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Leveraging the cognitive conflict-based learning model to deepen students' understanding of momentum and collisions

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Abstract

A solid conceptual understanding of physics is essential for students to internalize fundamental principles and engage effectively in higher-order scientific thinking. Recognizing the importance of this, the present study aimed to enhance students' conceptual understanding of Momentum and Collisions using Cognitive Conflict-Based Learning (CCBL). This study collected data from Grade 10 students using a two-tier conceptual understanding test, comprising multiple-choice questions and corresponding open-ended items that required reasoning. The test assessed seven sub-concepts: Momentum, Force and Change in Momentum, Impulse and Impulsive Force, the Law of Conservation of Momentum, Elastic Collisions, Inelastic Collisions, and Explosion. The results showed that 30 students (76.92%) achieved Partial Understanding (PU) or Complete Understanding (CU), and 9 students (23.08%) achieved Partial Understanding with Specific Alternative Conception (PS). Out of all the sub-concepts, the most significant number of students achieving Complete Understanding (CU) was for the concepts of Momentum and Explosion, with 22 students (56.41%) for each. Conversely, the fewest number of students with a Complete Understanding (CU) was in the concept of Impulse and Impulsive Force, where 14 students (35.90%) were found. Cumulatively, the findings confirm the potential of CCBL for addressing misconceptions and enabling conceptual learning in physics. Practical implications include designing lessons that integrate discrepant events, guided discussions, and technology-based tools such as simulations and video analysis, alongside focused support for difficult sub-concepts. These insights highlight the value of CCBL as a constructivist approach for enhancing physics education.

Keywords: Cognitive conflict-based learning, Conceptual understanding, Scientific concepts.

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1. Introduction

Understanding scientific concepts is fundamental to science learning, enabling students to think critically, make informed judgments, and apply knowledge in real-life contexts [1, 2]. Science is not just specialized knowledge but fosters scientific thinking, curiosity, active learning, and a growth mindset [3]. A solid understanding of science helps students explain natural phenomena and drives technological innovation [4]. Without conceptual understanding, students develop misconceptions that hinder deeper learning and application [5, 6]. Scientific conceptual understanding refers to students' ability to comprehend and interpret fundamental scientific principles and theories, and to make sense of phenomena in ways consistent with scientific concepts [7]. It forms the foundation for a deeper understanding [8] as students must first grasp basic concepts before fully understanding scientific theories [9]. While some students acquire concepts easily, others need more time and support. Those who struggle are more prone to misconceptions and persistent misunderstandings that hinder learning, especially in complex subjects like physics [10] and can negatively impact academic performance [11, 12].

In Thailand, scientific literacy remains a challenge. PISA 2022 reports show Thai students scoring 409 in science, below the OECD average of 485, with only 47% reaching basic proficiency [6]. This means that many students do not yet have a thorough understanding of physics concepts. It seems that learning relies more on memorization of formulas or mathematical symbols rather than comprehension of the underlying principles and the origin of formulas. Students cannot, therefore, answer conceptual questions or explain underlying concepts, thus leading to patchy learning. It becomes challenging for them to even apply physics knowledge in practical applications or problem-solving. It also decreases students' attitude towards physics, and the subject seems hard and boring, therefore decreasing their interest in active learning and preparation for higher education or careers in the science and technology fields [13]. Additionally, drawing on classroom experience, the author administered a two-tier test on Linear Motion [14, 15] to 40 students, revealing that 56.6% showed only partial understanding. Persistent misconceptions risk fragmenting learning and hindering problem-solving [16, 17]. Moreover, research globally highlights students' struggles with physics concepts, often due to prior misconceptions from informal sources. Addressing these requires targeted pedagogies [18-22]. While some success has been seen using misconception change models [23], limited research exists on topics like momentum and collisions, signaling the need for effective instructional strategies. These data suggest that students still have problems understanding physics concepts, which affects learning in many areas. A lack of conceptual understanding prevents students from connecting knowledge to real-world situations, explaining natural phenomena, or solving physics problems effectively. Students often learn by memorizing formulas or computational processes without understanding the meaning or principles behind them. This results in fragmented knowledge and shallow learning. There is also a tendency to develop permanent misconceptions, which can hinder the learning of more complex concepts in the future. It also affects students' attitudes towards physics, making them feel that this subject is complex and uninteresting. This may lead to a decrease in motivation to learn and a lack of readiness for further education or careers in the field of science and technology.

