



SUPPORTING CONCEPTUAL AND COGNITIVE PROGRESSION: INTEGRATING FLIPPED DESIGN AND PEER INSTRUCTION INTO AN UPPER-SECONDARY PHYSICS TUTORIAL MODEL

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Abstract. *A tutorial model for upper-secondary physics that combines peer instruction and a flipped design was developed to replace a lecture-based teaching approach. Implemented in two upper-secondary schools (N = 149), the intervention integrated pre-class preparation, structured worksheets, demonstrations, peer discussions, and mini-laboratories. Learning outcomes were evaluated through pre/post-tests, SOLO taxonomy coding, and semi-structured interviews, with test and interview protocols thoroughly examined for content validity (IOC = 0.73) and reliability (KR-20 = 0.78). A paired-samples t-test indicated significant improvements in students' conceptual understanding and problem-solving skills ($p < .001$, Cohen's $d = 3.72$ and 5.21), alongside substantial normalized gains ($g = 0.76$ and 0.77). Consistent with these quantitative results, SOLO analysis revealed a progression from prestructural and unistructural reasoning toward predominantly relational reasoning across the three physics topics. Thematic analysis of interview data ($n = 34$) further suggested that scaffolded worksheets and collaborative sense-making appeared to help students overcome cognitive bottlenecks, while also showing positive links to their engagement and confidence. Together, these findings suggest that a tutorial model integrating peer instruction and a flipped design can offer a viable pedagogical strategy for supporting conceptual and cognitive progression in physics.*

Keywords: *flipped design, upper-secondary physics, peer instruction, SOLO taxonomy, physics tutorials*

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Introduction

Observations in Thai upper-secondary physics classrooms suggest that a lecture-based teaching approach continues to dominate the learning environment. Even though the official teacher manuals developed by the Institute for the Promotion of Teaching Science and Technology [IPST] (2017) strongly advocate for structured inquiry and hands-on laboratories, classroom teaching is often shaped by the pressure of university entrance examinations. As a result, classroom teaching frequently emphasizes direct lectures, formula memorization, and repetitive drills using past exam papers. This heavy focus on teaching to the test leaves little room for genuine conceptual exploration, leaving many students with low engagement and weak problem-solving skills (Jones & Rhein, 2018). Since these standard practices rarely address persistent misconceptions or guide students in building coherent problem-solving frameworks, students with weaker foundational knowledge often struggle to keep up. Therefore, an urgent need exists to transition toward active pedagogical models that offer a practical compromise. By providing structured cognitive scaffolding, such approaches may preserve the investigative nature of science while still preparing students for competitive exams, ensuring that all learners receive the support they need to succeed.

Tutorials have been widely used as an active learning approach in physics education and have been shown to be associated with improvements in conceptual knowledge and problem-solving skills across a wide range of learning environments. They are consistent with the principles of inquiry-based learning, in which students construct understanding through questioning, exploring, and reasoning rather than simply receiving information. McDermott (2001) has shown how tutorials supported learning in introductory physics, where students worked in small groups on qualitative and quantitative problems. Benegas and Flores (2014) have further confirmed that tutorial implementations yielded higher normalized gains



than lecture-based teaching, provided that fidelity to the tutorial model and student intellectual engagement are maintained. Workshop tutorials have similarly highlighted the importance of peer collaboration in promoting deeper understanding (Lindström & Sharma, 2011). This emphasis on peer collaboration reflects the broader educational view that meaningful learning emerges when students are intellectually active, socially engaged, and encouraged to construct their own explanations. Peer collaboration is important in this process because it allows learners to work together on tasks that may be difficult to complete individually (Damon & Phelps, 1989). Socratic dialogue, guided by tutors, can provide timely support while encouraging students to develop their own reasoning (Sharma et al., 2005).

Mazur's peer instruction model is based on the principle that students grasp concepts more effectively when lectures are combined with conceptual questions, peer discussions, and consensus building (Crouch & Mazur, 2001; Mazur, 1997, 2009). Subsequent research has indicated that carefully implemented peer instruction can lead to conceptual gains and improved problem-solving outcomes (Leinonen et al., 2017). Moreover, a well-established student-centred approach is flipped classroom pedagogy (Bergmann & Sams, 2012). Rather than implementing the entire model, this study applies a flipped design based on three key elements: shifting direct teaching out of class, maximizing active and social learning in class, and requiring structured pre- and post-class learning (Lo & Hew, 2017). Studies have shown that flipped designs help students address misconceptions and develop strong conceptual frameworks (Leo & Puzio, 2016; Ölmefors & Scheffel, 2021).

Recent literature has shown that the combination of tutorials, peer instruction, and flipped design is effective. Pendrill (2022) has demonstrated that targeted teacher interventions in circular motion problems improved students' reasoning strategies in secondary classrooms. Pols and Diepenbroek (2023) have shown how well-designed practical activities reorient students' attention from rote procedures to sense-making. Guo (2025) has developed a low-cost lightboard to support students' pre-class preparation in flipped learning. These approaches align with the broader finding that tutorials increase inclusiveness; as Li and Singh (2023) have noted, a sense of belonging is crucial for equitable learning outcomes in physics. These studies suggest that integrated tutorial environments may support conceptual understanding and collaborative learning.

