Phi: Jurnal Pendidikan Fisika dan Terapan
Vol. 12, No. 2 (2026) 302-315
ISSN: 2460-4348, e-ISSN: 2549-7162
https://jurnal.ar-raniry.ac.id/index.php/jurnalphi/index

Article Type: *original research*

Mapping Conceptual Transformation of Pre-Service Physics Teachers in Modern Physics Learning

Teuku Muhammad Hary Ramadhan[1*], Andi Mustari[2], Mawarni Saputri[1], Musdar Musdar[1], Dimas Fernanda[1]

[1]Department of Physics Education, Universitas Syiah Kuala, Banda Aceh, Indonesia
[2]Department of Electrical Network Installation and Maintenance, Akademi Komunitas Negeri, Aceh Barat, Indonesia

Correspondence E-mail: tmharyramadhan@usk.ac.id

ARTICLE INFO

Article History:
Received: 17 May 2026
Revised: 19 June 2026
Accepted: 21 June 2026
Published: 26 June 2026

Keywords:
Conceptual change; Conceptual Transformation; Five-Tier diagnostic test; Misconception; Modern physics

ABSTRACT

Misconceptions in modern physics remain a major challenge among pre-service physics teachers due to the abstract nature of the concepts. This study aimed to analyze misconceptions and conceptual transformation after implementing the Conceptual Change Model (CCM) in modern physics learning. A mixed-methods sequential explanatory design was conducted involving 55 pre-service physics teachers at the Department of Physics Education, Universitas Syiah Kuala. Data were collected using a five-tier diagnostic test and semi-structured interviews. The diagnostic test identified five conceptual categories: Scientific Conception (SC), Lack of Knowledge (LK), False Positive (FP), False Negative (FN), and Misconception (MC). Conceptual transformation was analyzed through changes in conceptual categories between pretest and posttest results. Findings showed that misconceptions dominated the pretest phase (38.2%), while Scientific Conception increased from 18.2% to 61.8% after CCM implementation. Misconceptions also decreased significantly from 38.2% to 12.7%. The highest complete conceptual transformation occurred in pair production (58.2%), whereas photon–gravity interaction showed dominant partial transformation due to its abstract characteristics. Interview results indicated that conceptual transformation occurred through dissatisfaction, intelligibility, plausibility, and fruitfulness stages. Overall, CCM effectively promoted conceptual restructuring and reduced misconceptions, while the five-tier diagnostic test provided comprehensive information regarding conceptual understanding, reasoning consistency, and confidence levels among pre-service physics teachers.

This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License

1. INTRODUCTION

One of the hardest subjects to study in physics is modern physics, which includes concepts like quantum mechanics and relativity. Understanding based on macroscopic conceptions in the context of contemporary physics frequently leads to mental models that are at odds with the behavior of matter at the atomic scale. Similar to this, the idea of relativity necessitates a paradigm change from an absolute to an observer-relative understanding of space and time. Because modern physics is still understudied and has many misconceptions, especially with regard to the ideas of X-rays, the photoelectric effect, and the Compton effect, it was selected as the subject of the study (Halim et al., 2021). It is challenging for pre-service physics teachers, in particular, to gain a solid

conceptual grasp because of its abstract, intangible, and frequently paradoxical qualities. Meanwhile, pre-service physics teachers' past knowledge has a significant impact on how they learn current physics. (Tene et al., 2024).

Misconceptions, or understandings that are at odds with scientific notions but that people perceive to be true, are frequently the result of this mismatch between scientific concepts and empirical experience. Because they are based on pre-existing knowledge systems, misconceptions in modern physics are frequently enduring and difficult to dispel. This persistence happens at all educational levels and is impacted by ordinary events and instructional media (López & Marco, 2022). Pre-service physics teachers' misconceptions must be eliminated right away, as they might last a long time and lower the standard of subsequent instruction (Ramadhan et al., 2026). Otherwise, this condition frequently results in low conceptual understanding and the persistence of misconceptions in modern physics learning, since many students struggle to comprehend the physical meaning of an equation and connect its mathematical formulation to the microscopic phenomena it represents (Mazlina et al., 2026). This is in line with the results of research by Zamboni et al. (2026), which found that a weak link between mathematical representations and physical notions is one of the primary causes of mistakes in physics learning. Because of this, misconceptions become a systemic problem that can affect the standard of physics education in general rather than just an individual one. Learning must balance the numerical and conceptual components because pre-service physics teachers frequently know how to compute, but may not fully comprehend it (Santosa, 2021).

The identification and categorization of misconceptions has been a major focus of physics education research over the last few decades. This method has significantly aided in mapping the different types of conceptual errors that students encounter. Nevertheless, the majority of this research continues to see misconceptions as static, only "mistakes" that must be fixed, without thoroughly analyzing how these beliefs alter or develop throughout the learning process. According to a more modern viewpoint, learning is a dynamic process that involves conceptual transformation. The process of substituting faulty scientific notions with accurate ones is known as conceptual transformation (Tolba & Youssef, 2024). Conceptual transformation entails a complicated process of knowledge restructuring, rearranging cognitive schemas, and integrating new and old knowledge rather than just substituting faulty responses with correct ones (Posner et al., 1982). Conceptual transformation entails the coexistence of old and new concepts, influenced by one significant factor: cognitive conflict, rather than the replacement of old concepts. (Rusli et al., 2025). To put it another way, conceptual transformation is a reflection of cognitive transformation, which is a basic shift in people's comprehension, reasoning, and interpretation of concepts. Since differences in students' cognitive styles are one of the sources of misconceptions, misconceptions and cognitive transformation are strongly related (Mustofa et al., 2024). Therefore, fostering cognitive conflict and using a conceptual change strategy are two ways to address misconceptions and cognitive transformation (Nurlailah et al., 2025; Okumuş & Güveli, 2023). The conversion of misconceptions into scientific knowledge is the biggest transformation (Güveli et al., 2022).

