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Enhancing Students' Conceptual Reasoning on Pressure in Solids and Liquids through Team Games Tournament Cooperative Learning

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Abstract. Persistent challenges in science education lie in transforming students from formula driven problem solvers into conceptually grounded scientific reasoners, particularly in abstract topics such as solid and liquid pressure. This study examined the effectiveness of the team games tournament (TGT) learning model in improving students' conceptual reasoning on solid and liquid pressure topics. A quasi-experimental pre-test post-test control group design was employed, involving an experimental group taught using TGT and a control group receiving teacher centered instruction. Conceptual reasoning was assessed using a validated test addressing the relationship between force, surface area, and pressure, as well as fluid pressure concepts related to depth and container shape. The results showed a statistically significant difference in post-test conceptual reasoning scores between the experimental group (M = 74.72) and the control group (M = 59.12), with a mean difference of 17.66 points ($p = 0.000 < 0.05$). In addition, the experimental group demonstrated a significant pre-test to post-test improvement, as indicated by a moderate N-Gain score of 0.48 (47.78%), reflecting meaningful conceptual development. Further analysis revealed a very large instructional effect of the TGT model (Cohen's d = 1.597), indicating strong practical effectiveness beyond statistical significance. These findings indicate that the TGT model effectively enhances students' conceptual reasoning and reduces misconceptions in solid and liquid pressure learning, highlighting its potential as a powerful instructional approach in science education.

Keywords: Conceptual reasoning; cooperative learning; science learning; solid and liquid pressure topics; team games tournament

Introduction

Science learning today reveals a persistent intellectual challenge: many students struggle to translate physics formulas into conceptual reasoning that explains real-world events. This issue becomes particularly evident in physics topics involving abstraction, multivariable thinking, and the integration of mathematical relationships with physical logic (Murphy et al., 2018; Corrigan et al., 2025). Among these topics, solid and liquid pressure consistently produce conceptual failures, as learners often memorize formulas such as ($P = F/A$) or ($P = \rho gh$) yet show little comprehension of why pressure changes across surfaces,

why hydrostatic pressure acts in all directions, or why pressure depends on depth rather than volume (Maknun, 2020). These difficulties expose a foundational learning problem characterized by students are engaging in algorithmic learning rather than scientific reasoning (Chang et al., 2018). Traditional science instruction tends to present physics as a static set of facts rather than as an intellectual discipline that requires argumentation, comparison, problem interpretation, and conceptual exploration. Because reasoning is not trained in the same repetitive manner that memorization is, learners fail to articulate ideas verbally, cannot generalize concepts across contexts, and struggle to justify claims using physical logic (Allchin, 2020). This situation reveals an underlying weakness in science education philosophy and practice. When students rely solely on procedural repetition, they lose the ability to interpret the physical world through reasoning (Trninic, 2017). In this context, effectivening conceptual reasoning is crucial for transforming physics classrooms from environments of passive reception to spaces of active learning, especially in pressure topics that demand analytical thinking rather than computational recall.

The specific conceptual difficulties students face in the solid and liquid pressure domain can be traced to varying instructional and cognitive causes. Many students hold the belief that physics pressure is purely mathematical, assuming that correct numerical answers equate to genuine understanding (Minichiello et al., 2020). This perception leads to deeply rooted misconceptions: students frequently believe that pressure in liquids acts only downward, that volume determines pressure rather than depth, and that heavier solid objects always exert greater pressure regardless of surface area (Yalcin, 2012; Schäfle & Kautz, 2021; Robertson et al., 2023). These errors develop in environments where classrooms emphasize drills, worksheets, and teacher-centered explanations, without prompting learners to analyse meaning or question conceptual accuracy. In addition, students rarely engage in peer discussions that require comparison, argumentation, or critique of scientific reasoning (Howard & Mcneill, 2020). Without exposure to cognitive conflict, misconceptions remain unchallenged and internalized. The lack of collaborative problem-solving practices means that solid pressure examples such as footprints, hydraulic braking systems, or wide contact surfaces are not leveraged to develop reasoning (Rahman, 2016; Evangelou & Kotsis, 2019). In the same way, liquid pressure ideas involving depth and buoyancy require visual imagination and logical inference, which passive learning fails to support.

