IJSES International Journal of Studies in Education and Science

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# Pre-Service Teachers' Scientific Explanations of Evaporation: A Deductive Analysis of Causal Reasoning Levels

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## Article Info

***Article History***

Received:
14 September 2025

Revised:
18 November 2025

Accepted:
17 December 2025

Published:
1 January 2026

***Keywords***

Scientific explanation
Pre-service teachers
Causal reasoning
Deductive analysis

## Abstract

The purpose of this study was to examine the levels of causal reasoning in pre-service elementary teachers' scientific explanations of the evaporation phenomenon. A case study approach was adopted and a total of fourteen first-year university students enrolled in a primary teacher education program at a state university in Turkey. Individual interviews were conducted with students who volunteered, and each student was asked to explain why spilled water on a table dries up over time. Students' explanations were analyzed deductively based on a coding framework adapted from Braaten and Windschitl. The results indicated that while students can identify and describe the observable aspects of evaporation, they struggle to articulate a comprehensive scientific explanation that addresses the underlying causal mechanisms at a molecular or theoretical level. The findings highlighted the need for instructional strategies at middle and high school levels that explicitly target the development of scientific reasoning skills, especially those that help students link macroscopic observations to molecular-level processes and integrate these with established scientific theories.

***Citation:*** Saglam, Y. (2026). Pre-service teachers' scientific explanations of evaporation: A deductive analysis of causal reasoning levels. *International Journal of Studies in Education and Science (IJSES), 7*(1), 12-24. https://doi.org/10.46328/ijses.5655

## Introduction

### The Birth and Importance of Scientific Explanation

Deficiencies in the logical coherence of conclusions and in the regulation of volitional control appear to represent two central features of what Boas (1901) described as primitive cognition. To illustrate (Levy-Bruhl, 1923), a missionary in New Zealand recounted an encounter with a native man who was gravely ill, most likely due to exposure to cold and a lack of proper care. Rather than attributing his condition to natural causes, the man—as was common among his community—explained his suffering as the work of Atua, a spiritual being or deity. He believed that Atua resided within him, consuming his vital organs. In early societies (Ibid, 1923), people's ideas about themselves, their group, and the world were more about feelings and experiences than causal reasons. These ideas didn't follow strict logic, so nothing seemed fixed or definite. When we try to think about them like we do with ordinary objects, we miss the emotions and important experiences behind them. This is why it can be hard to understand the rules, traditions, and ways of life in these societies—they are based more on feelings and beliefs than on logical thinking.

However, beginning in the sixth century BCE, Greek philosophers initiated a significant intellectual shift by seeking to account for natural phenomena not through appeals to supernatural powers, but rather by examining their inherent causal relations (Russ, 2011). The antic Greek philosophers established a new intellectual path by seeking natural explanations independent of godly intervention. They regarded as valid only what could be observed or demonstrated, deriving one natural phenomenon from another. In this way, events such as earthquakes or lightning were no longer interpreted as signs of Zeus' or Poseidon's anger, but as occurrences that required rational and observational evidence. Their commitment to criticism and reasoned debate further strengthened this new approach, as philosophers challenged one another's ideas and refined their arguments. By the sixth century BCE, these practices had created intellectual conditions for a scientific attitude toward reality, thereby laying groundwork for the emergence of science. Although these early efforts were still rudimentary and far from the systematic rigor of modern science, they nonetheless marked a foundational departure from mythological worldviews. In this sense, they may be regarded as the first tentative steps toward the development of scientific explanation.