Research Problem

Despite the recognized benefits of these individual strategies, limited research has explored how the integration of flipped design, tutorial structures, and peer instruction may support the cognitive progression of upper-secondary students. Most existing studies have focused primarily on university-level introductory physics. Therefore, this study investigates how such an integrated model may provide structured cognitive scaffolding to support students' conceptual development.

Research Focus

To design effective physics interventions, it is necessary to examine how students' reasoning evolves from fragmented ideas into relational understanding rather than simply measuring score improvements. This study focuses on tracing this qualitative cognitive shift and examining how students perceive a structured collaborative environment in an upper-secondary school setting.

Research Aim and Research Questions

The aim of this study was to develop a tutorial model for upper-secondary physics that incorporates selected elements from peer instruction and flipped design. The model was designed to strengthen students' conceptual understanding, promote higher-order thinking, and foster positive attitudes toward learning physics. The study addressed the following research questions:

1. How does the integrated tutorial model relate to changes in upper-secondary students' conceptual understanding and problem-solving skills in physics?
2. In what ways does students' reasoning progress from surface-level to relational understanding during the intervention, as classified using the SOLO taxonomy?
3. How do students perceive the tutorial model's role in their engagement and in the cognitive scaffolding and learning support it provides?



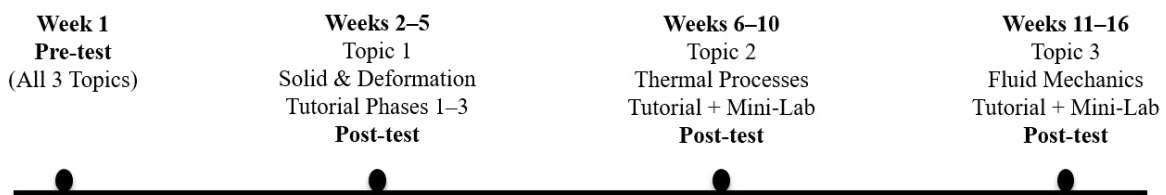
Research Methodology

General Background

This study adopted a mixed-methods research design, using a one-group pre-test-post-test design, to examine a tutorial model that integrates a flipped design and peer instruction in upper-secondary physics. The study was implemented in Semester 2 of the 2023 academic year. The tutorial model was designed as an alternative teaching approach combining flipped design and peer instruction to support active student engagement. The intervention spanned a 16-week semester, with four 50-minute periods each week, and focused on three physics topics: Solid and Deformation of Solids, Energy in Thermal Processes, and Fluid Mechanics. A comprehensive visual timeline detailing the progression of these topics, teaching phases, and the scheduling of all assessments is presented in Figure 1.

Figure 1

Implementation and Assessment Timeline



Participants

The sample size was determined by the available student population, which consisted of all Grade 12 students enrolled in the participating classrooms during the study period ($N = 149$). These classrooms were selected from schools that agreed to participate within the study's resource and scheduling constraints. The students were from two schools in Bangkok, Thailand. School 1, a university demonstration school, included 52 students from two classrooms. School 2, a general public school, included 97 students from two classrooms. The student population in School 2 reflected a wide range of achievement levels, providing a context for examining the tutorial model across students with different levels of prior achievement. In addition, a purposive sample of 34 students from both schools was selected to participate in semi-structured interviews. They were chosen to represent a diverse range of achievement profiles based on their pre- and post-test score ranges.

The intervention at both schools was conducted by one of the researchers, who had a relevant background in physics teaching and also contributed to the study's design. To mitigate potential bias, the implementation was supervised by the regular classroom teachers. Moreover, all activities were aligned with the learning indicators and core standards prescribed by the IPST (2017).

Research Tools

The primary tools were three-step structured worksheets designed to scaffold student learning by collaboratively guiding them through (i) interpreting situations, (ii) identifying variables, and (iii) applying physics equations (Eambaipreuk et al., 2021). Each worksheet was sequenced to move from simpler tasks to more complex contexts, ensuring alignment with the progression of physics content and supporting gradual conceptual development. After individual work, students compared and discussed their answers with peers, while the teacher provided minimal Socratic questioning. A representative practice problem for each physics topic is provided in the Supplementary Material.