Based on the conceptual challenges identified in solid and liquid pressure learning, this study seeks to examine the effectiveness of team games tournament (TGT) based science learning in enhancing students' conceptual reasoning abilities. Specifically, the research investigates whether students' conceptual reasoning differs before and after the implementation of the TGT learning model and evaluates the extent to which TGT-based instruction exerts a significant influence on students' conceptual reasoning compared to teacher centered teaching approaches (Zangori et al., 2017; Borgerding & Dagistan, 2018; Chen & Xiao, 2021). Through this investigation, the study aims to clarify the potential of TGT as an instructional strategy for strengthening conceptual reasoning in pressure-related physics topics. Therefore, the conceptual challenges in pressure learning are fundamentally tied to weaknesses in instructional design, student misinterpretation of physics, and the limited presence of reasoning dialogue (Chen & Xiao, 2021). Therefore, the conceptual challenges in pressure learning are fundamentally tied to weaknesses in instructional design, student misinterpretation of physics, and the limited presence of reasoning dialogue. However, research that specifically examines the effectiveness of the TGT model on students' conceptual reasoning in solid and liquid pressure topics remains limited.

This conceptual learning crisis matters deeply because reasoning ability forms the intellectual foundation of scientific literacy, long-term academic success, and daily decision making. Conceptual reasoning allows students to explain why physical relationships exist, not just how to calculate them (Fortus et al., 2022). In physics learning, reasoning

differentiates genuine understanding from mechanical correctness. Students require the ability to analyze unfamiliar pressure situations, recognize conceptual patterns, and defend answers using sound logic to move beyond superficial competence (Kubricht et al., 2017). Solid and liquid pressure knowledge also influences everyday reasoning: understanding why hydraulic machines multiply force, why divers experience pressure surrounding their bodies, or why large surface areas reduce solid pressure reflects true scientific engagement (Speirs el al., 2021). Without conceptual reasoning, learners struggle to transfer understanding to higher physics domains such as fluid dynamics, buoyancy, Bernoulli's principle, and thermodynamics. Globally, science education research emphasizes that reasoning-driven learners exhibit stronger motivation, better retention, increased academic confidence, and higher achievement in STEM disciplines. Thus, the cultivation of conceptual reasoning in pressure topics is not merely beneficial, but essential for building scientifically informed citizens and supporting national scientific advancement.

These challenges generate concern among educators and researchers, who observe declining reasoning ability in physics classrooms. It is increasingly common to encounter students able to recite formulas while being unable to respond to basic conceptual questions about daily pressure events, such as why bicycle tires are wide, why knives must be sharp, or why water pressure increases with depth (Bao, 2019; Robertson et al., 2023; Pacaci, 2024). This issue reflects deeper cognitive shortcomings rather than isolated academic gaps. Students disengage because they perceive physics as abstract, disconnected from lived experience, and overly procedural. When instruction relies on diagram repetition, formula exercises, and direct teaching without exploratory dialogue, misconceptions persist into adulthood (Eshach & Lin, 2017; Kubricht et al., 2017). Such conditions risk producing future generations lacking confidence in scientific thinking. Research also shows that students seldom experience instructional spaces where debate, inquiry, and argumentation are encouraged. This lack of intellectual challenge leads to boredom and inhibits creativity (Bao, 2019; Conradty, 2020; Giamellaro et al., 2025). Consequently, there is an urgent need to rethink instructional practices and develop pedagogical strategies that help students reason scientifically rather than memorizing isolated facts.

TGT emerges as an instructional model that directly addresses weaknesses in traditional physics teaching by emphasizing reasoning, interaction, and collaboration (Conradty, 2020). This model is grounded in cooperative learning principles that position students as active constructors of knowledge rather than passive recipients (Pesout & Nietfeld, 2020; Lee et al., 2021). Educational research has introduced many approaches to foster conceptual reasoning, such as inquiry-based learning, cognitive conflict strategies, and digital simulations (Chen et al., 2020). However, these models often demand extensive resources, advanced infrastructure, and significant instructional time. Such requirements limit their practical implementation in many school contexts. In contrast, TGT offers a more accessible and feasible alternative while maintaining strong pedagogical value.