Despite the fact that conceptual transformation has been extensively researched, the majority of studies still concentrate on learning outcomes, such as increases in pretest and posttest scores. This method frequently ignores internal student processes, including cognitive conflict, doubt, meaning negotiation, and understanding reconfiguration. As a result, our knowledge of how misconceptions give way to scientific understanding is still lacking. Additionally, while widely used diagnostic instruments like two-tier and four-tier tests are good at spotting misconceptions, they are not very good at exposing metacognitive aspects, especially a person's degree of confidence in their responses. When evaluating the stability of understanding, this confidence is a crucial metric. While someone who answers poorly but with high confidence suggests the existence of deeply ingrained misconceptions, someone who answers properly but with low confidence does not necessarily have a solid comprehension. The Conceptual Change Model (CCM) is one teaching strategy that can enhance conceptual understanding and lessen misconceptions. Although Indonesia has the most papers about CCM in physics education, it is still lacking when it comes to modern physics. (Wati et al., 2025).

Unlike previous studies that primarily focused on identifying misconceptions or measuring learning gains through pretest-posttest scores, this study specifically maps the conceptual transformation pathways of pre-service physics teachers using a five-tier diagnostic test integrated with the Conceptual Change Model (CCM). This approach enables the identification of complete transformation, partial transformation, conceptual regression, and conceptual stability across modern physics concepts. Additionally, this study included a five-tier diagnostic test, which adds a more thorough dimension of beliefs to earlier diagnostic instruments. This instrument enables a deeper examination of pupils' understanding as well as their level of confidence in it. Therefore, this study is able to differentiate between strong misconceptions, weak knowledge, and steady scientific understanding.

2. METHODS

2.1 Research Design

This study examined conceptual change in pre-service physics teachers during modern physics learning using a mixed-methods approach with an integrated design. While the qualitative component was incorporated to offer a deeper understanding of the conceptual transformation process encountered by pre-service physics teachers, the quantitative component was utilized to find patterns of conceptual change through pretest-posttest analysis.

A one-group pretest-posttest design was used in this research. This methodology was selected since the goal of the study was to map the dynamics of conceptual transformation that takes place during the learning process rather than to evaluate the efficacy of a specific learning model. Although the one-group pretest-posttest design allows detailed mapping of conceptual transformation, the absence of a control group may introduce threats to internal validity such as maturation and testing effects.

The Conceptual Change Model (CCM) approach, which emphasizes cognitive conflict and conceptual reconstruction, served as the foundation for the design of the learning process. The learning strategy was viewed in this study as a learning setting to support conceptual transformation rather than as an independent variable. The one-group pretest-posttest design is displayed in Table 1.

Table 1. One-group Pretest-posttest Design

Class	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2

Description:
X: Conceptual Change Model (CCM)

Treatment was conducted using the CCM approach and guided by four conditions of conceptual transformation according to Posner et al. (1982); 1) Dissatisfaction with initial conceptions; 2) Intelligibility of new scientific concepts; 3) Logical and scientific plausibility of new concepts; and 4) Fruitfulness of concepts in explaining various physical phenomena.

The CCM approach is designed to stimulate cognitive conflict and conceptual restructuring. CCM emphasizes that students already possess initial concepts before formal learning. If these initial concepts are incorrect, they need to be confronted with scientific concepts through a process of conceptual change (Munawaroh et al., 2021). In the CCM model, the instructor acts as a facilitator, negotiator, and director of scientific concept formation. According to Sari et al. (2021), the CCM learning process consists of six stages: 1) Presentation of conceptual and contextual problems; 2) Misconception confrontation; 3) Confrontation denial; 4) Scientific proof of concepts and principles. 5) Representation and contextual examples; and 6) Confirmation through questions. Figure 1 shows the research design in this study.