A physics conceptual achievement test was developed and administered as a pre-test and a post-test to measure learning outcomes. The test consisted of 15 multiple-choice items in total, with five questions for each physics topic, designed to assess both conceptual understanding and problem-solving skills. The total raw score was converted to a 10-point scale for analysis. The tests were constructed as parallel forms measuring the same concepts. The test items were reviewed by a panel of three experts in physics education to evaluate content valid-



ity and assess the comparability of difficulty between the parallel forms. The Index of Item-Objective Congruence (IOC) score was 0.73, indicating acceptable content validity (Rovinelli & Hambleton, 1976). The internal consistency reliability of the instrument was determined by the Kuder-Richardson 20 (KR-20) formula and was found to be 0.78. This value indicates an acceptable level of internal consistency, providing evidence for the instrument's reliability for measuring students' conceptual understanding (Kuder & Richardson, 1937). Additionally, a six-question semi-structured interview protocol was validated by the expert panel to gather qualitative insights on students' perceptions and learning experiences. The interviews were conducted in Thai. The questions were as follows:

- Q1. What difficulties did you previously face in learning physics, and how did these compare with your Grade 12 learning experience under the tutorial model?
- Q2. How did a teaching approach that began with conceptual explanation, progressed to simple problems, and then allowed peer practice in class contribute to your understanding of physics?
- Q3. To what extent did teacher guidance through worksheets during class enhance your understanding compared with previous problem-solving methods?
- Q4. In what ways, if any, were your quiz results related to what you learned in class?
- Q5. How did classroom activities, such as demonstrations and mini-laboratories, support your understanding of physics concepts?
- Q6. How did your views and attitudes toward learning physics change after the Grade 12 learning experience under the tutorial model?

Design of the Tutorial Model

The tutorial model was designed to support upper-secondary physics learning through three structured phases, as shown in Table 1. In line with the classroom design (Bergmann & Sams, 2012; Leo & Puzio, 2016; Lo & Hew, 2017; Ölmefors & Scheffel, 2021), the teaching process for each topic was organized as follows:

(1) Pre-class Preparation: The learning process began outside the classroom, where students were first introduced to basic concepts through online materials and recorded video lessons on the topic. These materials provided clear explanations of basic physics definitions, introduced governing equations, and included visual demonstrations of real-world phenomena related to the upcoming topic. By intentionally shifting direct teaching outside the classroom, more in-class time was made available for deeper cognitive exploration.

Table 1
Structure of the Tutorial Model Designed for Upper-Secondary Physics

Learning Phase	Duration	Teacher's Role (Facilitation & Scaffolding)	Student's Role (Active Engagement & Peer Instruction)	Theoretical Link
Phase 1: Pre-class (Preparation)	Out of class	Provides foundational learning materials (e.g., recorded concept explanations, books, previous lesson videos) for online access.	Studies the basic concepts independently before class to prepare for deeper in-class exploration.	Flipped Design: First exposure to concepts.
Phase 2: In-class (Conceptual Practice)	10 mins	Briefly reviews pre-class concepts, addresses common misconceptions, and performs a physical demonstration.	Observes the demonstration, asks questions, and connects pre-class knowledge to real physical phenomena.	Tutorial: Contextualizing physics.
	15 mins	Presents a conceptual problem. Guides students using Socratic questioning rather than giving direct answers.	Individual work: Thinks and interprets the situation. Peer Discussion: Discusses reasoning in small groups, sketches diagrams, and reaches a consensus.	Peer Instruction: Collaborative sense-making.
	10 mins	Introduces additional or more complex content building on the previous discussion.	Actively listens and integrates new variables into their current conceptual framework.	Scaffolding.

Learning Phase	Duration	Teacher's Role (Facilitation & Scaffolding)	Student's Role (Active Engagement & Peer Instruction)	Theoretical Link
	15 mins	Facilitates open-ended problem solving based on the worksheet's 3-step structured guide.	Applies physics concepts and equations to solve complex problems within peer groups.	Tutorial: Problem-solving.
In-class (Mini-Lab) For Topics 2 & 3	40 mins	Facilitates small-group laboratory work, encouraging students to discuss their observations and reasoning with peers.	Engages in hands-on exploration and collaborative data collection within peer groups.	Flipped Design: Active application of pre-class concepts. Peer Collaboration: Joint problem-solving.
	10 mins	Guides the whole-class discussion to connect laboratory results with pre-class theoretical concepts, validating student reasoning.	Shares group findings, compares reasoning with other groups, and reaches a final conceptual consensus.	Peer Instruction: Consensus building and meaning-making.
Phase 3: Post-class (Consolidation)	Out of class	Provides access to recorded lessons and evaluates student learning progress.	Reviews worksheet practices or recorded lessons to solidify relational understanding.	Flipped Design: Post-class reflection.

(2) In-class Active Engagement: A brief conceptual lecture was given. Structured problem solving and guided inquiry were then emphasized, allowing students to actively engage with concepts under teacher guidance. At the same time, elements of peer instruction (Crouch & Mazur, 2001; Leinonen et al., 2017; Mazur, 1997, 2009) were integrated into the design: students first considered conceptual questions on their own, then reasoned in small groups, and finally discussed solutions with the whole class. Moreover, for Topics 2 and 3, this in-class phase also incorporated hands-on mini-laboratories (one lab for each topic). Students collaboratively collected data and connected physical observations with theoretical principles. Supported by worksheets, demonstrations, and mini-laboratories, this process encouraged collaborative sense-making and helped students move from surface-level understanding toward higher-order reasoning (Benegas & Flores, 2014; Eambaipreuk et al., 2021; McDermott, 2001).

Three main physics topics were included in this study:

- Topic 1, Solid and Deformation of Solids: stress and strain, Young's modulus, and change in length.
- Topic 2, Energy in Thermal Processes: heat and internal energy, specific heat, latent heat, phase change, and energy transfer.
- Topic 3, Fluid Mechanics: pressure variation with depth, pressure measurements, buoyant forces and Archimedes' principle, and fluids in motion.