TGT-based science learning integrates cooperative group work with structured academic competition to stimulate student engagement (Chen, 2018; Chen et al., 2020). Through tournaments, students are encouraged to debate ideas, justify their reasoning, and explain scientific concepts to peers (Rahman, 2016; Lämsä et al., 2018). Prior to the tournament phase, students engage in peer-teaching activities, in which they collaboratively discuss and explain underlying concepts to their teammates, focusing on conceptual understanding rather than procedural calculation. During this phase, students are required to articulate why a scientific relationship holds, not merely how to apply formulas, thereby strengthening conceptual reasoning through verbal explanation and mutual clarification (Zhang et al., 2017). This learning atmosphere transforms classrooms into spaces of intellectual exchange where reasoning becomes a shared responsibility. Unlike teacher centered group discussions, TGT emphasizes individual accountability

because each student's performance contributes to team success (Chen et al., 2020; Lee et al., 2021). This structure motivates students to genuinely understand concepts rather than rely on memorization. Empirical studies confirm that cooperative academic games enhance student activeness, motivation, confidence, and conceptual mastery.

From a science learning perspective, the relevance of the TGT model lies in its alignment with the core characteristics of effective science instruction, namely inquiry, reasoning, and evidence-based explanation. Science learning emphasizes not only the acquisition of factual knowledge but also the development of students' ability to construct concepts, interpret phenomena, and apply scientific principles to real situations. TGT facilitates this process by embedding conceptual discussion, hypothesis testing, and argumentative reasoning within cooperative and competitive learning activities. Through structured interaction and guided questioning during tournaments, students actively engage in sense-making processes that mirror scientific practices, such as explaining causal relationships, evaluating alternative ideas, and justifying conclusions using scientific concepts (Borgerding & Dagistan, 2018; Pacaci, 2024). As a result, TGT creates meaningful learning experiences that support deeper conceptual understanding and strengthen students' scientific reasoning abilities within the framework of science education.

When applied to solid and liquid pressure topics, TGT effectively promotes deep conceptual reasoning. Students are guided to articulate relationships between force and surface area, analyze pressure changes with depth, and evaluate hydrostatic behavior (Chen, 2018). They are challenged to explain why pressure increases at greater depths, why fluid pressure is independent of container shape, and why increasing surface area reduces solid pressure. These reasoning-focused activities directly confront common misconceptions in physics learning. Through repeated explanation, argumentation, and peer feedback, students construct more coherent and scientifically accurate understandings (Murphy et al., 2018; Allchin, 2020). Consequently, TGT-based science learning stands out as a powerful, realistic, and pedagogically sound approach for strengthening conceptual reasoning in pressure topics.

Despite extensive research on students' misconceptions in solid and liquid pressure topics and growing evidence supporting cooperative learning approaches, a clear research gap remains. Most existing studies emphasize achievement, motivation, or general conceptual understanding, while conceptual reasoning as a distinct cognitive construct is rarely examined. In particular, empirical investigations that specifically evaluate the effectiveness of the TGT model in strengthening students' conceptual reasoning on pressure-related physics topics are still limited. In addition, few studies employ comprehensive effectiveness measures such as N-Gain and effect size to assess the magnitude of instructional impact (Zhang et al, 2017; Lee et al., 2021). As a result, systematic evidence is needed to clarify whether TGT-based science learning produces meaningful and substantial improvements in students' conceptual reasoning on solid and liquid pressure topics.

Methods

This study was conducted in accordance with established ethical standards for educational research. Institutional permission was obtained from the school administration, and informed consent was secured from all participating students prior to data collection. Following ethical approval, the study applied a quantitative research method using a quasi-experimental pretest–posttest two-group design to examine the effect of TGT-based science learning on students' conceptual reasoning in solid and liquid pressure topics. The population consisted of all Grade IX students at SMPN 6 Ponorogo in the academic year 2025/2026, from which two intact classes were selected using a cluster sampling technique. The study compared an experimental group (n = 32) taught through TGT with

a control group (n = 32) receiving teacher-centered instruction. The experimental class received TGT-based instruction, while the control class experienced teacher-centred learning.

Both groups completed an identical multiple-choice test to evaluate their initial conceptual reasoning ability, using an instrument that had undergone prior validity and reliability testing. Item validity analysis indicated that the test items demonstrated moderate to high validity, with correlation coefficients ranging from 0.465 to 0.844. Instrument reliability testing yielded a reliability coefficient of 0.850, exceeding the accepted threshold of 0.70, thereby indicating high reliability. The pretest was followed by a structured learning intervention aligned with the curriculum. After instruction, students in both groups took a posttest that measured conceptual reasoning effectiveness, focusing on understanding force–area relationships, hydrostatic pressure distribution, and depth-dependent pressure variation.