In the 21st century, education increasingly emphasizes helping students build strong conceptual foundations to support meaningful learning and lifelong thinking skills. Various teaching methods have been implemented to achieve conceptual change and correct misconceptions. Among the most utilized methods is what is called Cognitive Conflict-Based Learning (CCBL), or a learning process in which knowledge is developed by challenging the learner through experiences, creating cognitive conflict between prior knowledge or beliefs and new information, frequently through hands-on experiments and collaborative discussion sharing. Practice is based on the theory of cognitive constructivism, and the active learner is the focus on developing new knowledge from experience with the analysis of previous conceptions in comparison to new information or experience. Cognitive conflict instruction strategies have been an effective means of conceptual change instruction, leading learners from initial misconceptions to actual and profound scientific understanding. Research in various school environments has confirmed the effectiveness of this approach. In addition to reducing misconceptions, cognitive conflict-based learning enhances critical thinking capability and scientific interpretation using divergent educative resources, such as experimental videos. Moreover, it also leads to outstanding development in students' critical thinking, particularly in basic explanations and logical conclusions. Therefore, it has been advocated as an intentional entry point for instruction, allowing students to convert their previous misconceptions to scientifically accepted ideas [24-30].

Even though the research in this case is conducted within the Thai context, misconceptions regarding momentum and collisions are recognized as a global phenomenon. This research seeks to contribute to the existing body of knowledge by examining the implementation of the Cognitive Conflict-Based Learning (CCBL) model to enhance Grade 10 students' understanding of momentum and collisions in Thailand. By considering the cultural and instructional nuances of Thai classrooms, the study will provide valuable insights into the adaptability and effectiveness of CCBL in promoting conceptual change and deepening scientific understanding. The findings are expected to inform educators and policymakers on how to effectively integrate CCBL strategies in Thailand's physics education, ultimately supporting improved learning outcomes and fostering critical scientific thinking skills among students.

2. Materials and Methods

2.1. Research Design and Research Participants

This research used a pre-experimental research design. The samples of this study were Grade 10 students under the Science-Mathematics program in Sarakhampittayakhom School, Thailand, using a cluster random sampling technique by classroom as a sampling unit. At this school, students in each grade level are assigned to classrooms with varied academic abilities and adhere to the same curriculum and evaluation criteria. As a result, the sampled class represents the usual academic distribution and learning context of the full Grade 10 student body at the school. Consequently, the findings can be deemed strongly representative of this population, providing valuable insights for improving teaching and learning in the school setting.

2.2. Research Instruments

1) CCBL Lesson Plans: 10 hours of training covering the subject of Momentum and Collisions are covered in seven lesson plans. In each lesson plan, there are four phases: 1) Activation of Preconceptions and Misconceptions, 2) Presentation of Cognitive Conflict, 3) Discovery of Concepts and Equations, 4) Reflection. The learning activities in each phase are structured as follows [31]:

Phase 1: Involved the teacher presenting the lesson with a real scenario or simulation of the subject, posing guiding questions, and having students answer on a worksheet to summarize prior knowledge and reveal existing misconceptions.

Phase 2: The teacher introduced a scenario or demonstration that challenged students' prior knowledge, then asked them to formulate hypotheses about the phenomenon before conducting the experiment.

Phase 3: The small groups of students carried out experiments, while the instructor facilitated group discussions to enable students to collaboratively identify key concepts and formulas.

Phase 4: All groups presented their results to the class. The teacher used questioning strategies to trigger reflection and helped students record accurate scientific concepts on their worksheets.

Upon completion of the lesson plan, its quality was assessed by five experts. The evaluation revealed a mean appropriateness score of 4.73 with a standard deviation of 0.21, indicating a high level of suitability.

2) Conceptual Understanding in Science Test: This instrument consisted of seven two-tier items designed to assess students' conceptual understanding in physics. The test covered the following topics: (1) Momentum, (2) Force and Change in Momentum, (3) Impulse and Impulsive Force, (4) Law of Conservation of Momentum, (5) Elastic Collisions, (6) Inelastic Collisions, and (7) Explosions. Each item comprises two parts.:

Part 1: A multiple-choice question with four options, only one of which was the correct answer.

Part 2: An open-ended question requiring students to justify their choice from Part 1.

To ensure the quality of the instrument, content validity was examined using the Index of Item-Objective Congruence, with values ranging from 0.60 to 1.00. Item difficulty and discrimination indices were analyzed using the Whitney and Sabers method, resulting in difficulty values between 0.65–0.77 and discrimination values between 0.25–0.60. The test also demonstrated acceptable internal consistency, with a Cronbach's alpha coefficient of 0.82.

2.3. Data Collection and Data Analysis

Data on students' scientific conceptual understanding were collected from 39 Grade 10 students following the implementation of cognitive conflict-based learning. Prior to data collection, informed consent was obtained from all participants and relevant stakeholders, and the research protocol was reviewed and approved by the Institutional Review Board (IRB) to ensure ethical compliance. The data were gathered using the Scientific Conceptual Understanding Test, administered after the instructional intervention. Students' responses were then analyzed by categorizing their levels of conceptual understanding according to the criteria proposed by Westbrook and Marek [32] which allowed for a nuanced interpretation of students' conceptual development. The items' scores were interpreted using the classification criteria, which allowed for the assignment of scores according to their five-level grouping system, as follows.:

Table 1.
Criteria for Categorizing Conceptual Understanding Levels.

