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Making Sense of Force and Motion: Insights into Grade 10 Students' Construction of Scientific Explanations

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Abstract
Scientific explanation, defined as the ability to describe natural phenomena using empirical evidence through claims, evidence, and reasoning, is essential in physics learning as it supports the exploration of natural phenomena and strengthens conceptual understanding. This study aimed to evaluate students' scientific explanation skills in force and motion experiments. The sample consisted of 36 Grade 10 students from a secondary school in Thailand, selected through cluster random sampling. Data were collected using a rubric-based test assessing claims, evidence, and reasoning analysed using mean and percentage and one-sample t-test to compare students' mean scores against a predetermined criterion level. The analysis revealed that the students' mean scientific explanation score was 4.25 (35.42%), reflecting a low level of ability and being significantly lower than the 75% criterion. When broken down by component, the students' average scores were as follows: Claims scored 2.69 (67.37%) indicating a moderate level; Evidence scored 0.83 (20.83%) and Reasoning scored 0.72 (18.06%), both of which indicated a low level. Given these findings, scientific explanation is a critical skill for enhancing student learning, particularly in the areas of evidence and reasoning. Future research should explore instructional approaches, such as inquiry-based or cognitive conflict-based learning, to strengthen these skills and examine their development across broader contexts.
Keywords: Scientific Explanation, Scientific Conception, Science Education, Teaching Physics, Secondary School Students

Introduction

Scientific literacy in the 21st century refers to the ability to understand scientific concepts and processes sufficiently to make informed decisions, analyze events, and participate effectively in a society driven by science and technology. Therefore, scientific literacy has become a key goal of science education, as it provides a fundamental basis for improving the quality of human life and enabling individuals to live successfully in modern society. According to the Programme for International Student Assessment (PISA) framework, competencies that reflect scientific understanding consist of three key aspects: the ability to explain scientific phenomena, design and evaluate

scientific investigations, and interpret data and use scientific evidence logically. These competencies relate to the ability to investigate, analyze, evaluate, and apply scientific information in order to make informed decisions in various real-life situations. Among these competencies, explaining scientific phenomena is considered a fundamental component, as it directly involves rational thinking processes in identifying the causes of phenomena and drawing conclusions based on empirical evidence (McNeill & Krajcik, 2008a).

The ability to construct scientific explanations plays a crucial role in developing students' higher-order thinking skills, as the process of explanation requires data analysis, the integration of scientific concepts, and the use of reasoning to systematically support conclusions. These skills contribute to the development of creativity, problem-solving abilities, scientific communication, and evidence-based argumentation (McNeill & Krajcik, 2008a). Construction of scientific explanations allows students to communicate their understanding of the world on a scientific level (De Andrade et al., 2019; Laliyo et al., 2023). To understand phenomena, scientific explanations are important as they depend on evidence as well as observed and tested evidence (Ruiz-Primo et al., 2010). A scientific explanation is not merely a description of what happened but rather a process that is based on data, evidence, and reasoning to arrive at a scientific answer (McNeill & Krajcik, 2008b). In general, a scientific explanation consists of three parts: a claim, which is a clear and logical answer to the question asked; evidence, which is the data that is used to make the claim; and reasoning, which is a link between the evidence and the claim by applying what science or theories is telling it (McNeill et al., 2006). If the students' scientific explanations lack any of the three elements, then the quality of what they believe is scientific is not as good. For example, if students are able to identify a claim but cannot provide supporting evidence, the conclusion may remain merely an opinion or conjecture lacking scientific credibility. Conversely, if students can identify both a claim and supporting evidence but cannot explain the reasoning that connects the evidence to the claim based on scientific principles, they may be unable to demonstrate a genuine conceptual understanding of the phenomenon. As a result, learning may remain at the level of memorizing facts rather than developing meaningful conceptual understanding (Lee et al., 2025; Sanimkam et al., 2024). Constructing scientific explanations is therefore central to science learning, as it helps students develop a deeper understanding of scientific concepts and promotes important skills such as reasoning, questioning, analysing evidence, and synthesizing data to reach credible conclusions. Practicing the process of scientific explanation also fosters systematic thinking, evidence-based practice, and a scientific attitude, which are important foundations for learning in the 21st century (Tang, 2016).