Table 1. Two group pre-test and post-test design

Class	Pre-test	Treatment	Post-test
Experiment	X_1	T	X_2
Control	X_1	O	X_2

Information:

X_1 = Giving pre-test to the experimental class and control class
X_2 = Giving post-test to the experimental class and control class
T = Treatment with the TGT learning model
O = Treatment with teacher-centered learning

Normality and homogeneity tests were conducted as preliminary analyses to verify that the pretest and posttest scores met the assumptions required for parametric statistical testing. The results confirmed that the data were normally distributed and that variances between the experimental and control groups were homogeneous, thereby justifying the use of t-test analyses. To address the research question regarding the effectiveness of the TGT-based science learning model, a paired sample t-test was employed to compare students' pretest and posttest conceptual reasoning scores within the same group. This analysis was used to identify statistically significant improvements attributable to the TGT intervention.

As part of the analytical framework, to examine the research question related to differences in conceptual reasoning between TGT-based instruction and teacher centered learning, an independent sample t-test was employed. In addition to inferential statistical testing, N-Gain score analysis was utilized to assess the level of effectiveness of students' conceptual reasoning improvement. The N-Gain index represents the proportion of learning gain achieved by students relative to the maximum possible improvement (Pujiastuti & Haryadi, 2024). This analysis provides a descriptive interpretation of learning improvement levels (low, moderate, or high), thereby complementing significance testing with pedagogical meaning.

Table 2. Effectiveness criteria based on N-Gain percentage

N-Gain Range (%)	Effectiveness Category
<40	Ineffective
40 - 55	Moderately Effective
56 - 75	Effective
>75	Highly Effective

Within the conceptual framework outlined in the introduction, N-Gain analysis serves to confirm that the observed improvements reflect substantive conceptual development rather than mere score fluctuations. Overall, the integration of assumption testing, paired sample t-tests, independent sample t-tests, and N-Gain analysis constitutes a comprehensive analytical framework for identifying students' conceptual reasoning development and evaluating the instructional impact of the TGT model in solid and liquid pressure learning.

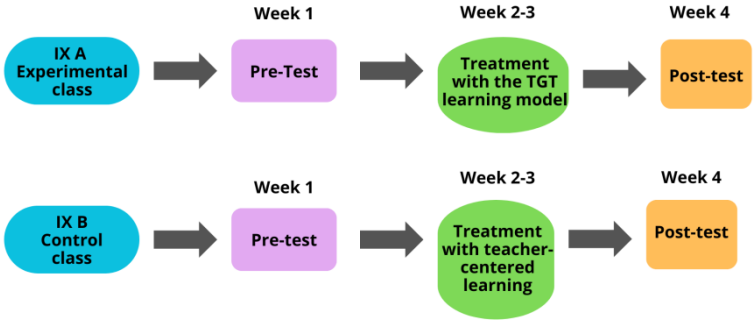

Figure 1. TGT Implementation Schedule

This schedule illustrates the implementation stages of the TGT learning model across two groups: the experimental class and the control class. In Week 1, the experimental class completes a pre-test to measure students' initial understanding before receiving the intervention, while the control class directly takes a post-test to establish their baseline outcome. During weeks 2–3, the experimental class receives treatment using the TGT model, whereas the control class undergoes teacher-centered learning activities. At the end of Week 4, both groups complete a post-test to evaluate the impact of the different instructional approaches on students' achievement. This structured timeline supports a clear comparison between the effectiveness of TGT learning and teacher centered teaching methods.

Within the TGT implementation, students are organized into heterogeneous teams of four to five members and engage in a structured academic game using problem-based media, in which question sets are categorized by difficulty level and associated with differentiated point values. Team representatives select and attempt questions, while responses are discussed collaboratively within teams; correct answers contribute to cumulative team scores. The questions presented during the tournament are intentionally designed to stimulate students' conceptual reasoning by requiring explanation, interpretation, and justification of physical relationships, rather than rapid procedural calculation. The tournament concludes with the recognition of teams achieving the highest scores, reinforcing both individual accountability and cooperative learning.