Scientific Conceptual Understanding	Description	Criteria
Complete Understanding (CU)	The student's multiple-choice answers are correct, and the reasoning is complete and thorough, covering all the essential components of each concept.	Explaining the concept or theory, the equations used in the calculations, and the demonstration of the thought process.
Partial Understanding (PU)	Correct answer with a largely correct explanation but missing significant elements.	Explanation is mostly accurate but incomplete.
Partial Understanding with Specific Alternative Conception (PS)	Correct answer but explanation includes a misconception, or no explanation provided.	Misconception Evidence or explanation missing.
Alternative Conception (AC)	Incorrect answers and explanation reflect a misconception.	Both answer and reasoning is incorrect.
No Understanding (NU)	Irrelevant response or no response at all.	No response, or the answer fails to address the question.

In this study, the researcher evaluated students' conceptual understanding using the criterion that students must demonstrate either a PU or CU level in all sub-concepts in order to be considered as having passed the threshold [33]. The overall results of students' conceptual understanding were analyzed using basic descriptive statistics, namely, percentage.

3. Results

The results presented below show the number and percentage of students at various levels of scientific conceptual understanding across the sub-concepts of Momentum and Collisions. These data are summarized in Table 2 as follows:

Table 2.
Number and Percentage of Students by Level of Understanding of Scientific Concepts.

Conceptual Understanding	Number of Students (%)	Assessment Outcome
CU /PU	30 (76.92)	Passed
PS	9 (23.08)	Failed
AC	0 (0.00)	Failed
NU	0 (0.00)	Failed

The number of students at each level of scientific conceptual understanding shows that 76.92% (30 students) met the requirements by achieving either PU or CU. At the same time, 23.08% (9 students) did not meet the requirements because they continued to have conceptual understanding at the PS level.

Then the researcher divided the data gathered from the scientific conceptual understanding test by the sub-concepts, i.e., Momentum, Force and Change in Momentum, Impulse and Impulsive Force; Law of Conservation of Momentum; Elastic Collision; Inelastic Collision; and Explosion, to determine how the students viewed each sub-concept. The results are as follows.

3.1. Sub-Concept 1: Momentum

Students' comprehension of momentum is evaluated using the following concept: Momentum is the quantity of motion of an object that tends to move or continue moving forward. It is a vector quantity, having a direction that corresponds to the direction of velocity. A moving object possesses momentum, which is defined as the product of its mass and velocity. The unit of momentum is kilogram meter per second (kg·m/s), and it is represented by the equation: $\vec{p}=m\vec{v}$. The analysis of test results is presented in the following pie chart, illustrating the percentage of students' conceptual understanding.

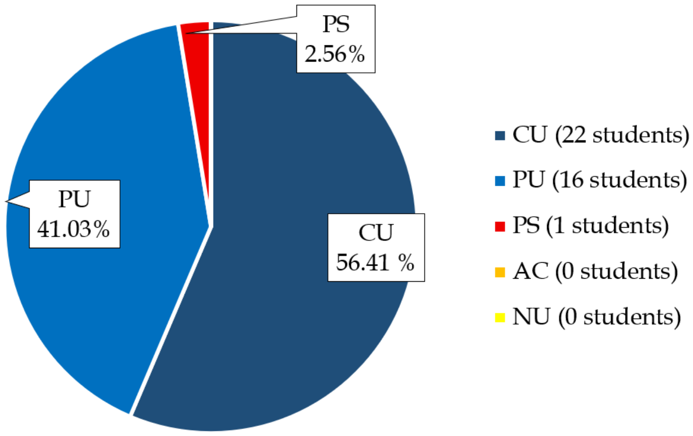

Figure 1.
Levels of Scientific Conceptual Understanding on the Topic of Momentum.

As shown in Figure 1, a CU was attained by 22 students (56.41%). These students demonstrated the ability to select appropriate answers and skillfully explain how the link between mass, velocity, and motion direction determines momentum. Such learners were also cognizant, for instance, that momentum is a vector quantity that has both magnitude and direction. Even though two objects have other directions of movement, their magnitudes of momentum are equal when both have the same velocity and mass. Meanwhile, 16 students (41.03%) demonstrated PU. Such students could choose the appropriate options and explain the basic relationship between mass and velocity, but had no idea of the direction of momentum. For instance, they knew that momentum equals the product of mass and velocity, but could not effectively relate this to the component of direction. A student (2.56%) demonstrated PS. Although they selected correct answers, their explanations reflected conceptual weaknesses, such as only considering direction without thoroughly integrating all the factors of momentum. For example, they believed that momentum changes when directions are opposite to each other, irrespective of equal mass, such as when two cars are travelling in opposite directions.