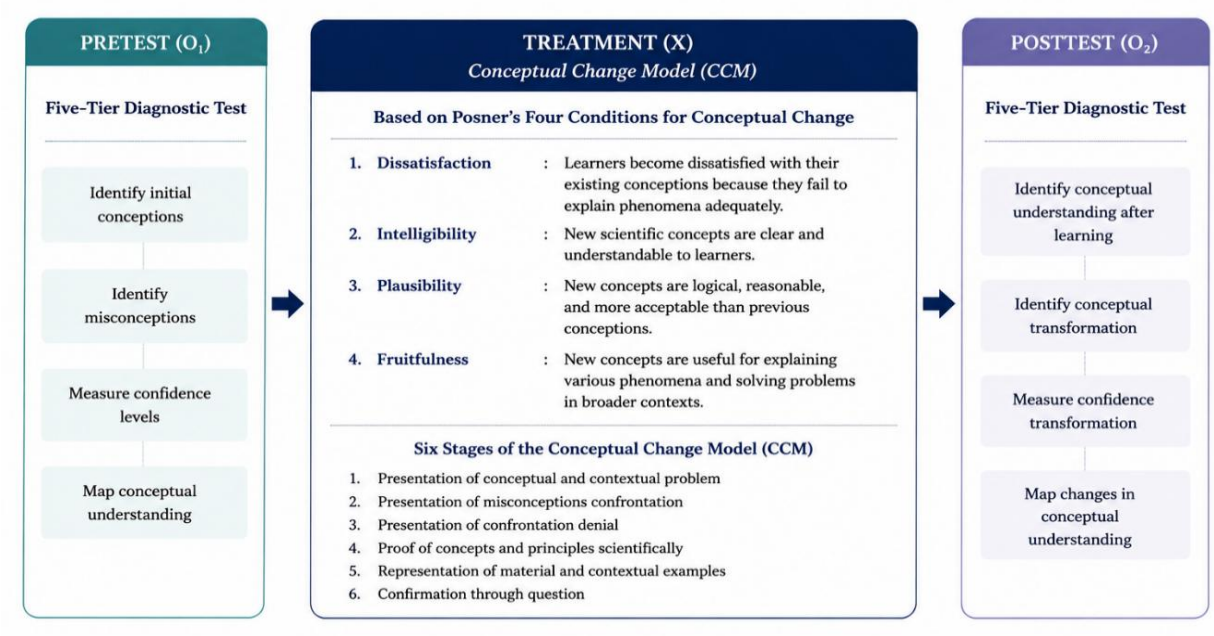


Figure 1. Research Design

2.2 Research Participants

Pre-service physics teachers enrolled in the Modern Physics course at Syiah Kuala University's Department of Physics Education participated in this study. Purposive sampling was used to choose participants based on their involvement in the course during the study's semester. Both the quantitative and qualitative stages involved 55 pre-service physics teachers. A pretest and posttest were used for the quantitative phase, while semi-structured interviews were used for the qualitative phase.

2.3 Research Instruments

2.3.1 Five-Tier Diagnostic Test

Converting a four-tier test into a five-tier test with response confirmation at the fifth level in the form of image or conclusion questions can strengthen the analysis of misconceptions and students' conceptual knowledge (Hidayatullah & Mufit, 2023). The advantage of this five-tier diagnostic test is its ability to produce more detailed tracking data, resulting in more accurate conclusions (Royani & Setyarsih, 2022). While the five-tier multiple-choice test was created with learning needs in mind, the inclusion of additional instruments to identify misconceptions enables users to perform more thorough analysis and boost learning efficacy (Dirman et al., 2022). Additionally, by identifying certain misconceptions and comprehending their underlying causes, this instrument facilitates more focused and successful learning interventions (Triani & Fahlani, 2024). Previously, misconception identification often used conventional diagnostic tests, such as the two-tier test. However, these instruments were limited in revealing the depth of students' understanding and level of confidence. Therefore, the five-tier diagnostic test was developed, which can analyze answers, reasoning, level of confidence, and cognitive patterns more comprehensively (Musdar et al., 2025).

In this study, we used a five-tier diagnostic test instrument developed by Asnidar et al. (2026). The instrument was validated by expert lecturers and tested on pre-service physics teachers of Physics Education. The validation results showed a very high level of content validity with a CVL value of 1.00 and IRA = 1.00. The reliability of the instrument was in the moderate category with a Cronbach's Alpha value ranging from 0.54 to 0.64, which was considered sufficient for diagnostic purposes. In addition, the responses of lecturers and pre-service physics teachers showed that the instrument was very practical to use in digital-based learning. The modern physics topics in the instrument consisted of 5, namely: 1) X-rays; 2) Photoelectric Effect; 3) Compton Effect; 4) Pair Production; and 5) Photon–Gravity Interaction. Although six-tier diagnostic instruments have

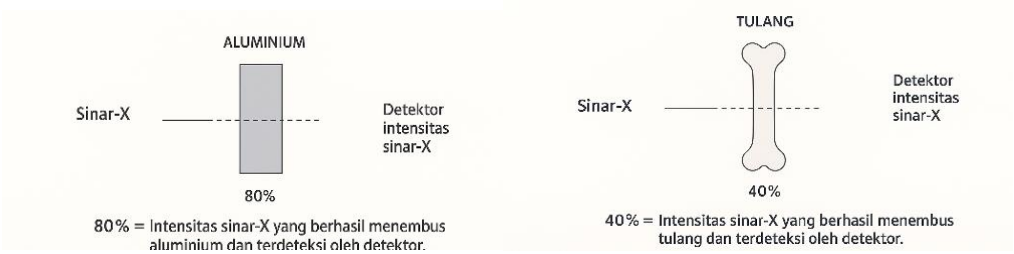
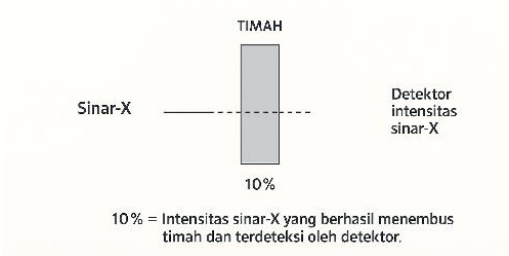
recently been introduced, the five-tier diagnostic test was selected because it sufficiently captures answer accuracy, reasoning quality, confidence level, and source of conception, which directly support the objective of conceptual transformation mapping.

Table 2 presents the structure of the five-tier diagnostic test instrument, while Table 3 provides examples of instruments developed and used in this study.

Table 2. Structure of The Five-Tier Diagnostic Test Instrument

Tier	Description
Tier 1	Multiple-choice answers
Tier 2	Level of confidence in the answer
Tier 3	Reason
Tier 4	Level of confidence of reason
Tier 5	Source of conception

Table 3. Examples of Instruments Developed

Tier	Content
Tier 1	Look at the following image!   **Image Source:** Bushberg, J. T., Seibert, J. A., Leidholdt, E. M., & Boone, J. M. (2012). The Essential Physics of Medical Imaging (3rd ed.). Philadelphia: Lippincott Williams & Wilkins. Based on the data in the image above, which material absorbs the most X-rays? A. Aluminum B. Bone C. Tin D. All materials have the same penetrating power
Tier 2	How confident are you in your answer to the previous question? A. Sure B. Not Sure
Tier 3	What is the best reason to support your answer to Tier 1? A. Materials with low transmissivity will absorb more X-rays, resulting in a lower transmitted X-ray intensity. B. Materials with high transmissivity will absorb more X-rays, resulting in a higher transmitted X-ray intensity. C. All materials have the same X-ray absorption capacity, so the difference is only due to the intensity of the X-ray source. D. D. X-ray transmissivity is unrelated to the material's ability to absorb X-rays, so the results are random.