Results and Discussion

The results section presents empirical evidence on the effectiveness of the TGT learning model in improving students' conceptual reasoning on solid and liquid pressure topics. The findings are reported through a systematic analysis that includes descriptive statistics, assumption testing, and inferential comparisons between the experimental and control groups. Rather than emphasizing statistical significance alone, the results highlight observable patterns of score improvement and variability that reflect changes in students' conceptual reasoning performance (Fritz et al., 2012; Tintle et al., 2018). The presentation of results is organized to move from baseline conditions to post-instruction outcomes, providing a clear quantitative basis for subsequent interpretation. This results-focused

structure ensures that learning outcomes are transparently documented before being examined in relation to instructional processes and theoretical perspectives.

Table 3. Descriptive statistics of students' conceptual reasoning scores

Group	Test	N	Min	Max	Mean	Std. Deviation
Experimental	Pre-test	32	40	85	62.53	11.63
	Post-test	32	62	100	74.72	8.47
Control	Pre-test	32	27	75	51.37	11,26
	Post-test	32	45	80	59.12	9.14

Baseline Equivalence and Post-Instruction Conceptual Gains

The pre-test results indicate that the experimental group (M = 62.53) and the control group (M = 51.37) exhibited differing initial levels of conceptual reasoning. Although the experimental group demonstrated a higher mean score, both groups showed comparable score dispersion, as reflected by similar standard deviations. This similarity in variability suggests that the distributions of conceptual reasoning scores were relatively consistent across groups prior to the intervention. The pre-test data reveal that students in both groups experienced conceptual challenges related to solid and liquid pressure topics, as indicated by moderate mean scores and wide score ranges. These baseline conditions provide an important reference point for interpreting subsequent learning gains. Thus, changes observed in the post-test can be meaningfully analyzed in relation to instructional effects rather than random variation.

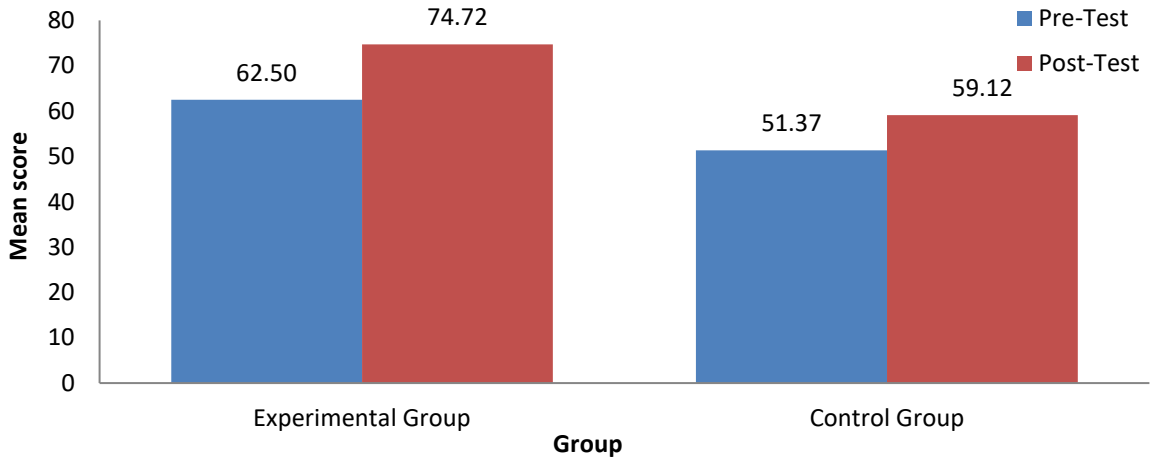

Figure 2. Descriptive Statistics Graph

Following the instructional treatment, the experimental group showed a substantial improvement in conceptual reasoning, with the post-test mean increasing to 74.72. In contrast, the control group demonstrated only a modest increase, reaching a post-test mean of 59.12. The gain of more than 12 points in the experimental group indicates a meaningful enhancement of students' conceptual reasoning after participating in TGT-based learning. Notably, the reduction in standard deviation and the increase in minimum score suggest that learning gains were experienced across achievement levels, not only among higher-performing students. This pattern implies that TGT supports more equitable conceptual development. Overall, the descriptive statistics provide preliminary empirical evidence that TGT-based instruction positively influences students' conceptual reasoning on solid and liquid pressure topics.