In the context of physics education, physics plays a crucial role in explaining natural phenomena and forms the foundation of modern technology. Essential concepts that students need to understand include motion and force, which are central to many fundamental laws of physics, such as Newton's laws of motion, the law of universal gravitation, and the principle of conservation of energy. Knowing the concepts is not only about numerical calculations; it is important to be able to reason and connect physics concepts with real-world events (Cashata et al., 2022; Chen et al., 2021; Lee & Park, 2013). However, in physics education we have found that many students are still struggling with the scientific reasoning of physics concepts and how to apply physics concepts in the context of other applications such as projectile motion analysis or problems with Newton's laws of motion. The students find it difficult to connect theoretical concepts with the explanations of real-world phenomena in order to understand them at the level of physics theories (Docktor & Mestre, 2014; Etkina et al., 2023; Srisa & Cojorn, 2025). Many physics topics, including mechanics, thermodynamics, and electromagnetism, are not only abstract but also very conceptually challenging to understand, so students find it challenging to identify the conceptual framework and how different physical variables relate (Dessie et al., 2023; Potvin & Bélanger, 2024). Despite the recognized importance of these skills, there remains a significant gap in pedagogical research regarding how students specifically structure their reasoning

when faced with complex, multi-variable physics problems. Most existing studies focus on general science contexts, leaving a lack of detailed empirical evidence on the specific obstacles students encounter when articulating the 'Reasoning' component in physics-specific explanations. Given the importance of constructing scientific explanations for science and physics learning, this study aims to analyze students' ability to construct scientific explanations in detail. The explanation is then examined in a very quantitative way: claims, evidence, reasoning, etc. It should be useful to see how we are doing with students' ability to construct scientific explanations, to see what they are doing well and where we could improve our science and physics teaching practices in the future.

Methodology

Samples

The sample consisted of 36 Grade 10 students from a secondary school in Maha Sarakham Province, Thailand, during the first semester of the 2025 academic year. The participants were selected through cluster sampling from a population of 120 students, in which one classroom from the science–mathematics track was chosen. Students in this track are systematically assigned to classrooms with mixed academic abilities, and all classes follow the same curriculum and assessment standards. Therefore, the selected classroom is considered representative of the typical academic distribution and learning environment of Grade 10 students within the school. Participation in the study was voluntary, and informed consent was obtained from all students prior to data collection.

Research Instruments

The research instrument consisted of a short-answer test designed to assess students' ability to construct scientific explanations. The test comprised two items focusing on the topic of gravitational acceleration. Each item was developed based on contextualized scenarios and experimental situations. Each question was structured to elicit the three essential components of scientific explanation, as proposed by McNeill and Krajcik (2008a): claim, evidence, and reasoning. The instrument was adapted from the work of Kansa et al. (2021). Content validity was examined by a panel of experts using the Index of Item-Objective Congruence (IOC), with 0.89. The overall appropriateness of the instrument was 4.96, indicating an acceptable level of validity for educational research. The score was interpreted by scoring rubrics of scientific explanation showed in Table 1.

Table 1 The Scoring Rubrics of Scientific Explanation

Component	Scores		
	2	1	0
Claims	Make a correct and complete claim or summary	Make a claim or summary, but only partially	Make a claim or summary, but it is incorrect
Evidence	Presents relevant and sufficient evidence to support the claim	Presents evidence that is somewhat relevant but insufficient to support the claim	Does not present evidence or presents irrelevant evidence
Reasoning	Logically connects evidence and claim with correct and sufficient scientific reasoning	Partially connects evidence and claim; includes reasoning using scientific principles, but insufficient.	Provide reasoning or provides reasoning that does not logically link the evidence and the claim

Data Collection and Analysis

The methods by which the study was designed and accomplished were structured in the following ways: Based on this first, some literature review was conducted to lay the theoretical basis and build the research instrument. Second, the Scientific Explanation Test was developed and completed by the participants. As the measure of student performance, a scoring rubric was used to evaluate the accuracy and depth of the students' conceptual understanding in relation to the three components (Claim, Evidence, and Reasoning). The quantitative

data were analysed using descriptive statistics, including mean, standard deviation, percentage and one-sample t-test to compare students' mean scores with a predetermined criterion level of 75%. Moreover, the students' mean scores were classified into Low (<50%), Moderate (50–74%), and Good (>75%) proficiency groups. In addition, a qualitative exploration of representative students' responses was conducted. By understanding similar but not identical response forms, the researchers got a more complete picture of the students' reasoning processes and explanations, giving them information beyond the numerical data.

Result and Findings

This study examined the level of grade 10 students' ability to construct scientific explanations. It had 36 students involved in it. Table 2 gives a summary of the overall distribution of students' scientific explanation ability, where 4 students (11.11%) were classified as high level of ability, 6 students (16.67%) were classified as medium level, and 26 students (72.22%) were classified as low level. When comparing students' ability at different proficiency levels according to their part of the profile, some differences were there. For the claim component, the highest proportion of students was at the good level. In contrast, only three students (8.33%) reached the good level in evidence and two students (5.56%) in reasoning. Most students were at the low level in evidence (83.33%) and reasoning (80.56%), while eight students (22.22%) were at the low level in claims. These distributions are shown in Figure 1.