Tier	Content
Tier 4	How confident are you in the reason you chose? A. Sure B. Not Sure
Tier 5	Explain the relationship between the penetration power of X-rays and the ability of materials to absorb X-rays, based on the results of observations of X-ray images that penetrate aluminum, bone, and lead!

2.3.2 Interview Guidelines

Semi-structured interviews were conducted to explore students' conceptual transformation processes in greater depth. The interviews focused on: 1) Dissatisfaction; 2) Intelligibility; 3) Plausibility; and 4) Fruitfulness.

2.4 Data Analysis Technique

2.4.1 Misconception Analysis

The results of the five-tier diagnostic test, which included the responses, explanations, and confidence levels of pre-service physics teachers with respect to the responses and explanations provided, were used to conduct misconception analysis. The goal of this analysis was to more thoroughly determine the conceptual conditions of pre-service physics teachers based on the consistency of reasoning and the degree of conceptual confidence, in addition to the accuracy of the answers. The conceptual conditions of pre-service physics teachers were classified into five categories, namely: 1) Scientific Conception (SC); Lack of Knowledge (LK); False Positive (FP); False Negative (FN); and Misconception (MS). Table 4 shows the levels of conception based on the combination of answers for the five-tier diagnostic test, according to Fatonah et al. (2022).

Table 4. Combination of Responses in the Five-Tier Diagnostic Test

Tier					Level of Conception
1	2	3	4	5	
0	S	0	S	Books, online resources, teachers, observations, personal reasoning, explanations from others, and various additional sources.	MC
1	S	1	S	Books, online resources, teachers, observations, personal reasoning, explanations from others, and various additional sources.	SC
1	S	0	S	Books, online resources, teachers, observations, personal reasoning, explanations from others, and various additional sources.	FP
0	S	1	S	Books, online resources, teachers, observations, personal reasoning, explanations from others, and various additional sources.	FN
1	S	1	NS	Books, online resources, teachers, observations, personal reasoning, explanations from others, and various additional sources.	LK
1	NS	1	S		
1	NS	1	NS		
1	S	0	NS		
1	NS	0	S		
1	NS	0	NS		
0	S	1	NS		
0	NS	1	S		
0	NS	1	NS		
0	S	0	NS		

Tier					Level of Conception
1	2	3	4	5	
0	NS	0	S		
0	NS	0	NS		

Description:

0	: False	LK	: Lack of Knowledge
1	: True	FP	: False Positive
S	: Sure	FN	: False Negative
NS	: Not Sure	MC	: Misconception
SC	: Scientific Conception		

The data was analyzed using the following equation (Ramadhan et al., 2026):

$$P = \frac{f}{N} x100\% \quad (1)$$

Description:
P = represents the percentage of a category
F = denotes the frequency of responses within a specific category
N = refers to the total number of samples

2.4.2 Conceptual Transformation Analysis

Based on changes in pre-service physics teachers' conceptual states as determined by the pretest and posttest findings of the five-tier diagnostic test, conceptual transformation analysis was carried out. The purpose of this analysis is to determine the dynamics of conceptual changes made by pre-service physics teachers following their participation in Conceptual Change Model (CCM) learning. The interpretation of conceptual transformation based on changes in the conceptual levels of pre-service physics teachers is displayed in Table 5.

Table 5. Interpretation of Conceptual Transformation Based on Changes in the Level of Conception

Conceptual Transformation	Transformation Category	Interpretation
MC → SC	Complete Transformation	Misconceptions turn into stable scientific understandings
LK/FP/FN → SC	Complete Transformation	Understanding develops into a scientific conception
MC → FP/FN/LK	Partial Transformation	Conceptual improvements have occurred but are not yet stable.
FP/FN/LK → FP/FN/LK	Partial Transformation	There has been a change in understanding, but it is still inconsistent
SC → SC	Not Undergoing Transformation	Scientific understanding remains stable
MC → MC	Not Undergoing Transformation	Misconceptions persist
SC → FP/FN/LK/MC	Conceptual Regression	There is a decline in the quality of conceptual understanding

The number and percentage of pre-service physics teachers in each conceptual change pattern were determined to conduct conceptual transformation analysis. Additionally, the interpretation of the stability of the conceptual transformation was strengthened by the confidence levels of the pre-service physics teachers. The distribution of conceptual transformation categories, the percentage change in misunderstandings, and an interpretation of the pre-service physics

instructors' conceptual transformation patterns during modern physics training were the next three presentations of the analysis's findings.

This research clarifies conceptual transformation as a movement from misconceptions to a more solid and significant scientific understanding, in addition to a change in right and wrong replies.

3. RESULT AND DISCUSSION

3.1 Misconception

Based on the findings of a five-tier diagnostic test at the pretest and posttest stages, a misconception analysis was carried out to get a thorough picture of the pre-service physics teachers' conceptual knowledge. The photoelectric effect, the Compton effect, X-rays, pair production, and photon-gravity interaction are some of the fundamental ideas in modern physics that served as the foundation for the development of the test apparatus. The analysis took into account the logic, degree of confidence, and consistency of conceptual comprehension for each concept assessed in addition to the accuracy of the pre-service physics teachers' responses.