Table 4. Results of the normality test (Shapiro–Wilk)

Group	Test	Statistic	df	Sig.	Interpretation
Experimental	Pre-test	0.963	32	0.334	Normal
	Post-test	0.941	32	0.081	Normal
Control	Post-test	0.957	32	0.224	Normal

Assumption Testing for Parametric Statistical Analysis

Results of the Shapiro–Wilk normality test for pre-test and post-test scores. All significance values exceed the threshold of 0.05, indicating that the data are normally distributed. This finding satisfies a key assumption for parametric statistical analysis, particularly t-tests. Normal distribution of scores implies that the mean is an appropriate measure of central tendency for interpreting learning outcomes. The confirmation of normality enhances the credibility of subsequent inferential analyses (Tintle et al., 2018). Moreover, the normal distribution suggests that the learning gains observed are representative of the broader student population rather than driven by outliers. Thus, Table 4 provides essential methodological support for valid statistical inference.

Table 5. Results of the homogeneity of variance test

Variable	Levene Statistic	df1	df2	Sig.	Interpretation
Post-test Scores	3.498	1	62	0.066	Homogeneous

The results of the Levene's test for homogeneity of variance. The significance value of 0.066 exceeds the 0.05 threshold, indicating that the variances between experimental and control groups are homogeneous. This finding confirms that group variability is comparable and that the independent sample t-test assumptions are met. Homogeneity of variance is critical because unequal variances can bias test results and lead to inaccurate conclusions. By satisfying this assumption, the analysis ensures that observed differences in post-test scores reflect true instructional effects. Consequently, Table 5 reinforces the methodological rigor of the study and strengthens confidence in the comparative results.

Table 6. Results of t-test comparisons

Test Type	Group Comparison	Mean Difference	Std. Error Mean	Sig. (2-tailed)
Paired Sample	Experimental Group (Pre-test vs Post-test)	−16.97	2.10	0.000
Independent Sample	Experimental vs Control Group	17.66	3.49	0.000

Inferential Analysis of TGT Effects on Conceptual Reasoning

The paired sample t-test results indicate a statistically significant improvement in the experimental group's conceptual reasoning scores ($p = 0.000$). The mean difference of −16.97 demonstrates a substantial learning gain following TGT implementation. This result confirms that students experienced meaningful conceptual development within the same group over time. The low standard error suggests that the improvement was consistent among students. Such findings align with prior research indicating that cooperative game-based learning enhances conceptual understanding. The paired t-test thus provides strong evidence that TGT effectively improves conceptual reasoning in pressure topics.

The independent sample t-test further reveals a significant difference between the experimental and control groups' post-test scores ($p = 0.000$). The mean difference of 17.66 points highlights the improved learning performance of TGT-based instruction over teacher-centered learning. This result demonstrates that the improvement observed is not merely a general learning effect but a specific outcome of the instructional model. The large difference underscores the limitations of teacher centered teaching approaches in fostering reasoning skills. By contrast, TGT creates opportunities for explanation, argumentation, and peer feedback. Therefore, Table 6 provides robust statistical confirmation of TGT's instructional effectiveness.

Table 7. Results of effectiveness analysis (N-Gain and effect size***)***

Analysis	Value	Interpretation
N-Gain Score (Experimental Group)	0.4778	Moderate
N-Gain Percentage (Experimental Group)	47.78%	Moderately Effective
Cohen's *d* (Effect Size)	1.597	Very Large Effect

Effectiveness Analysis Based on N-Gain and Effect Size

Result on the N-Gain score of 0.4778, categorized as moderate effectiveness. This indicates that nearly half of the maximum possible improvement in conceptual reasoning was achieved. In educational research, moderate N-Gain values are considered pedagogically meaningful, particularly for abstract physics topics. The N-Gain percentage of 47.78% suggests that TGT produces substantive learning gains rather than superficial score increases. Importantly, N-Gain analysis contextualizes improvement relative to initial ability levels. Thus, the findings indicate that TGT facilitates genuine conceptual growth.