3.2. Sub-concept 2: Force and Change in Momentum

The following concept serves as the basis for assessing students' understanding of force and change in momentum: Newton's Second Law states that "an object's acceleration is inversely proportional to its mass and directly proportional to the net force exerted on it." This principle leads to the conclusion that an object's momentum will change when a net force is applied to it. The rate of change of momentum, which is represented by the following equation, equals the net force: $\sum \vec{F} = \frac{\Delta \vec{p}}{\Delta t}$. The figure illustrates the analysis results, showing the percentage of students' conceptual understanding as follows.

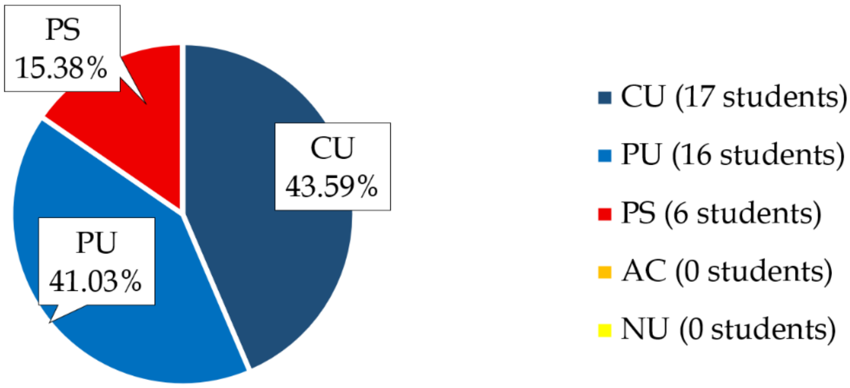

Figure 2.
Levels of Scientific Conceptual Understanding on the Topic of Force and Change in Momentum.

According to Figure 2, 17 students (43.59%) achieved CU, correctly explaining that a net force causes a change in momentum, for example, a force opposite the motion slows a car, altering its momentum. Meanwhile, 16 students (41.03%) showed PU, partly linking force to momentum change, but with incomplete reasoning, such as saying deceleration reduces the force of motion without a full explanation. The 6 students (15.38%) demonstrated PS, selecting correct answers but giving jumbled or incorrect reasoning, e.g., claiming the car slows because it touches the ground without clearly relating it to momentum change.

3.3. Sub-concept 3: Impulsive Force and Impulse

Students' conceptual understanding of Impulsive Force and Impulse is measured against the following concept: An Impulsive Force refers to a force applied to an object over a short period of time. Its unit is newton-second (N·s), and it can be expressed by the equation: $\sum \vec{F} = \frac{\Delta \vec{p}}{\Delta t}$. The product of the force and the time interval during which it acts is referred to as impulse. Impulse is defined as the effect of a continuous force acting over a specific period of time. A larger force applied over a shorter time interval, or a smaller force applied over a longer interval, can result in the same impulse. The unit of impulse is either kilogram meter per second (kg·m/s) or newton-second (N·s), and it is expressed by the equation: $I = mv - mu$. This shows that the change in momentum is equal to the impulse. Impulse can also be determined from the area under the force–time graph. The figure below presents the assessment results, indicating the percentage of students' conceptual understanding as follows.

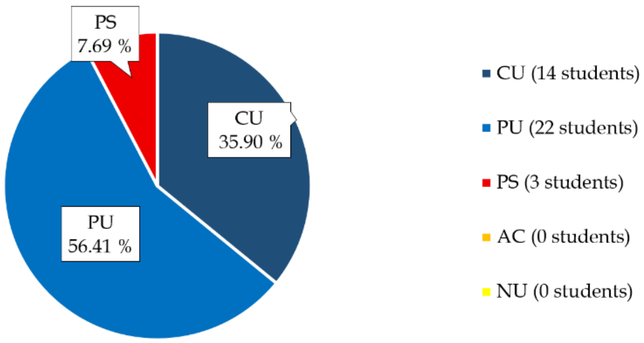

Figure 3.
Levels of Scientific Conceptual Understanding on the Topic Impulsive Force and Impulse.

As shown in Figure 3, a CU was demonstrated by 14 students (35.90%). These students made the correct options and were able to explain the scenario based on the definitions of Impulsive Force and Impulse. For example, they were aware that if a body is subjected to an Impulsive force for a limited duration, then the momentum is boosted, and the Impulse is equal to the change in momentum. The majority of the 22 students (56.41%) demonstrated PU. They selected the correct answers but were not able to clearly describe how an Impulsive Force leads to a change in momentum. For instance, they indicated that when someone is exposed to an Impulsive Force for a short period, their momentum will change. They cited the equation $I = \Delta P$ and noted that the change in momentum depends on the force and the time the force acts. Nevertheless, they lacked understanding. The 3 students (7.69%) exhibited PS. They applied the right formula but were unable to articulate explicitly the relationship between Impulse and the change in momentum. For example, they applied $I = \Delta P$ but defined the change in momentum as object- and time-dependent without explicitly relating it to the definition of Impulse.