Through this analysis, the pre-service physics teachers' conceptual understanding was classified into five categories: Scientific Conception (SC), Lack of Knowledge (LK), False Positive (FP), False Negative (FN), and Misconception (MC). This classification was used to identify the stability of scientific understanding and the patterns of misconceptions experienced by pre-service physics teachers in modern physics material. Overall, the percentages of pre-service physics teachers' conceptual categories based on the results of the five-tier diagnostic test are presented in Table 6.

Table 6. Percentage of Conceptual Categories of Pre-service Physics Teachers

Conceptual Categories	Pretest (%)	Posttest (%)	Change (%)
SC	18.2	61.8	+43.6
LK	21.8	10.9	-10.9
FP	12.7	9.1	-3.6
FN	9.1	5.5	-3.6
MC	38.2	12.7	-25.5

Based on Table 6, the Misconception (MC) category was the most dominant conceptual condition in the pretest stage, with a percentage of 38.2%. These results indicate that most pre-service physics teachers still hold understandings that are inconsistent with scientific concepts in modern physics materials. The misconceptions that emerged were generally accompanied by a high level of confidence, thus indicating that these misconceptions are stable. This finding is in line with research on four-tier and five-tier diagnostic tests, which stated that misconceptions accompanied by high confidence indicate a strong but unscientific conceptual structure (Istiyono et al., 2023; Triani & Fahlani, 2024).

The Lack of Knowledge (LK) category was also found at a fairly high percentage of 21.8%. This indicates that some pre-service physics teachers do not yet have an adequate basic understanding of modern physics concepts. This condition supports the view that modern physics concepts are abstract, non-intuitive, and difficult to visualize for Pre-service physics teachers (Vosniadou, 2013). Meanwhile, the Scientific Conception (SC) category was only found at 18.2% in the pretest. This percentage indicates that only a small percentage of pre-service physics teachers have a correct and stable scientific understanding before the learning process begins. This low initial scientific understanding of modern physics concepts has also been found in various previous studies related to X-rays, the photoelectric effect, and relativity (Sudirman et al., 2023; Triani & Fahlani, 2024).

After implementing the Conceptual Change Model (CCM), there was a significant increase in the Scientific Conception (SC) category to 61.8%. This 43.6% increase indicates that most pre-service physics teachers successfully reconstructed their initial conceptions toward a more stable scientific understanding. This finding supports the theory by Posner et al. (1982), which states that conceptual

change occurs when students experience cognitive conflict and begin to accept new, more scientifically sound concepts.

In contrast, the Misconception (MC) category experienced a significant decrease from 38.2% to 12.7%. This 25.5% decrease indicates that the CCM approach is effective in facilitating conceptual change in pre-service physics teachers through cognitive conflict and knowledge restructuring. These results align with research in Physics Education Research, which shows that cognitive conflict-based learning can significantly reduce misconceptions in abstract physics concepts (Chi, 2008; DiSessa, 2014).

False Positive (FP) and False Negative (FN) categories also decreased, although not significantly. This finding indicates that some pre-service physics teachers still experience inconsistencies between their answers, reasoning, and confidence levels after the lesson. According to Bao (2006), this condition indicates that Pre-service physics teachers are still in the conceptual transition stage or intermediate conceptual states, a state where conceptual restructuring is not yet fully stable.

Overall, the results of the study indicate that the implementation of CCM can improve the scientific understanding of pre-service physics teachers and reduce the level of misconceptions in modern physics learning. Furthermore, the use of the five-tier diagnostic test allows for a more comprehensive identification of conceptual changes in Pre-service physics teachers because it not only analyzes correct and incorrect answers but also considers the reasoning and level of conceptual beliefs of Pre-service physics teachers (Istiyono et al., 2023; Triani & Fahlani, 2024).

3.2 Conceptual Transformation

To obtain a more specific picture of the patterns of misconceptions and conceptual transformations in each modern physics topic, further analysis was conducted based on the concept indicators contained in the questions. This analysis aimed to identify which topics had the highest levels of misconceptions and which underwent the most significant conceptual transformations after implementing the Conceptual Change Model (CCM).

The topics analyzed included the photoelectric effect, the Compton effect, X-rays, pair production, and photon-gravity interactions. The percentage of misconceptions and conceptual transformations in each topic was obtained from the changes in pre-service physics teachers' conceptual categories between the pretest and posttest using the results of the five-tier diagnostic test. The results of this analysis are presented in Tables 7 and 8.

Table 7. Percentage of Misconceptions Based on Modern Physics Material

Modern Physics Material	SC (%)	LK (%)	FP (%)	FN (%)	MC (%)	Dominant Category
Photoelectric Effect	21.8	18.2	10.9	9.1	40.0	MC
Compton Effect	20.0	16.4	12.7	10.9	40.0	MC
X-ray	18.2	20.0	10.9	12.7	38.2	MC
Pair Production	16.4	21.8	9.1	10.9	41.8	MC
Photon–Gravity Interaction	14.5	23.6	10.9	12.7	38.3	MC

Table 8. Percentage of Conceptual Transformation Based on Modern Physics Material

Modern Physics Material	No Transformation (%)	Partial Transformation (%)	Complete Transformation (%)	Regression (%)	Dominant Category
Photoelectric Effect	10.9	27.3	54.5	7.3	Complete Transformation
Compton Effect	12.7	30.9	47.3	9.1	Complete Transformation
X-ray	14.5	34.5	43.7	7.3	Complete Transformation
Pair Production	9.1	25.5	58.2	7.2	Complete Transformation
Photon–Gravity Interaction	18.2	36.4	36.3	9.1	Partial Transformation