The Cohen's *d* value of 1.597 reported in Table 7 indicates a very large effect size, reflecting an instructional impact that extends well beyond statistical significance to substantive educational importance. In educational research, an effect size of this magnitude signifies a pronounced shift in students' learning outcomes attributable to the intervention, rather than variability arising from sampling error or measurement noise. This

result demonstrates that the implementation of the TGT model produced a robust and consistent enhancement in students' conceptual reasoning abilities across the experimental group. The magnitude of the effect implies that the average student exposed to TGT outperformed a substantial proportion of students in the control group, underscoring the model's strong comparative advantage over teacher centered instruction.

Instructional Mechanisms of TGT in Developing Conceptual Reasoning

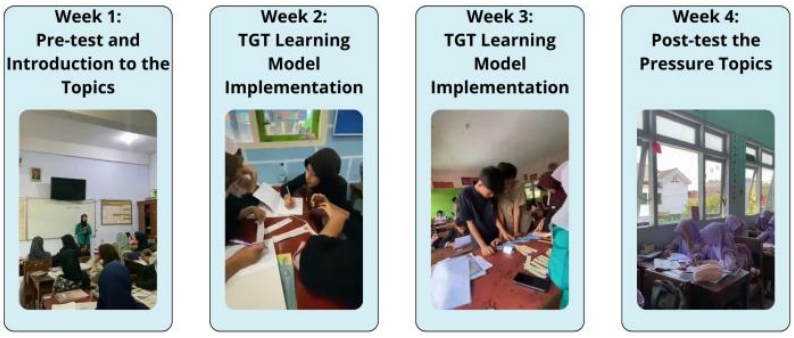

Figure 3. TGT Implementation

The implementation of the TGT learning model facilitates students' conceptual reasoning by transforming classroom interactions into active, explanation-centered learning processes (Speirs, Stetzer and Lindsey, 2021). Throughout instruction, students engage in collaborative discussions, shared problem-solving, and academically structured competitive tasks that require them to articulate, justify, and evaluate conceptual ideas. Rather than relying on procedural calculation, learners are positioned as active constructors of meaning who verbalize their reasoning and critically respond to peers' explanations. This instructional design distributes cognitive responsibility across group members and supports collective knowledge construction, which is essential for developing coherent conceptual understanding in physics, particularly in topics involving solid and liquid pressure.

In addition, the social and competitive dimensions embedded in TGT play a critical role in strengthening conceptual reasoning. Peer-to-peer discourse encourages students to externalize their thinking, confront alternative explanations, and reconstruct misconceptions through collaborative critique (Isik-ercan, 2020). At the same time, the tournament structure sustains engagement and motivates conceptual preparation, as successful participation depends on conceptual mastery rather than memorization (Conradty, 2020). By integrating cooperation, regulated competition, and explanation-focused tasks, TGT creates instructional conditions that align with constructivist learning principles and effectively support the development of students' conceptual reasoning in pressure-related topics.

Implications of TGT for Conceptual Reasoning in Science Learning on Solid and Liquid Pressure Topics

The findings of this study indicate a significant difference in students' conceptual reasoning related to the relationship between force, surface area, and pressure between those taught using the TGT model and those receiving teacher centered instruction. Students in the TGT group demonstrated a higher level of ability to explain why increasing surface area reduces pressure or why identical forces can produce different pressure outcomes depending on contact area. This difference suggests that TGT facilitates reasoning beyond formula application ($P = F/A$) by engaging students in explanation, comparison, and justification processes (Kafyulilo et al., 2015; Zhang et al., 2017;

Masruroh & Muna, 2024). Unlike teacher centered instruction, which often emphasizes procedural calculation, TGT creates structured opportunities for students to verbalize causal relationships, enabling deeper conceptual connections between force distribution and pressure phenomena.

With regard to fluid pressure concepts, the results reveal that the application of the TGT model substantially improves students' conceptual reasoning related to pressure variation with depth and its independence from container shape. Students exposed to TGT-based learning showed stronger reasoning when explaining why pressure increases with depth regardless of vessel geometry, indicating a shift from intuitive or visual misconceptions toward scientifically grounded understanding. This improvement reflects the role of peer discussion and competitive questioning in challenging naïve conceptions, such as the belief that wider containers produce greater pressure. Through repeated conceptual dialogue during tournaments, students were encouraged to reconcile conflicting ideas, supporting conceptual restructuring rather than rote memorization.