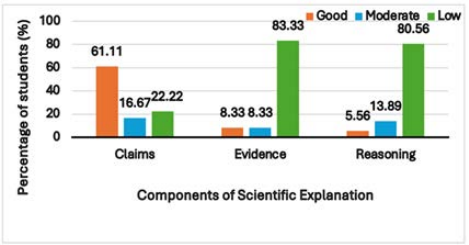

Figure 1 Percentage of Students (%) at Each Proficiency Level by Component

Table 2 The Results of the Analysis of Scientific Explanations

Components	N	Full score	Mean (%)	S.D.	t	p-value	Levels
Claims	36	4	2.69 (67.37)	1.21	-1.58	.123	Moderate
Evidence	36	4	0.83 (20.83)	0.91	-16.74*	.000	Low
Reasoning	36	4	0.72 (18.06)	1.00	-12.14*	.000	Low
Scientific explanations	36	12	4.25 (35.42)	2.71	-10.38*	.000	Low

*p < 0.05

The analysis revealed that the students' mean scientific explanation score was 4.25(35.42), which was significantly below the 75% criterion. Similarly, the Evidence and Reasoning components were also significantly lower than the criterion, while the Claims component did not differ significantly from the 75% benchmark. When considering the overall performance across components, the mean score for the claim component was at the moderate level, indicating that students demonstrated a moderate level of understanding and ability in formulating appropriate claims. On the contrary, the mean scores for the evidence and reasoning components were low level. The mean scores for all components show the relative strengths and weaknesses of students in the creation of scientific explanations. The claim component had the highest mean score of 2.69(67.37%), and the students were generally able to make statements or draw conclusions by answering the questions. The evidence component had the lowest mean score of 0.83(20.83%), which means students are not able to use scientific data to support their claims. The reasoning component was the least able component to explain the evidence with science, as it has an average of 0.72(18.06%), and students are not able to understand with science what is going on and so cannot make a claim. As a whole, students show that their strongest component of building scientific explanations is making claims, but they struggle to provide evidence or to present reasoning. These findings are consistent with previous studies (e.g., Ruiz-Primo et al., 2010) that show that students are better able to make claims than to provide evidence and scientific reasoning.

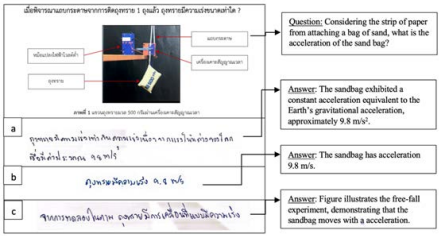

Figure 2 Examples of Student Answers in Claims at Different Levels

Student responses to the free-fall sandbag experiment (Figure 2) were divided into three groups. As can be seen from Figure 2a, the students in the top group have a complete understanding of gravity and can give correct numerical results by using the correct SI units (9.8 m/s²), which is in line with the principle that in free fall, (except for air resistance) all objects have a constant acceleration. In the bottom group (Figure 2b), we know the force of gravity on Earth (9.8 m/s²), but there are no technical details for the use of the SI units. This suggests that they are aware but not very well informed—in other words, they do not talk about science explicitly. Finally, as shown in Figure 2c, a part of the population was unable to give a clear conclusion, highlighting the major cognitive obstacles in translating observed physical phenomena into structured scientific knowledge and a lack of grasp of fundamental kinematics.

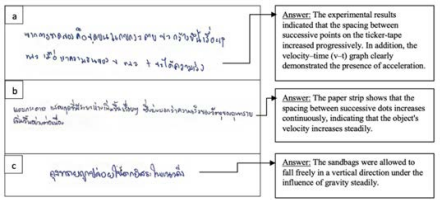

Figure 3 Examples of Student Answers in Evidence at Different Levels

Students' ability to provide scientific evidence to support their claims showed different levels of understanding, as illustrated in Figure 3. The students in the high-level group (Figure 3a) were able to find empirical evidence consistent with the experimental scenario and tie the results to the claims they made. The students in the moderate-level group (Figure 3b) found evidence that they made, such as the increasing movement of positions between them over time, but did not make a logical fit between those observations and their claims. As can be seen in Figure 3c, many students struggle to provide good evidence (even to make the correct claims). Most students will simply describe experiments rather than provide any specific data or results in detail. This is a conceptual barrier to differentiate between a description of the methodology and the empirical evidence.

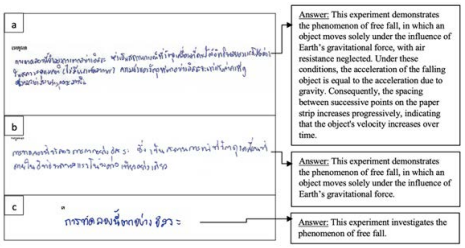

Figure 4 Examples of Student Answers in Reasoning at Different Levels

As can be seen from the students' reasoning answers in Figure 4, there are different levels of their understanding of the scientific principles to the real data (see also Table). As far as we can see in Figure 4a, in the high-level group students were able to articulate a coherent reasoning in which they connected the evidence and the claim. For example, in the high-level reasoning group (Figure 4b) they clearly stated that for the constant gravitational acceleration g to be maintained, the position must be shifted from one place to another over equal time intervals. But in the moderate-level students (Figure 4c) they were only able to identify the scientific principle (for example, that the gravitational acceleration is constant), and they could not explain how that scientific principle was used to explain the real data. This suggests a continuing problem of integrating claims and evidence into a coherent logical framework.