Based on Table 7, the Misconception (MC) category is the dominant conceptual condition in all modern physics materials. The highest percentage of misconceptions was found in pair production material at 41.8%, followed by the photoelectric effect and the Compton Effect at 40.0%. While the lowest percentage was found in Photon-Gravity Interaction at 38.3%. The high misconceptions in these concepts indicate that modern physics is still a difficult material to understand because it is abstract, microscopic, and contrary to the daily experiences of pre-service physics teachers. This condition is in line with the results of research by Winarni et al. (2026) which showed that misconceptions on modern physics topics and abstract concepts are still dominant among Pre-service physics teachers in physics education. In the photoelectric effect material, pre-service physics teachers tend to experience misconceptions related to the relationship between light intensity and photon energy. Some pre-service physics teachers still believe that light intensity determines electron release, not light frequency. This finding is consistent with the research on the development of a five-tier diagnostic test in modern physics by Winarni et al. (2026), who reported that the photoelectric effect is one of the concepts with a high level of misconception among Pre-service physics teachers.

Meanwhile, based on Table 8, the majority of pre-service physics teachers experienced a complete conceptual transformation after participating in learning using the Conceptual Change Model (CCM). The highest percentage of complete conceptual transformation observed in pair production (58.2%) may be explained by the strong cognitive conflict generated when pre-service physics teachers were confronted with the scientifically accepted concept of mass–energy conversion. Before instruction, many participants believed that matter and energy were fundamentally different entities and could not be transformed into one another. The pair production phenomenon directly challenged this misconception by demonstrating that a high-energy photon can generate an electron–positron pair. This contradiction between prior beliefs and scientific evidence created a powerful sense of dissatisfaction, which is considered the first prerequisite for conceptual change according to Posner et al. (1982).

Furthermore, the plausibility and intelligibility components of the Conceptual Change Model (CCM) played a critical role in facilitating conceptual transformation. The explanation of pair production through Einstein's mass–energy equivalence principle ($E = mc^2$), supported by visual representations and quantitative reasoning, enabled participants to perceive the new conception as both logical and scientifically valid. Consequently, many pre-service physics teachers successfully replaced their initial misconceptions with stable scientific conceptions. This finding supports previous studies suggesting that conceptual change is more likely to occur when abstract physics concepts are accompanied by explicit cognitive conflict, coherent scientific explanations, and meaningful conceptual reconstruction processes (Chi, 2008; Tolba & Youssef, 2024). In the Photon–Gravity Interaction topic, partial transformation was the dominant category. This indicates that the concept of Photon–Gravity Interaction remains difficult to fully restructure because it involves highly abstract concepts of space-time and gravity.

Therefore, the application of the Conceptual Change Model (CCM) in this study is relevant because it can facilitate conceptual change through cognitive conflict, scientific evidence, and gradual reconstruction of understanding. In addition to reducing misconceptions about modern physics, this approach also supports the development of critical and adaptive thinking patterns needed by prospective teachers in the era of Artificial Intelligence and the Industrial Revolution 4.0 (Hasanuddin et al., 2025).

3.3 Interview Analysis Results

According to the results of the interviews, the majority of pre-service physics teachers encountered cognitive conflict when their preconceived notions ran counter to scientific explanations during the course. At first, pre-service physics teachers were confident in their knowledge, especially with regard to wave-particle dualism and the photoelectric effect. However, pre-service physics teachers started to recognize that their preconceived notions were insufficient to provide a scientific explanation for physical phenomena after being confronted with challenging issues and debates centered on conceptual conflict.

A potential pre-service physics teacher said:

"At first, I thought that whether or not electrons could escape from metal depended on the strength of the light. I became aware that my prior understanding was flawed after hearing about the threshold frequency".

These results suggest that pre-service physics teachers' conceptual shift begins with the onset of "dissatisfaction" with early notions.

In terms of Intelligibility, after experiencing cognitive conflict, pre-service physics teachers began to understand new scientific concepts through conceptual explanations, visual representations, and scientific discussions during the lesson. Regarding the concept of Compton scattering, pre-service physics teachers began to understand that light is not only a wave but also has particle properties that can carry momentum. One pre-service physics teacher explained:

"Previously, I had difficulty understanding why the wavelength of light could change after a collision. After the illustration of a photon and an electron explained it, I began to understand the process."

These results indicate that the use of visual representations and contextual explanations helped pre-service physics teachers understand abstract concepts of modern physics more clearly and logically.

In the Plausibility aspect, interview results indicated that pre-service physics teachers began to accept new scientific concepts when they were perceived as more reasonable than their initial conceptions. In the pair production material, pre-service physics teachers began to understand that energy can be converted into particle mass based on Einstein's mass-energy equivalence principle.

One pre-service physics teacher stated:

"At first, I found it hard to believe that energy could be converted into particles. But after the relationship between the energy of a gamma photon and the mass of an electron-positron was explained, the concept made more sense."

These findings indicate that pre-service physics teachers began to reconstruct their thinking frameworks and accept new scientific concepts as more rational explanations for modern physics phenomena.

In the final aspect (fruitfulness), conceptual transformation was seen when pre-service physics teachers were able to use new scientific concepts to explain other phenomena more broadly. In the topic of general relativity, several pre-service physics teachers began to be able to connect the concept of relativistic gravity with the phenomena of gravitational redshift and the deflection of light.

One pre-service physics teacher stated:

"Now I'm starting to understand why light can be deflected by gravity and why its frequency changes when it exits a gravitational field."

However, some pre-service physics teachers still had difficulty applying the concept of general relativity to other contexts because the concept was considered too abstract and difficult to visualize.