3.4. Sub-concept 4: The Law of Conservation of Momentum

Measurement of students' conceptual understanding of the Law of Conservation of Momentum with respect to the following concept: In one-dimensional collisions between objects, when an external force does not act on the system or when the net external force is zero, every action force has an equal and opposite reaction force, i.e., action and reaction forces are opposite and equal. In all such cases, the total momentum of the system before collision is the same as the total momentum after collision, according to the postulate of conservation of momentum. This may be expressed as: $\sum \boldsymbol{p}_{before} = \sum \boldsymbol{p}_{\text{after}}$. The figure illustrates the results of the analysis and highlights the percentage of students who demonstrate conceptual understanding, as shown below.

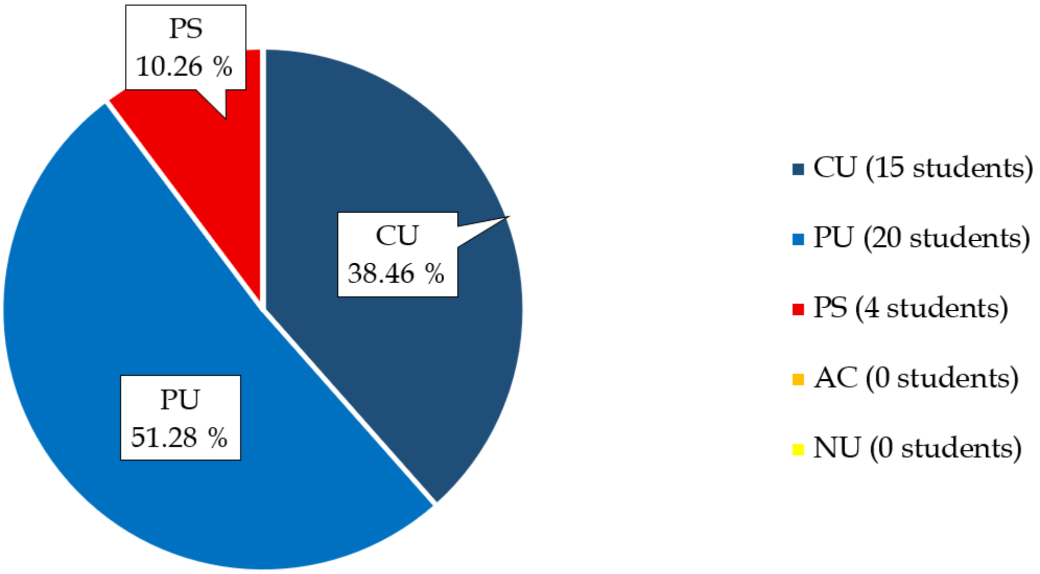

Figure 4.
Levels of Scientific Conceptual Understanding on the Topic of the Law of Conservation of Momentum.

According to the results summarized in Figure 4, 15 students, representing 38.46%, reached the level of CU. These students correctly identified the response and were able to describe the cart collision situation as an example consistent with the Conservation of Momentum. For instance, they pointed out that when two carts of equal mass approach each other at constant speed, the total momentum of the system before and after the collision is zero, which can be represented by the equation: $= \sum \vec{p_i} = \sum \vec{p_f}$. Additionally, twenty students, accounting for 51.28%, demonstrated a PU. They selected the correct answers and referred to the Law of Conservation of Momentum, but their explanations lacked clarity. For example, they mentioned that $\sum \vec{p_i} = \sum \vec{p_f}$, but did not elaborate on the implications or conditions of the principle, indicating an incomplete conceptual understanding. Conversely, four students, representing 10.26%, showed PS. These pupils chose incorrect answers or provided confused accounts. For instance, they stated that after the collision, the two objects rebound and become distorted upon impact, or that conservation of momentum only occurs when objects move in different directions. Some also mistakenly believed that the forces in the collision alter the momentum of the system.

3.5. Sub-concept 5: Elastic Collisions

Measurement of students' conceptual understanding of elastic collisions based on the following framework: An elastic collision occurs when one object strikes or impacts another over a short period, or in some cases, even when the objects do not physically touch but a force acts on one object, resulting in an effect similar to a collision. This type of interaction is still considered a collision. Most collisions involve some degree of external force acting on the objects, and the magnitude of this force depends on the nature of the collision. In one-dimensional collisions, both objects move along a straight line before and after the collision. The kinetic energy of the system during such collisions may be conserved or not. However, if the total kinetic energy of the system remains constant before and after the collision, the collision is defined as elastic. In elastic collisions, both the total kinetic energy and the total momentum of the system are conserved. This can be expressed by the following equations: $\sum p_{before} = \sum p_{after}, \sum k_{before} = \sum k_{after}$. Analysis of the test results is given in the pie chart below, indicating the percentage of conceptual understanding by students.