The designed activities emphasized collaborative learning and higher-order thinking. By combining conceptual introduction, peer discussion in small groups of two to three members (Lindstrøm & Sharma, 2011), and open-ended problem-solving in the worksheet's practice section, students were guided to reconstruct their knowledge and apply it in new contexts.

(3) Post-class Consolidation: By reviewing completed worksheets and accessing recorded lessons, students could independently reinforce their conceptual understanding, thereby completing the flipped learning cycle.

Novelty and Scope of the Tutorial Model

The core contribution of this study is a structured teaching design developed specifically for upper-secondary physics, rather than a new theoretical framework. This design is referred to as a tutorial model, following established usage in tutorial-based physics education research (e.g., McDermott, 2001). The three core components were each adapted from established approaches: the pre-class video preparation from flipped-design principles (Bergmann & Sams, 2012), the three-step structured worksheets from prior active learning worksheet work (Eambaipreuk et al., 2021), and the peer-discussion sequence from Mazur's peer instruction (Mazur, 1997, 2009). Table 1 shows how each phase of this design aligns with these established approaches. The pre-class video, three-step worksheets, and peer-discussion sequence are essential to the design; the mini-laboratories are an optional, resource-dependent addition. What distinguishes this combination from prior approaches is the specific pairing and sequencing of these elements: it differs from McDermott's tutorials in introductory physics (McDermott, 2001) by targeting

upper-secondary rather than university students within a flipped structure rather than a standalone in-class activity; from Mazur's peer instruction by using only the discussion-consensus sequence without clicker-based voting; from workshop tutorials (Lindstrøm & Sharma, 2011) by adding structured worksheets and mini-laboratories; and from other flipped-learning designs (e.g., Bergmann & Sams, 2012) by adopting only three specific elements rather than a full flipped-mastery model.

Data Analysis

Quantitative data analysis was used to evaluate students' learning through the normalized gain (g), computed from pre- and post-test scores, a widely used method to measure learning gains in interactive-engagement settings (Hake, 1998). To track cognitive progression, student artifacts (worksheets, homework, mini-laboratories, and quizzes) were analysed using the Structure of the Observed Learning Outcome (SOLO) taxonomy (Biggs & Collis, 2014). The responses were coded into four hierarchical levels: prestructural (P), unistructural (U), multistructural (M), and relational/extended abstract (R) (Georgiou & Sharma, 2010). For the qualitative data, transcripts from the semi-structured interviews were analysed thematically to identify overarching patterns related to cognitive scaffolding, learning support, and attitudinal shifts toward learning physics. To enhance the trustworthiness of the qualitative analysis and mitigate potential researcher bias, the coding of student artifacts was performed by two independent raters who were familiar with the SOLO taxonomy framework. Prior to formal coding, a calibration session was conducted using a random sample of student responses. The raters used predefined SOLO descriptors and exemplar responses as coding guidelines. Inter-rater reliability was assessed using Cohen's kappa (κ). The analysis yielded substantial agreement, with $\kappa = 0.85$. Any initial coding discrepancies were resolved through discussion until consensus was reached.

Research Results

Learning Outcomes and Individual Progression

The pre-test was administered once at each school at the beginning of the semester, and the post-tests were given at the end of each of the three topics to evaluate student learning. As shown in Table 2, students in both schools improved substantially, with normalized gains of 0.76 ± 0.04 and 0.77 ± 0.02 , respectively. These gains suggest that the tutorial model was associated with improvements in students' problem-solving skills and conceptual understanding.