In general, the interview results indicated that the conceptual transformation of pre-service physics teachers occurred gradually, progressing through cognitive conflict, understanding new concepts, acceptance of scientific concepts, and finally the ability to use these concepts to explain modern physics phenomena more broadly. This finding supports the quantitative results that the implementation of the Conceptual Change Model (CCM) was able to facilitate pre-service physics teachers' conceptual transformation in modern physics instruction.

In addition, the results support recent systematic review findings reported by Wati et al. (2025), which highlighted that cognitive conflict-based learning strategies are among the most effective approaches for addressing misconceptions in physics education. The high percentage of complete conceptual transformation identified in this study suggests that conceptual change does not occur solely through the transmission of information but through active reconstruction of prior knowledge. This finding reinforces the view that conceptual understanding in modern physics requires instructional approaches capable of challenging students' existing beliefs while simultaneously providing scientifically acceptable alternative explanations. Consequently, the Conceptual Change Model (CCM) can be considered a promising instructional framework for improving conceptual understanding in abstract and complex physics topics.

4. CONCLUSION

This study provides evidence that the Conceptual Change Model (CCM), when integrated with a five-tier diagnostic test, can effectively promote meaningful conceptual transformation among pre-service physics teachers in learning modern physics. The results suggest that CCM contributes not only to the reduction of misconceptions but also to the development of scientifically accurate conceptions through processes of cognitive conflict, conceptual refinement, and knowledge reconstruction. In addition, the five-tier diagnostic test proved valuable in capturing diverse patterns of conceptual change, including complete transformation, partial transformation, conceptual regression, and conceptual stability.

Nevertheless, several limitations should be considered when interpreting these findings. The study was conducted with participants from a single institution and utilized a one-group pretest-posttest design without a comparison group, which may restrict the broader applicability of the results. Moreover, the investigation was limited to selected topics in modern physics and evaluated conceptual transformation only in the short term following instruction. Future studies are encouraged to involve more diverse participant populations, employ comparative or experimental research designs, explore a wider range of modern physics concepts, and investigate the long-term retention and stability of conceptual change through delayed posttest evaluations.

REFERENCES

Bao, L. (2006). Model analysis: Assessing the dynamics of student learning. *Physical Review Special Topics - Physics Education Research*, *2*(1), 010103. https://doi.org/10.1103/PhysRevSTPER.2.010103

Chi, M. T. H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *International Handbook of Research on Conceptual Change* (pp. 61–82). Routledge.

Dirman, H. M., Mufit, F., & Festiyed, F. (2022). Review and Comparison of Four-Tier Multiple Choice and Five-Tier Multiple Choice Diagnostic Tests to Identify Mastery of Physics Concepts. *Jurnal Penelitian Pendidikan IPA*, *8*(1), 1–12. https://doi.org/10.29303/jppipa.v8i1.838

DiSessa, A. A. (2014). A history of conceptual change research: Threads and fault lines. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 88–108). Cambridge University Press. https://doi.org/10.1017/CBO9781139519526.007

Fatonah, U., Maison, M., & Hidayat, M. (2022). Development of Five-Tier Diagnostic Test to Identify Misconception in Rigid Body Equilibrium. *Berkala Ilmiah Pendidikan Fisika*, *10*(2), 199–206. https://doi.org/10.20527/bipf.v10i2.13077

Güveli, H., Baki, A., & Güveli, E. (2022). The Impact of the Cognitive Conflict Approach on the Elimination of the Misconception in Square Root Numbers. *Education Quarterly Reviews*,

5(Special Issue 2), 39–52. https://doi.org/10.31014/aior.1993.05.04.604

Halim, A., Nurhasanah, Zainuddin, Musdar, Elisa, Mahzum, E., & Irwandi, I. (2021). Student's misconception and thinking style on modern physics course. *Journal of Physics: Conference Series*, *1882*(1), 1–8. https://doi.org/10.1088/1742-6596/1882/1/012018

Hasanuddin, N., Amalia, D. F., Hary, T. M., & Ramadhan, H. Q. (2025). Do Generation Z Pre-Service ESL Teachers Perceive Artificial Intelligence Negatively? Rasch Analysis. *Afeksi: Jurnal Penelitian Dan Evaluasi Pendidikan*, *6*(4), 787–800.

Hidayatullah, & Mufit, F. (2023). Five-Tier Multiple-Choice Instrument for Assessing Students' Understanding of the Straight Motion. *Indonesian Journal of Educational Research and Review*, *6*(2), 250–265. https://doi.org/10.23887/ijerr.v6i2.52366

Istiyono, E., Dwandaru, W. S. B., Fenditasari, K., Ayub, M. R. S. S. N., & Saepuzaman, D. (2023). The Development of a Four-Tier Diagnostic Test Based on Modern Test Theory in Physics Education. *European Journal of Educational Research*, *12*(1), 371–385. https://doi.org/10.12973/eu-jer.12.1.371

López, A. I. M., & Marco, P. T. (2022). Misconceptions, Knowledge, and Attitudes Towards the Phenomenon of Radioactivity. *Science and Education*, *31*(2), 405–426. https://doi.org/10.1007/s11191-021-00251-w

Mazlina, H., Silviana, F., Mustika, C. R., & Maulida, M. (2026). Development of An AI-Assisted Instructional Video for The Schrodinger Equation in Modern Physics. *Re-JIEM (Research Journal of Islamic Education Management)*, 397–409. https://doi.org/10.19105/re-jiem.vi.24270

Munawaroh, A., Wilujeng, I., & Hidayatullah, Z. (2021). Physics Learning Instruction Based on the Conceptual Change Model for Senior High Schools. *Proceedings of the 6th International Seminar on Science Education (ISSE 2020)*, *541*(ISSE 2020), 441–446. https://doi.org/10.2991/assehr.k.210326.063