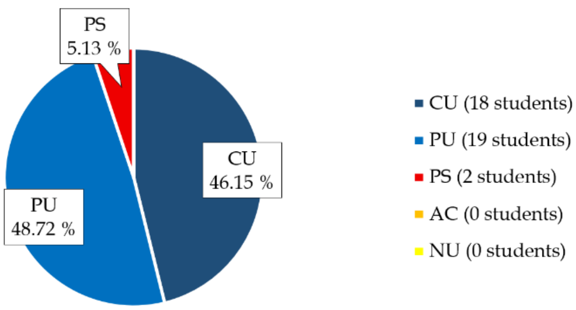

Figure 5.
Levels of Scientific Conceptual Understanding on the Topic of Elastic Collisions.

As shown in Figure 5, the 18 students (46.15%) demonstrated a CU of the concept. These students chose the correct answers and were able to justify the circumstances according to the definition of an elastic collision. For instance, they stated that after the impact, the objects changed velocities such that the total momentum and kinetic energy of all the objects before and after the collision remained the same. Another 19 students (48.72%) demonstrated a PU of the concept.

They selected the correct answers and could apply the principle of momentum conservation, but they could not clearly explain the process. For example, they recognized that momentum was conserved before and after the collision and that there was an exchange of velocities; however, their interpretation was incomplete. Meanwhile, 2 students (5.13%) showed a PS. Although their answer choices were correct and they provided some interpretation of the scenarios, they included incorrect information and/or omitted relevant details. Examples include explanations such as "the object with less mass moves along with the heavier object at the same speed" and "in an elastic collision between two objects, the faster object transfers its motion to the slower one," which indicate only a partial conceptual understanding of elastic collisions.

3.6. Sub-concept 6: Inelastic Collisions

The following framework underpins the assessment of students' conceptual understanding of Inelastic Collisions: an inelastic collision is any collision in which some of the kinetic energy is converted to other forms of energy during the collision. This can cause the colliding object to heat up, change shape, or even explode. The objects experience forces from the surrounding environment in most collisions, and the strength of these forces varies for each type of collision. A one-dimensional collision is a linear interaction where the objects move along the same straight line both before and after the collision. The external force exerted on the objects/system in such collisions exceeds the impulsive force of the objects involved; energy loss is observed in this type of collision. Thus, the system's total kinetic energy is not conserved. This type of collision is referred to as an inelastic collision. However, the linear momentum of the system remains conserved. The relationships can be expressed as follows: $\sum k_{before} > \sum k_{after}$,$\sum p_{before} = \sum p_{after}$. Analysis of test results is displayed in the following pie chart, which is a percentage measure of conceptual understanding.

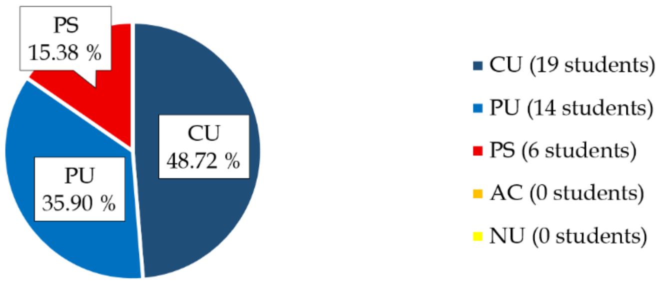

Figure 6.
Levels of Scientific Conceptual Understanding on the Topic of Inelastic Collisions.

According to Figure 6, 19 students (48.72%) achieved CU, selecting correct answers and accurately explaining collision principles. For example, they described an inelastic collision between two bodies of unequal mass moving linearly, noting that after sticking together, they moved in the direction of the greater momentum and that total kinetic energy decreased as expected. PU was shown by 14 students (35.90%). Though this subgroup also underlined the correct answers and used appropriate equations, their answers were incomplete and illegible. Some students displayed a limited understanding of the involved physics, for example, by incorrectly stating that the total kinetic energy before the collision is greater than the total kinetic energy after the collision ($\sum k_{before} > \sum k_{after}$). However, they did not elaborate on the conceptual explanation for this outcome in detail. The remaining 6 students (15.38%) fell into the PS category. Although they selected appropriate options, their explanations for the inelastic collision were either concise or conceptually weak. For example, they believed that some of the energy that is lost is used to generate electricity or wrongly assumed that the total momentum prior to the collision was greater than the total momentum after ($\sum k_{before} > \sum k_{after}$), and hence concluded that $\sum k_{before} > \sum k_{after}$ for the wrong reasons.

3.7. Sub-concept 7: Explosion

Conceptual understanding test of students for Explosion according to the concept below: the separation or disintegration of objects in one dimension, commonly referred to as an explosion, occurs in the absence of external forces and follows the same conservation conditions as those in both elastic and inelastic collisions. Specifically, the overall momentum of the system is conserved, which means that the sum of the momenta before and after the explosion is equal to $\sum p_{before} = \sum p_{after}$. Kinetic energy behaves differently, though. In contrast to inelastic collisions, where kinetic energy is partially lost, explosions typically result in an increase in total kinetic energy. Accordingly, the total kinetic energy after the explosion is greater than the total kinetic energy before the explosion: $\sum k_{before} < \sum k_{after}$. This increase is due to the conversion of stored internal energy, such as chemical or elastic potential energy, into kinetic energy during the explosion. As a result, the objects gain speed and move apart with a greater total kinetic energy than they originally possessed prior to separation. Analysis of test results is displayed in the following pie chart, which is a percentage measure of conceptual understanding.