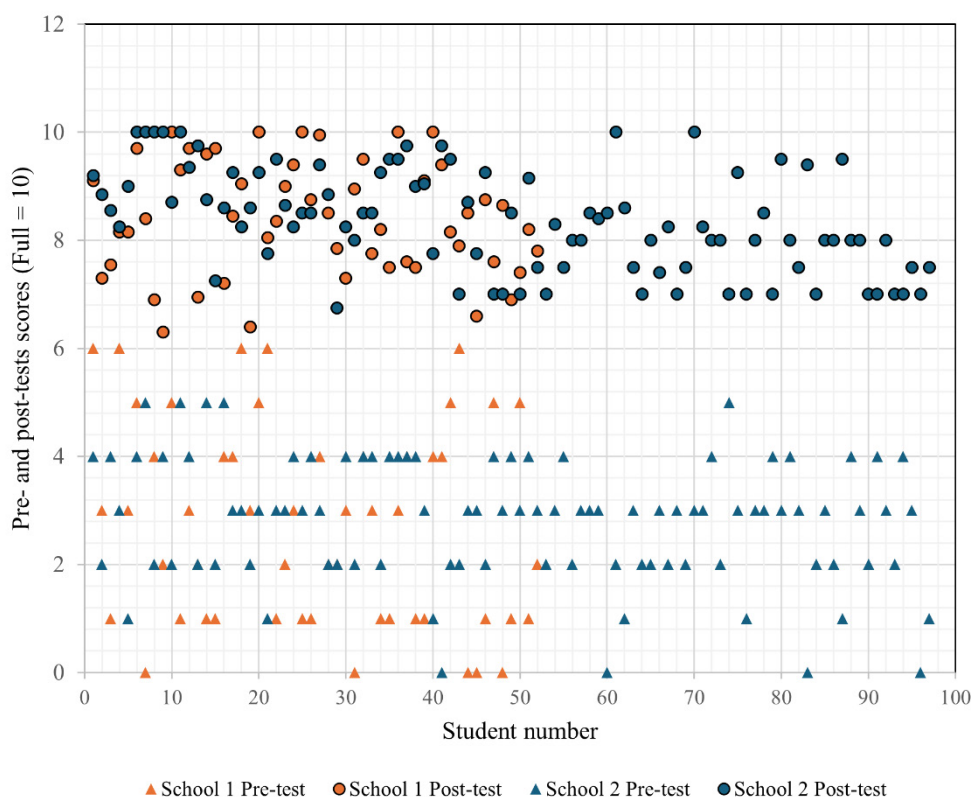
Table 2

Pre- and Post-Test Scores and Normalized Gains

Group	Scores (Full=10)		Normalized gain, g
	Pre-test	Post-test	
School 1 ($n = 52$)	2.78 ± 1.88	8.40 ± 1.05	0.76 ± 0.04
School 2 ($n = 97$)	2.85 ± 1.16	8.49 ± 0.95	0.77 ± 0.02

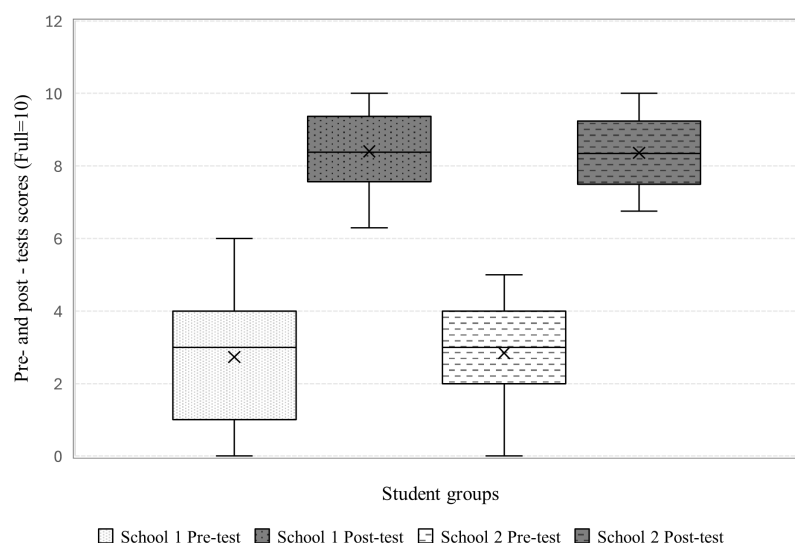
A paired-samples t-test was conducted to evaluate the statistical significance of the improvement from pre-test to post-test scores. The analysis revealed a statistically significant increase in students' conceptual understanding across both schools. In School 1, the scores increased significantly from the pre-test ($M = 2.78$, $SD = 1.88$) to the post-test ($M = 8.40$, $SD = 1.05$), $t(51) = 19.90$, $p < .001$. Similarly, in School 2, the scores increased significantly from the pre-test ($M = 2.85$, $SD = 1.16$) to the post-test ($M = 8.49$, $SD = 0.95$), $t(96) = 38.52$, $p < .001$.

Furthermore, Cohen's d was calculated to estimate the effect size of the intervention. The calculated effect sizes were very high: $d = 3.72$ for School 1 and $d = 5.21$ for School 2. These very large effect sizes ($d > 0.8$) are consistent with substantial improvements in students' conceptual learning within this study context.

Figure 2*Scatter Plot Illustrating the Relationship Between Individual Students' Pre-Test and Post-Test Scores*

To further examine individual learning trajectories, student performance was analysed by comparing pre-test and post-test scores. Figure 2 illustrates the individual progression of students. Notably, the data points were densely clustered in the upper region of the y-axis (post-test scores), regardless of students' initial positions (pre-test scores). The results from all participants ($N = 149$) showed a post-test score ranging from a minimum of 6.30 to a maximum of 10.00. The interquartile range (the middle 50% of the scores) clustered between 7.50 and 9.25, and only 13 students (8.72%) achieved the maximum score. Additionally, the item difficulty index (p -values) for the post-test items was rigorously evaluated using strict scoring criteria, yielding a difficulty range from 0.23 to 0.79. This distribution demonstrates an appropriate spectrum of difficulty, encompassing both challenging and accessible items.

The boxplot in Figure 3 further illustrates the substantial change in overall class performance. The analysis revealed an upward shift in the median score from the pre-test to the post-test, accompanied by a narrower interquartile range at the higher score level.

Figure 3*Distribution of Student Conceptual Achievement Scores before and after the Intervention*

Notes: The horizontal line within each box = median score; the x mark = mean score.

