789004405400_019
- Hong, J. C., Hwang, M. Y., & Tsai, C. R. (2021). The effect of object-free and object-related intelligences on hands-on making self-efficacy and attitude toward quality improvement. *International Journal of Science and Mathematics Education*, 19, 863–879. <https://doi.org/10.1007/s10763-020-10093-7>
- Institute for the Promotion of Teaching Science and Technology. (2011). *Teacher's*

- guide for physics, volume 2*. Suksapan Panit Publishing House. [http://www.kruseksan.com/teachkey/\(คู่มือ\)หนังสือเรียนสสวท%20เพิ่มเติมฟิสิกส์2.pdf](http://www.kruseksan.com/teachkey/(คู่มือ)หนังสือเรียนสสวท%20เพิ่มเติมฟิสิกส์2.pdf)
- Jackson, H., & Tarhini, K. (2022). *Compendium of civil engineering education strategies: Case studies and examples*. CRC Press. <https://doi.org/10.1201/9781003280057>
- Jovanović, V. M., McLeod, G., Alberts, T. E., Tomovic, C., Popescu, O., Batts, T., & Sandy, M. M. L. (2019). Exposing students to STEM careers through hands-on activities with drones and robots. *Engineering Technology Faculty Publications*, 132. https://digitalcommons.odu.edu/engtech_fac_pubs/132
- Kanapathy, S., & Azhari, A. M. (2024). Exploration of the experience of hands-on learning and its impacts on STEM learning. *Pedagogika*, 155(3), 104–125. <https://doi.org/10.15823/p.2024.155.6>
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. <https://books.google.com/books?id=jpbeBQAAQBAJ>
- Lemus-Delgado, D., & Cerda, C. (2025). ASEAN, gender equality and women's empowerment in STEM. *Asian Education and Development Studies*. <https://doi.org/10.1108/AEDS-07-2024-0138>
- Li, H., Öchsner, A., & Hall, W. (2019). Application of experiential learning to improve student engagement and experience in a mechanical engineering course. *European Journal of Engineering Education*, 44(3), 283–293. <https://doi.org/10.1080/03043797.2017.1402864>
- Mongkholsiriwattana, C., Phengpom, T., & Precharattana, M. (2023). Development of computer-aided learning with hands-on activities kits on the topic of gears for a flipped robotics camp. *Journal of Physics: Conference Series*, 2653(1), 012002. <https://doi.org/10.1088/1742-6596/2653/1/012002>
- R Core Team. (2021). *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing. <https://www.R-project.org>.
- Satyam, S. (2024). *Zero to hero physics: Level up your physics*. PhysicsFactor. https://www.google.co.th/books/edition/Zero_to_Hero_Physics_Volume_01_for_High/CXz3EAAQBAJ?hl=th&gbpv=0
- Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, 52(3–4), 591–611. <https://doi.org/10.1093/biomet/52.3-4.591>
- Slightam, J. E., & Nagurka, M. M. (2015, June). Machine design experiments using gears to foster discovery learning. *2015 ASEE Annual Conference & Exposition Proceedings*. American Society for Engineering Education. <https://doi.org/10.18260/p.24438>

- Student. (1908). The probable error of a mean. *Biometrika*, 6(1), 1-25. <https://doi.org/10.2307/2331554>
- Stump, S. L. (2000). Activities for students: Doing mathematics with bicycle gear ratios. *Mathematics Teacher*, 93(9), 762–770. <https://doi.org/10.5951/mt.93.9.0762>
- Tep, P., Mongkholsiriwattana, C., Thitayanuwat, W., & Cummon, P. (2024). Enhancing student comprehension in aviation science and aircraft construction through hands-on and experiential learning. In *2024 9th International STEM Education Conference (iSTEM-Ed)* (pp. 1–6). IEEE. <https://doi.org/10.1109/iSTEM-Ed62750.2024.10663186>
- Wahono, B., Lin, P. L., & Chang, C. Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education*, 7(1), 36. <https://doi.org/10.1186/s40594-020-00236-1>
- Wang, J. C., & Wang, T. H. (2023). Learning effectiveness of energy education in junior high schools: Implementation of action research and the predict–observe–explain model to STEM course. *Heliyon*, 9(3), e14058. <https://doi.org/10.1016/j.heliyon.2023.e14058>
- Wangdi, D., Precharattana, M., & Kanthang, P. (2020). A guided inquiry laboratory to enhance students’ understanding of the law of mechanical energy conservation. *International Journal of Innovation in Science and Mathematics Education*, 28(1). <https://doi.org/10.30722/IJISME.28.01.003>
- Zhao, Y., Muhamad, M. M., & Mustakim, S. S. (2022). English teaching objectives from the perspective of Bloom’s cognitive domain: A case study of Yuxi Normal University, China. *Journal of Positive School Psychology*, 6(3), 5622–5635. <https://www.journalppw.com/index.php/jpsp/article/view/3201>

Appendix

Satisfaction Result Grade 8-12

No	Topic	Questions	G. 8-9 (Mean, SD)	Avg. mean	G. 10-12 (Mean, SD)	Avg. mean
1	Lesson topic	The topic of the lesson was interesting	3.56, 0.78	2.83	4.41, 0.62	3.92
2		The lesson was suitable with the student level	2.94, 0.87		3.65, 0.93	
3		The lesson was easy to understand	2.00, 0.77		3.71, 0.92	
4	Teacher's instruction	The teacher help to learned the lesson.	3.83, 0.71	3.50	4.18, 0.73	4.18
5		The teacher respected the views of the students.	3.94, 0.87		4.71, 0.47	
6		The language teacher used was easy to understand.	2.72, 1.07		3.65, 1.06	
7	Classroom activities	The classroom activity made me actively involved in it.	3.72, 0.89	3.26	3.53, 0.87	3.73
8		The activity helped me to use my head, hands and heart.	3.61, 1.24		4.12, 0.70	
9		The activity was easy to understand the concept.	2.44, 0.92		3.53, 1.01	
10	Learning method	The learning method was easy to follow.	3.06, 0.87	3.28	4.24, 0.75	3.91
11		This method helped me share my knowledge and ideas	3.44, 0.92		3.94, 0.56	
12		This method encouraged me to work in group.	3.50, 1.04		3.82, 0.95	
13		I would prefer this learning method in the future.	3.11, 0.96		3.65, 1.00	
14	Hands-on model	The hands-on model was user-friendly.	3.78, 0.94	3.81	4.18, 0.81	4.19
15		The hands-on model was safe to use.	3.89, 0.83		4.35, 0.61	
16		The hands-on model was new and beneficial to me	3.89, 0.83		3.88, 0.99	
17		The hands-on model helped to understand the concept better.	3.67, 0.84		4.35, 0.70	

The score ranges from 1 to 5, with 1 = Strongly Disagree and 5 = Strongly Agree.

Bionote

Chinapat Mongkholsiriwattana is a project engineering teacher at DSIL with master's degree in Physics Education. His interests research include integrating technology in physics class, creating educational tools with laser cutting machines, Flip-classroom with STEM, Physics education, and project engineering such as aviation camp.

Monamorn Precharattana is an assistant professor at the Institute for Innovative Learning. She holds a Ph.D. in Science (Physics) from Mahidol University, Thailand. Her research interests include technology-enhanced learning, such as gaming and simulation, VR and 360 Degree VDO, ubiquitous learning, Flip-classroom, Personalized Learning, and Hands-on Lab in both scientific and non-scientific fields including physics, engineering, nursing, general science, agricultural systems, marketing, design thinking, computational thinking, STEM, and coding.