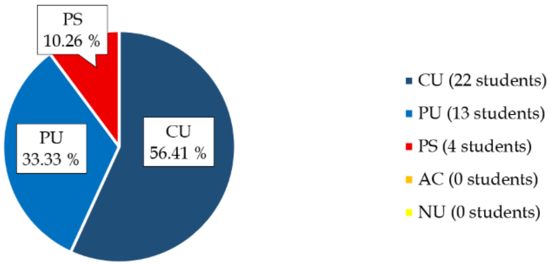

Figure 7.
Levels of Scientific Conceptual Understanding on the Topic of Explosions.

The results, as evident in Figure 7 indicate that 22 students (56.41%) demonstrated understanding of the principle in CU. These students selected the correct answers and were able to easily describe the situation in terms of the separation of objects, as per the One-dimensional Explosions principle. They correctly pointed out that if two pieces are shattering apart without an external force being used, the sum of momentum prior to and after the event is conserved ($\sum p_{before} = \sum p_{after}$). They also recognized that the total kinetic energy after the explosion exceeds that before it, as stored internal energy is converted into motion. Another 13 students (33.33%) showed PU; they chose correct answers but gave incomplete or unclear reasoning. For example, some stated that momentum in the x-direction must be zero due to no external forces, but failed to relate this properly to the explosion. Meanwhile, 4 students (10.26%) showed PS; although they selected correct options, their reasoning was flawed. Some wrongly believed objects always move in exactly opposite directions after separation, or offered oversimplified analogies like comparing it to an arrow leaving a stationary bow without invoking conservation principles.

4. Discussion

The findings show that students' scientific conceptual comprehension was improved by Cognitive Conflict-Based Learning (CCBL), as 76.92% of students achieved either PU or CU. This result demonstrates the effectiveness of teaching strategies that lead to cognitive conflict through situations contrary to students' preconceptions. This conflict sparks interest and motivation, prompting students to question their existing knowledge and actively build scientifically accurate concepts. The structure of Cognitive Conflict-Based Learning (CCBL) plays a vital role in fostering meaningful learning processes and facilitating conceptual change by encouraging students to reconcile discrepancies between their prior knowledge and new evidence [34, 35].

Particularly, salient processes such as questioning, presenting conflicts in realistic contexts, and peer discussion were accountable for conceptual change. These facilitated the learners' ability to transcend their primary misunderstandings and achieve a more accurate and enhanced understanding of the subject. These instructional practices not only deepened students' conceptual understanding of physics but also served them usefully in developing analytical thinking and problem-solving skills. This was very notable in learning settings where students were encouraged actively through the performance of experiments and guided group discussion that enabled collaborative investigation [36].

Concept analysis revealed that the students attained a maximum score of CU in two of the concepts. The first was the concept of Momentum, and 22 students (56.41%) achieved Complete Understanding. The students were able to equate the fundamental quantities of velocity, direction, and mass appropriately. The second concept, regarding the one-dimensional separation of objects in the case of an Explosion, was also recorded among 22 students (56.41%) at the CU level. They were able to explain the relationship between total momentum and kinetic energy before and after the event. Classroom observations revealed that, while teaching this subject, Complete Understanding students were seen to take time to interpret mock phenomena through scrutiny and comparison of quantities before and after object separation. The students took the time to discuss in groups and determine whether kinetic energy was preserved in both cases. These findings underscore the strength of a learning cycle that begins with hypothesis generation and is sustained by systematic experimental verification. Data analysis work and peer discussion allowed students to draw certain connections between theory concepts and experimental results. Outcome comparison and idea exchange also helped foster a better conceptual understanding of physics [37].

Overall, 23.08% of the students demonstrated a partial understanding within PS, indicating some weaknesses in the pedagogical approach. One potential weakness lies in the complexity of the scenarios used to generate cognitive conflict. When scenarios are too complex, they are likely to cause confusion rather than enable deep learning [38]. Additionally, class activities revealed that some students struggled with interpreting data and applying it to real-life situations. Some students, for instance, misread graphs or were unable to adequately describe quantitative data e.g., velocity or kinetic energy, about the experimental situations.