Student Performance during the Tutorial Model Intervention

The SOLO taxonomy was used to classify students' reasoning into four levels (Georgiou & Sharma, 2010). In the context of the physics problems in this study, the four SOLO levels were operationalized as follows:

Prestructural (P): Responses indicate a lack of understanding of the relevant physics concepts and are often characterized by blank answers, random guesses, or the use of irrelevant information.

Unistructural (U): Responses focus on a single relevant aspect or isolated fact. For example, a student might correctly identify one physical variable or write down an equation without demonstrating how to apply it appropriately to a specific situation.

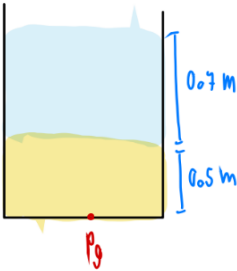
Multistructural (M): Responses demonstrate knowledge of multiple independent facts, variables, or formulas but fail to integrate them. A student at this level may calculate individual values correctly but not recognize the underlying physical relationship required to construct a complete solution.

Relational/extended abstract (R): Responses show a strong conceptual understanding of how the different components interact. At this level, students integrate multiple concepts, physical diagrams, and mathematical equations to form a coherent, correct solution to complex physical situations.

Students' in-class work provides insight into this cognitive progression. Figure 4 shows an excerpt from a student's fluid mechanics worksheet involving water and mercury in the same container. The three-step worksheet guided the student to interpret the situation by drawing the two-fluid system, identify the relevant variables, and apply the hydrostatic pressure equations. Small-group discussion and the teacher's Socratic questioning may have helped the student distinguish the water depth from the mercury depth and determine how the two pressure contributions should be combined. The student then selected the appropriate equations and calculated the total gauge pressure correctly. The response was classified at the relational level (R) of the SOLO taxonomy because the student connected the diagram, relevant variables, and equations to form a complete solution. This example suggests that the worksheet structure and classroom discussion may have supported a more systematic approach to problem-solving.



Figure 4
Student's Worksheet Practice after Peer Discussion during the In-Class Session in Topic 3, Fluid Mechanics

สถานการณ์ (Situation)	แผนภาพ/ระบุตัวแปร (Diagram/Variable identification)	คำนวณ/คำตอบ (Calculation/Answer)
8. ภาชนะใบหนึ่งใส่ปรอทและน้ำสูง 1.2 เมตร ส่วนที่เป็นน้ำสูง 70 เซนติเมตร จงหาความดันเกจที่ก้นภาชนะ A container is filled with water and mercury to a total height of 1.2 meters. The depth of water is 0.7 meters. Determine the total gauge pressure at the bottom of the container.		$P_{g\text{ total}} = P_{g\text{ water}} + P_{g\text{ Hg}}$ $P_{g\text{ total}} = P_w g (0.7) + P_{Hg} g (0.5)$ $= 10^3 \times 10 \times 0.7 + 13600 \times 10 \times 0.5$ $P_{g\text{ total}} = 4.6 \times 10^4 \text{ Pa}$

The percentages reported in Table 3 represent the proportion of responses classified at each SOLO level relative to the total number of responses to the pre-test and to each artifact type (worksheets, homework, mini-laboratories, and quizzes). The pre-test results revealed that most students were at the prestructural (P) and unistructural (U) levels, with only a small proportion demonstrating multistructural (M) and none showing relational reasoning (R). In the post-intervention data, a notable shift was observed. For Topic 1 (Solid and Deformation of Solids), 68.4% of homework responses and 72.4% of quiz responses were classified at the relational level (R), indicating that most students were able to integrate concepts meaningfully and apply them in problem-solving. Worksheet results showed that most students were at the multistructural (M) and relational (R) levels, with none at the lower levels, suggesting that the in-class guided work may have provided greater support than independent tasks. For Topic 2 (Energy in Thermal Processes), relational responses increased even further, reaching 84.8% on worksheets and 85.0% on quizzes. The mini-laboratory activity also showed that over 65% of the responses were at the relational level, suggesting that the hands-on experiments may have helped students link the physical observations to the theoretical principles. In Topic 3 (Fluid Mechanics), relational responses were somewhat lower in the mini-laboratory (52.1%), although worksheets and quizzes still showed relatively high proportions (69.4% and 69.6%, respectively). This may reflect the greater conceptual complexity of fluid mechanics compared with the earlier topics, suggesting that this topic may require more scaffolding. However, most students moved beyond unistructural reasoning, with more than 30% demonstrating multistructural responses and almost 70% producing relational responses.

Table 3
Classification of Student Reasoning in Pre-Test, Worksheets, Homework, Mini-Laboratories, and Quizzes Using the SOLO Taxonomy

Topics	Data Source	P	U	M	R
All Topics (Baseline)	Pre-test	40.3	55.7	4.0	0.0
Topic 1: Solid and Deformation of Solids	Worksheet	0.0	2.0	30.0	68.0
	Homework	3.5	14.0	14.0	68.4
	Quiz	6.5	12.6	8.5	72.4
Topic 2: Energy in Thermal Processes	Worksheet	0.0	0.0	15.2	84.8
	Mini Lab	0.0	0.0	34.7	65.3
	Quiz	2.1	5.8	7.1	85.0

Topics	Data Source	P	U	M	R
Topic 3: Fluid Mechanics	Worksheet	0.0	0.0	30.6	69.4
	Mini Lab	0.0	16.7	31.3	52.1
	Quiz	2.1	7.5	20.8	69.6

Notes: P = prestructural; U = unistructural; M = multistructural; R = relational.