Musdar, M., Hamid, A., & Saputri, M. (2025). Identifikasi Miskonsepsi Mahasiswa Fisika Menggunakan Five-Tier Diagnostic Test (FTDT) Pada Materi Kesetimbangan Benda Tegar. *GRAVITASI: Jurnal Pendidikan Fisika Dan Sains*, *8*(01), 31–38. https://doi.org/10.33059/gravitasi.jpfs.v8i01.11494

Mustofa, H. A., Zain, Z. A., Tsania, H., Azman, M. N. A., Marmoah, S., & Masfuah, S. (2024). Analysis of Students' Conceptions Based on Cognitive Style on Newton's Law Understanding. *Jurnal Pendidikan IPA Indonesia*, *13*(2), 301–312. https://doi.org/10.15294/jpii.v13i2.4230

Nurlailah, Utama, R., Mustava, O., Toifur, M., & Dina, D. F. (2025). Exploring Misconceptions of Light and Shadow Formation among Senior High School Students: A Qualitative Study in Physics Education. *Kasuari: Physics Education Journal (KPEJ)*, *8*(2), 370–379. https://doi.org/10.37891/kpej.v8i2.1028

Okumuş, M. G., & Güveli, E. (2023). Elimination of Misconceptions about Percentages with the Cognitive Conflict Approach. *Journal of Computer and Education Research*, *11*(21), 162–192. https://doi.org/10.18009/jcer.1223434

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, *66*(2), 211–227. https://doi.org/10.1002/sce.3730660207

Ramadhan, T. M. H., Mustari, A., Mustika, C. R., & Haya, F. (2026). Misconceptions of Prospective Physics Teachers in Heat Concepts: Implementation of Three-Tier Diagnostic Tests (TTDT). *Jurnal Kajian Pendidikan IPA*, *6*(1), 50–62. https://doi.org/10.52434/jkpi.v6i1.43204

Royani, A., & Setyarsih, W. (2022). Development of Google Form-Based Five-Tier E-Diagnostic Test to Identify Conception Levels and Track Students' Misconceptions on Thermodynamics Materials. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *10*(3), 450–465. https://doi.org/10.33394/j-ps.v10i3.5209

Rusli, M., Nursalim, M., Rahmasari, D., Putri, R., Wardana, M. D. K., Putri, R. A. R., & Yulia, N. M. (2025). Cognitive Processing and Neurodevelopmental Perspectives on Misconceptions in Elementary Science Education: A Comprehensive Analysis. *Jurnal Penelitian Pendidikan IPA*, *11*(11), 86–97. https://doi.org/10.29303/jppipa.v11i11.13003

Santosa, I. E. (2021). Analysing Students' Problem Solving Skills on The Topics of Modern Physics. *Journal of Physics: Conference Series*, *2019*(1), 1–6. https://doi.org/10.1088/1742-

6596/2019/1/012026

Sari, N. P. E. A., Santyasa, I. W., & Gunadi, I. G. A. (2021). The Effect of Conceptual Change Models on Students' Conceptual Understanding in Learning Physics. *Jurnal Pendidikan Fisika Indonesia*, *17*(2), 94–105. https://doi.org/10.15294/jpfi.v17i2.27585

Sudirman, S., Ningsih, N. J., Saparini, S., Ariska, M., Andriani, N., & Pasaribu, A. (2023). The Identification of Misconceptions of Physics Education Students at Universitas Sriwijaya Using Four-Tier Diagnostic Test on Static Fluid Material. *Journal of Mathematics, Science, and Computer Education (JMSCEdu)*, *3*(1), 26–33. https://doi.org/10.20527/jmscedu.v3i1.8664

Tene, T., Bodero-Poveda, E., López, D. V., Gomez, C. V., & Bellucci, S. (2024). Assessing the State of Modern Physics Education: Pre-test Findings and Influencing Factors. *Emerging Science Journal*, *8*(Special Issue), 1–19. https://doi.org/10.28991/ESJ-2024-SIED1-01

Tolba, E. G. A., & Youssef, N. H. (2024). Conceptual Change and Developing Mental Motivation in Physics: Effects of Transformational Learning Theory. *International Journal of Instruction*, *17*(4), 359–384. https://doi.org/10.29333/iji.2024.17421a

Triani, E., & Fahlani, I. (2024). Five-Tier Format Misconception Diagnostic Instrument: Systematic Literature Review. *EduFisika: Jurnal Pendidikan Fisika*, *9*(3), 113–121. https://doi.org/10.59052/edufisika.v9i3.38725

Vosniadou, S. (2013). *International handbook of research on conceptual change* (2nd ed.). Routledge. https://doi.org/10.4324/9780203154472

Wati, E., Samsudin, A., Saepuzaman, D., & Sozbilir, M. (2025). Trend of Applying the Conceptual Change Model in Physics Learning: Systematic Literature Review. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *14*(1), 131–143. https://doi.org/10.24042/jipfalbiruni.v14i1.26130

Winarni, S., Asnidar, V., Halim, A., Nurulwati, Musdar, & Ramadhan, T. M. H. (2026). Development of a Google Forms-Based Five-Tier Diagnostic Test for Identifying Misconceptions in Modern Physics. *JTP - Jurnal Teknologi Pendidikan*, *28*(1), 113–131. https://doi.org/10.21009/jtp.v28i1.66006

Zamboni, A., Marzari, A., Malgieri, M., Onorato, P., & Oss, S. (2026). A diagnostic multiple-choice questionnaire on student misconceptions about relativity in classical mechanics. *European Journal of Physics*, *47*(1), 1–17. https://doi.org/10.1088/1361-6404/ae2e5d