The results of this study suggest that the ability to construct scientific explanations (based on McNeill and Krajcik's framework) is an important skill that comprises three key components: Claim, Evidence and Reasoning. The results show that it is still a challenge for students in physics education to generate scientific explanations in terms of evidence and reasoning. This is consistent with the findings of this study, which show that students struggle to link evidence to reasoning.

Discussion

Most students showed moderate to low ability in building scientific explanations based on research data and reasoning. In fact, students struggled harder on the evidence and reasoning part while they were better on the claim part of the study. This may be because physics education is very much teacher-centered in nature and students are used to getting the right answer or plugging numbers into the formula, rather than investigating the phenomenon on the basis of science and evidence, so we do not get to see students in a situation where they start to experience the cognitive process of linking what they are learning in a scientific way when they are trying to understand this more abstract way (Kansa et al., 2021). Also, science teaching in Thailand still is very much a teacher-centered environment where more often than not the assessment methods are based on rote memorization rather than on higher-order thinking skills. This environment restricts students' growth in scientific explanation and argumentation (Uthaikanchanakul et al., 2025), and is in line with Venville and Dawson who noted that learning to construct scientific explanations is a skill that needs to be cultivated by continuous inquiry and classroom discussion.

Regarding the claim component, a significant number of students were able to draw conclusions from the experimental scenario of free-falling sandbags. Students categorized at the "good" level accurately stated the numerical value of Earth's gravitational acceleration, demonstrating a solid conceptual grasp. However, those at the "moderate" level often struggled with technical precision, such as omitting or misapplying units, which rendered their responses incomplete. These findings support the assertion by McNeill and Krajcik (2006) that making a claim is the most accessible element of a scientific explanation for students, as it aligns with their habit of seeking a single "correct" conclusion.

The evidence part, however, was more difficult. Only a small percentage of students could provide empirical evidence that was relevant and compelling. The good students were able to connect what they expected experimental data with their claims, while many others simply substituted real data with a description of the experimental procedure. This suggests a fundamental misconception of students. Students tend to view the action of an experiment as evidence itself, not data generated by that action. This is in line with Kansa et al. (2021), who identified the link between data and concepts as a key obstacle in physics education and highlighted Osborne et al. (2016) that there is a need for specific analytical skills that need to be explicitly learned through real-world data engagement.

The reasoning part was the most difficult for students, and it was the biggest gap in their understanding. High-performing students could identify the scientific principles (e.g., Newton's laws or gravity) that link evidence to claims, but the moderate-level students often gave circular reasoning: simply repeating the claim in different words, without a logical "bridge." When students fall back to procedural explanations rather than conceptual ones, it implies that students do not have the "scaffolding" to translate abstract physics theories into logical arguments. This is consistent with Osborne et al. (2016) who found that it was reasoning that is the most cognitively demanding part of scientific literacy. And as Berland and Reiser (2015) have suggested, building strong reasoning skills requires a culture of scientific argumentation and evidence to justify conclusions in the classroom. Appropriate instructional activity design by teachers effectively promotes the development of students' scientific explanations and thinking competencies in a concrete manner (Cojorn & Sonsupap, 2024). Therefore, teachers should understand and design activities that align with the learners' context.

Conclusion

Developing a scientific explanation is a significant aspect of how well students learn the information presented to them as science. On this study's assessment most students show low-medium level of understanding when constructing a scientific explanation; all students tended to have good levels of understanding with claims but poor level of understanding with evidence & reasoning. Based on these results it seems that students may have the rudimentary knowledge needed for science, however their inability to connect empirical evidence to scientific principles demonstrates that they do not

yet possess the skills needed to build an effective and logical scientific explanation.

This study contributes to understanding the characteristics of students' scientific explanation abilities through the Claim–Evidence–Reasoning (CER) framework, which helps identify areas for improvement in physics teaching. Although this study has limitations due in part to its sample being taken from one classroom's environment and used research-specific assessments for evaluation, it provides opportunities to enhance evidence based practice in instruction. Furthermore, there is a need for researchers to assist teachers in developing instructional strategies that facilitate science-based reasoning and use of evidence. Additionally, assessments need to be designed for measuring students' reasoning abilities with better accuracy and effectiveness in order to support continued development of students' thinking and knowledge about science.

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