Student Perceptions and Thematic Analysis

The interview responses shown in Table 4 were analysed thematically and categorized into three themes related to the pedagogical benefits of the tutorial model.

Theme 1: Structured Scaffolding and Reduction of Cognitive Bottlenecks

The interviews revealed that all students had previously struggled with fast-paced, lecture-based physics teaching. However, the integration of step-by-step worksheets and physical demonstrations into the tutorial model provided cognitive scaffolding. More than 88% of the students noted that this structured guidance made abstract concepts easier to grasp. Instead of simply memorizing formulas, they learned how to visualize and break down problems. An example of this reflection can be seen in a student's response to Q3 (see Table 4).

Theme 2: Collaborative Sense-Making and Learning Support

A notable finding from the interviews was students' perception that the model provided sufficient support for their learning and academic preparation. Although this was not directly measured in the quantitative phase, over 91% of the interviewed students reported that the combination of peer discussions, in-class slides, and practice exercises was important for their preparation. Peer discussion during the practice appeared to play an important role in this perceived sufficiency, as illustrated by students' responses to Q2 and Q4 (see Table 4).

Theme 3: Increased Engagement and Attitudinal Shifts

The final theme captures the positive changes in students' attitudes toward physics. More than 94% of the respondents reported that classroom activities, particularly demonstrations and mini-laboratories, made the lessons engaging and helped them connect physics concepts with observable phenomena. Moreover, the flipped design allowed them to access recorded lessons and review material before class, which helped reduce their learning anxiety. An example of this reflection can be seen in a student's response to Q6 (see Table 4).

Overall, most students expressed increased motivation, confidence, and a more positive attitude toward learning physics.

Table 4
The Interview Results

Questions	Examples of students' responses	"Agree" (%)	"Disagree" (%)
Q1	In Grades 10 and 11, I felt that physics was very difficult. The lectures were too fast, and I could not follow. I tried to review by the material on my own, but that made it even more confusing, so I lost motivation to study. However, in Grade 12, learning in the classroom with friends made me understand more. I could also ask the teacher directly, which helped me to keep up. In addition, the teacher provided online classes, so when I was absent, I could watch the recorded lessons to catch up.	100	0.0
Q2	Discussing with friends while doing the worksheets helped me realize what I did not understand. Sometimes I asked the teacher questions during the worksheets, and the demonstrations made the concepts very clear. While the teacher was explaining, I could follow what the teacher wanted us to learn, and I also had a chance to think and discuss with my peers.	94.1	5.9
Q3	I think this method is very good. Not many teachers use it. First, I understand what the problem is asking for, and then I can see how to find the correct answer. It helps me see the process step by step, so I can gradually reach the answer.	88.2	11.8

Questions	Examples of students' responses	"Agree" (%)	"Disagree" (%)
Q4	For the quizzes, I studied on my own. I never joined any extra classes. I just reviewed the teacher's slides and the practice exercises from class, and that was enough for me to understand.	91.2	8.8
Q5	The demonstrations made the concepts clearer while the teacher was explaining them. I could follow and understand what the teacher wanted us to learn. At the same time, I could think and discuss with my friends. The activities also made the classroom more interesting and engaging, so I paid more attention to the lesson.	94.1	5.9
Q6	I like the teaching method. It makes the lesson easier to follow because the teacher breaks it down into clear steps and shows the connections between ideas. This helped me understand without needing to spend much extra time reviewing. I also liked that the teacher provided recorded lessons, which I could review later. The teacher's style encouraged me to ask questions more freely.	94.1	5.9

Note: The "Agree (%)" indicates the percentage of the interviewed students whose responses aligned with the example presented for each question, whereas "Disagree (%)" indicates the proportion of the students whose responses differed.

Discussion

Learning Outcomes and Individual Progression

The normalized gains of 0.76 and 0.77 (Table 2) indicate substantial improvement in conceptual understanding and suggest that the tutorial model was associated with gains consistent with the interactive-engagement environments reported by Hake (1998). The individual progression data also show a convergence in performance. In the scatter plot (Figure 2) and boxplot (Figure 3), students who started with lower pre-test scores ended up with post-test scores similar to their higher-achieving peers, with most scores clustering near the top of the range. This pattern fits with the idea that the tutorial model helped narrow the initial achievement gap within this sample, although the one-group design does not allow us to confirm the model as the cause. A plausible but untested explanation is that moving foundational content teaching to the pre-class phase gave students with weaker backgrounds a chance to review material at their own pace before tackling more complex tasks in class (Bergmann & Sams, 2012; Ölmefors & Scheffel, 2021). This would be broadly consistent with Chen et al. (2025) and Kariri (2025), who reported similar patterns in flipped physics classrooms, although the present data cannot pinpoint which part of the intervention was responsible.