The significant pre-test to post-test improvement observed in the experimental group also demonstrates that TGT effectively reduces common misconceptions in solid and liquid pressure topics. Misconceptions such as "heavier objects always exert greater pressure" or "liquid pressure only acts downward" were progressively addressed through explanation-driven interaction (Yalcin, 2012; Pujiastuti & Haryadi, 2024). The tournament mechanism required students to defend answers publicly, increasing cognitive accountability and encouraging conceptual accuracy. In contrast, students in the control group showed limited conceptual growth, suggesting that teacher centered instruction may insufficiently disrupt entrenched misconceptions due to its limited emphasis on reasoning-based discourse.

This evidence supports the claim that TGT promotes reasoning beyond formula application, as students were required to interpret the physical meaning of the equation ($P = F/A$). As a result, students developed more coherent conceptual understanding of solid pressure. With respect to liquid pressure concepts, the results show that TGT substantially improves students' reasoning about pressure variation with depth and its independence from container shape. Students exposed to TGT-based learning demonstrated stronger explanations for why pressure increases with depth regardless of vessel geometry. This improvement indicates a shift from intuitive or visual reasoning toward scientifically grounded understanding. Many students initially believed that wider containers exert greater pressure than narrower ones at the same depth. Through structured discussion and competitive questioning, such misconceptions were directly challenged. Consequently, students reconstructed their understanding based on depth-dependent pressure principles rather than container shape.

The moderate N-Gain score combined with a very large effect size indicates that the observed conceptual improvement is not only statistically significant but also educationally meaningful (Fritz et al., 2012; Plonsky & Oswald, 2014). The moderate N-Gain reflects substantial conceptual development relative to students' initial understanding, particularly for abstract physics topics that are known to resist conceptual change. Meanwhile, the large effect size underscores the strong instructional advantage of TGT over teacher-centered approaches in fostering conceptual reasoning (Rice & Harris, 2005; Gignac & Szodorai, 2016). These findings reinforce the argument that learning environments emphasizing interaction, explanation, and cognitive challenge are more effective in developing scientific reasoning than transmission-based instruction.

Overall, the results suggest that the TGT model serves as an effective pedagogical framework for strengthening students' conceptual reasoning in solid and liquid pressure learning. By integrating cooperative learning, structured competition, and reasoning-focused tasks, TGT aligns closely with constructivist and reasoning-centered science education principles. The model not only improves conceptual reasoning scores but also

supports conceptual coherence and misconception reduction. Therefore, TGT represents a promising instructional alternative for science educators seeking to enhance students' understanding of pressure concepts through meaningful reasoning rather than procedural mastery alone.

Despite the positive findings, this study is subject to several limitations that should be acknowledged. First, the implementation of the TGT model was limited to solid and liquid pressure topics, which restricts the generalizability of the findings to other physics concepts that may involve different cognitive demands. Second, the duration of the intervention was relatively short, which may not fully capture the long-term development and retention of students' conceptual reasoning. Third, the study was conducted within a single school context, limiting the diversity of student characteristics and instructional settings. Future research is therefore encouraged to apply TGT across broader physics topics, extend the intervention period, and involve multiple schools to enhance external validity. Additionally, longitudinal studies and mixed-method approaches are recommended to further explore how TGT influences conceptual reasoning development over time and across varying learning contexts.

Conclusion

This study confirms that the implementation of the TGT learning model significantly improves students' conceptual reasoning on solid and liquid pressure topics. The results demonstrate a clear difference in students' conceptual reasoning before and after the application of TGT, as indicated by a significant pre-test to post-test improvement in the experimental group. In addition, the comparison between instructional approaches reveals that students taught using TGT achieved higher conceptual reasoning performance than those receiving teacher-centered instruction, with a substantial mean difference in post-test scores. The improvement is further supported by a moderate N-Gain value (0.48) and a very large effect size (Cohen's d = 1.597), indicating that the learning gains are both statistically significant and educationally meaningful. These findings indicate that TGT-based science learning effectively facilitates students' ability to explain pressure relationships conceptually, including the influence of surface area on solid pressure and the dependence of liquid pressure on depth rather than container shape. Overall, the study concludes that the TGT model provides an effective instructional approach for strengthening students' conceptual reasoning in solid and liquid pressure learning within science education.

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