Additionally, students still hold misconceptions about the Law of Conservation of Mechanical Energy, even after being taught it. This is because students often overlook energy transformations in real-life situations, such as collisions or air resistance[39]. The topics with the highest percentage of students with Partial Understanding with PS included Force and Change in Momentum, as well as Inelastic Collisions. These topics, especially those concerning the direction of Force, Conversion of Energy, and the nature of Collisions, were the most challenging ones. Observations made during the lessons revealed that these topics were found to be highly abstract, and students required them to be connected to concrete, real-world applications. However, the majority of the students would resort to intuition or experience in reasoning through such problems, which ultimately resulted in conceptual muddles [19].

The concept on which most of the students showed PU was Impulsive Force and Impulse, as 22 students (56.41%) belonged to this category. Most of these students had been able to define the effect of Force on the Change in Momentum but did not have a complete understanding of the relationship between the variables. For instance, some understood Impulse only as the result of a short-time force but were not able to quantify it in relation to Momentum Changes. This reflects the need for creating learning activities to reinforce systems thinking and more profound conceptual connections. Activities explicitly illustrating how the strength of the force and the duration for which it is applied influence the Change in Momentum can be very significant to students' conceptual understanding of Impulse. Constraints were also seen in the application by students of their conceptual know-how to abstract situations. Most students did not demonstrate sufficient confidence in applying quantitative data to test hypotheses, instead relying on intuition or experience rather than physics principles [40]. For momentum, a significant percentage of students, 16 students, which is 41.03% could not define the direction of the momentum vector. This result highlights a common difficulty in helping students relate mathematical concepts, such as vectors, to physical phenomena. The difficulty is particularly exacerbated for students with poor mathematics backgrounds, making it challenging for them to apply quantitative thinking in a specific and meaningful manner to describe physics concepts [41].

Scientific concept learning, which incorporates the exposure of students to cognitive conflicts in an online environment, is also a determinant in facilitating a deep understanding of scientific concepts [42]. Interactions among students in class activities indicated that the use of cognitive conflict situations delivered through PhET simulations and other simulated scenarios played a significant role in prompting students to ask questions, reconsider their prior knowledge, and share ideas. These activities are essential in developing new conceptual knowledge. Group discussion, for example, enabled students to draw comparisons between their answers and those of others, engage in critical thinking, and justify their thoughts with greater depth and clarity [31, 43]. Encouraging students to pose questions that challenge their understanding and are discussed in group forums led to some productive exchanges of ideas. By comparing their own experiences with those of others and reflecting on their prior knowledge, students can critically re-examine and refine their misconceptions. This process helped students play an active role in developing a more accurate and scientifically acceptable understanding [44]. Additionally, Cognitive Conflict-Based Learning not only integrates scientific concepts with problem-solving in real-life scenarios but also fosters analytical thinking capabilities among groups. The necessity of having people justify their thinking to others helps them reflect on and refine their own concepts, moving closer to scientific understanding [45]. This type of learning also contributes to promoting creativity in students' analysis and problem-solving [62]. However, it was also discovered that the students lacked confidence in sharing ideas and were reluctant to ask questions. This might limit the conceptual change process, as confidence in knowing and being prepared for discussion is a significant factor affecting learning and altering students' conceptions [46].

This study finds Cognitive Conflict-Based Learning (CCBL) to be an effective tool for developing students' understanding of scientific concepts, particularly for concepts where well-crafted conflict-generating situations can be applied [47]. However, for more abstract and complex concepts such as impulse, conservation of momentum, and total energy the use of a variety of instructional media, including animations, videos of experiments, and simulation computer programs, is recommended to help students more effectively connect theoretical principles to everyday life. In addition, learning activities need to be tailored to suit the learners' environment, facilitating the systematic analysis and integration of scientific concepts.

5. Conclusion

This study demonstrates that Cognitive Conflict-Based Learning (CCBL) is highly effective in building concept knowledge of Momentum and Collisions among students. The approach is extremely successful in simulated environments and experimental comparisons where students can think in terms of variable interactions. However, the results also indicate that students still struggle with certain concepts, e.g., Force and Change in Momentum, Inelastic Collisions, and Energy Transformation during Collisions. These difficulties reflect the inherent complexity of relating abstract physical concepts to real-world phenomena. Study outcomes align with the research objectives through a learning process that actively engages students in situations challenging their existing knowledge. This enables students to formulate hypotheses, conduct experiments, analyze data, and engage in peer discussions. These processes help motivate the learner and empower them to construct meaning from direct experiences and evidence. Theoretically, this study contributes to the science learning domain by providing empirical support for constructivist theories, most notably, the function of cognitive conflict as a motivator of profound and long-term conceptual change. The findings validate the value of cognitively conflicting learning environments as a device for promoting scientific understanding of abstruse and intricate subject matter. Practically, the research offers valuable and interesting pedagogies that enable secondary school science teachers to enhance students' conceptual understanding. The findings also suggest fruitful directions for innovation in instructional design, e.g., using interactive simulations or video analysis to help students visualize and make sense of physical processes more effectively. Lastly, there is potential for future research to examine the implementation of CCBL in various educational contexts and with diverse student populations, further extending its generalizability of use and effects.

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