Student Performance during the Tutorial Model Intervention

The analysis of students' reasoning using the SOLO taxonomy (Table 3) provides evidence of cognitive progression. The pre-test results indicated that students' responses were predominantly at the prestructural (P) and unistructural (U) levels, but their performance moved toward the relational (R) level across all three topics following the intervention. This qualitative transition suggests that students moved beyond surface-level memorization and integrated multiple physics concepts into coherent problem-solving frameworks. The application of the SOLO taxonomy captured this shift, demonstrating its usefulness for assessing students' capacity to connect physical ideas and synthesize knowledge in this context. The structured three-step worksheets and peer discussions may have acted as cognitive scaffolds, guiding students through interpreting situations and identifying variables before applying mathematical equations (Eambaipreuk et al., 2021; Lindstrøm & Sharma, 2011). The SOLO data show a clear contrast: relational responses reached 68–85% for Topics 1 and 2, but only 52.1% for the Topic 3 (Fluid Mechanics) mini-laboratory (Table 3). This finding suggests that fluid mechanics was conceptually more challenging, at least within this setting. More speculatively, abstract topics like fluid mechanics may need additional scaffolding (Pendriil, 2022).

Student Perceptions

Qualitative insights from the student interviews (Table 4) help explain these quantitative findings. Students reported that the structured scaffolding provided by the worksheets and teacher demonstrations made abstract physics concepts more accessible. Instead of relying on rote formula memorization, students reported that they had learned to visualize and break down complex problems systematically (Theme 1). Second, the model provided a supportive learning environment through collaborative sense-making (Theme 2). By identifying and addressing misconceptions through peer-mediated explanations, students engaged in collaborative learning, which Li and Singh (2023) identified as a critical predictor of equitable academic performance in physics. Finally, the integration of demonstrations and mini-laboratories helped students connect physics concepts with observable phenomena and increased their engagement (Pols & Diepenbroek, 2023). Together with the reduced learning anxiety associated with access to recorded lessons, these aspects of the tutorial model appeared to foster greater motivation, confidence, and more positive attitudes toward learning physics (Theme 3).

Conclusions and Implications

This study sought to develop and evaluate a tutorial model integrating flipped and peer instruction strategies for upper-secondary physics. The findings revealed that this integrated model was associated with improvements in students' conceptual understanding and problem-solving skills. Quantitative results showed substantial normalized learning gains ($g = 0.76$ and 0.77). More importantly, students with limited prior knowledge also showed academic progression, reaching levels of conceptual development comparable to their higher-achieving peers within this study context.

Tracking cognitive progression using the SOLO taxonomy indicated a qualitative shift in students' reasoning. The data showed a transition from fragmented, surface-level responses to more integrated, relational problem-solving across the physics topics. This cognitive progression may have been systematically scaffolded by structured worksheets and peer instruction, which may have helped students overcome cognitive bottlenecks. Regarding students' perceptions, qualitative insights highlighted that this self-paced and peer-supported approach was associated with a supportive learning environment and with students reporting increased engagement, confidence, and motivation.

In summary, this study shows that the integration of peer instruction and flipped learning approaches makes the tutorial model practical and flexible for upper-secondary education. The model provides students with opportunities to prepare before class, discuss their reasoning with peers, and apply physics concepts through structured activities during class. The three-step worksheets, demonstrations, and collaborative mini-laboratories developed in this study may be adapted by teachers to support conceptual understanding and problem-solving in similar classroom settings. However, such adaptations should consider differences in student backgrounds, available classroom time, and school resources.

Limitations

While the results show clear conceptual improvements, the study has several limitations. First, the study did not include a control group. Therefore, other factors that may have contributed to student learning over time cannot be completely ruled out. Second, the researcher acted as the instructor, which may have introduced allegiance bias. To minimize this concern, the regular classroom teacher supervised the implementation, and the intervention followed the standard curriculum throughout the semester. Future replications of this model should ideally involve a researcher who is not the course instructor to further reduce this risk. Finally, although the SOLO taxonomy coding showed a high level of inter-rater reliability (Cohen's $\kappa = 0.85$), evaluating student reasoning still involves some subjective judgment. Because of these limitations, the findings should be interpreted as evidence of positive learning progression within the present research context.

Future Work

Despite the positive outcomes, several areas require further investigation. As observed in the fluid mechanics topic, abstract and conceptually demanding subjects may require further refinement of scaffolding strategies to maximize relational reasoning. Future research should explore the long-term retention of the conceptual gains



achieved through this model. Additionally, expanding the implementation of this integrated tutorial model to other STEM disciplines, different socio-economic school contexts, and more diverse student populations would provide further evidence of its scalability and potential to support higher-order thinking in science education.

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Declaration of Interest

The authors declare no competing interest.

Supplementary Material

Please visit the link https://drive.google.com/file/d/1LjawE-QSGftV1wDNUFluX7_W5olwt5OP/view for the examples of worksheets' practice problems.

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