However, this worldview of ancient Greece did not gradually and smoothly evolve into an accepted and science-oriented mode of thought. With the adoption of Christianity as the official religion in the West, this perspective was largely abandoned. Scientific activity was instead pursued based on religious texts or in ways intended to support them. However, in the 16th century, with the revival of Greek texts—a return to earlier traditions, so to speak—the perspective on nature shifted once again. The God-centered conception of the universe gave way to an understanding that placed nature at the center (Cucen, 2005). It is in this period that we first observe the presence of systematic observation and reasoning. Francis Bacon (1561–1626) stated (Ozpek, 2019) that science rests on three fundamental principles: it is based on observation or experimentation, scientific knowledge is acquired through induction, and science both produces and is sustained by practical outcomes. His views played a revolutionary role in the development of natural sciences. In contrast to approaches that emphasized human reason and relied on a priori knowledge as a starting point—deriving theories from such prior assumptions and applying them to life through deduction—Bacon insisted that knowledge could only emerge through observation and experimentation through induction. Thus, modern science was born.

From that point on, scientists could no longer advance ideas arbitrarily; they were required to support their claims with empirical evidence. McNeill and Krajcik (2008) stated that science is, at its core, concerned with explaining phenomena by identifying the mechanisms through which they occur, the conditions under which they arise, and the consequences they produce. To them, for instance, ecologists may seek to explain the decline in species diversity within an ecosystem, while astronomers may account for the phases of the Moon by examining the relative positions of the Sun, Earth, and Moon. In constructing explanations and advancing claims, scientists support their arguments with evidence and reasoning to justify their conclusions and to persuade the scientific community of their validity. Therefore, a scientific explanation requires that any claim be supported through the establishment of a causal connection with empirical data. In other words, a truly scientific explanation, therefore, demands the establishment of a causal relationship between any claim and the data that supports it.

The fact that the emergence of scientific explanation in human history took such a long time demonstrates that it is not an innate capacity of human beings and, also, that it cannot be discovered through individual reasoning and effort alone. Further to that, scientific understanding is achieved through grasping correct scientific explanations (Strevens, 2013), meaning that there is no path to understanding without explanation. According to McNeill and Krajcik (2008), to develop scientific literacy, students must engage in analogous forms of inquiry. They should be able to understand and critically evaluate explanations presented in public discourse—such as those found in newspapers, magazines, or news broadcasts—to assess their credibility and accuracy. For example, a news article may assert that stem cell research is essential for advancing human health and treating disease. Students must therefore cultivate the ability to analyze such claims by scrutinizing the evidence and reasoning on which they are based. This capacity enables students to make informed and reasoned decisions as scientifically literate citizens. The explicit or implicit teaching of scientific explanation in schools is therefore of critical importance, and teachers should be highly attentive to this task. It is equally vital that teachers themselves possess a thorough understanding of this concept. Accordingly, this study seeks to examine the extent to which the current teacher candidates possess the ability to construct scientific explanations. A similar study by Sakyi-Hagan (2024) found that approximately 61.4% of the pre-service science teachers' scientific explanations were predominantly descriptive and rooted in everyday reasoning, making them informal and lacking the use of formal scientific language.

## Theoretical Frameworks

### Evaporation

In a liquid, molecules are in constant motion and collide with one another, resulting in a continuous exchange of kinetic energy. Because of these collisions, molecules in the liquid have a wide distribution of speeds: some move very rapidly while others move slowly. As the temperature of the liquid increases, the average kinetic energy of the molecules rises, which means more molecules have higher speeds. When faster-moving molecules collide with slower ones, they can transfer some of their kinetic energy, causing some surface molecules to gain enough energy to overcome the attractive forces holding them in the liquid phase. If a surface molecule gains sufficient kinetic energy through these collisions, it can break free from the liquid and move into the gas phase. Once free, these molecules escape into the space above the liquid and become part of the vapor, which is called evaporation. Therefore, evaporation occurs because molecular motion and collisions cause some surface molecules to gain enough energy to overcome intermolecular forces, allowing them to transition from the liquid to the gas phase (Burdge, 2017; Hewitt, 2021; Zumdahl & DeCoste, 2017).

In the 2024 Turkish Science Curriculum (M.E.B., 2024), the concept of phase change, specifically evaporation, is introduced for the first time at the 4th grade level, within the unit Matter and Its Changes. In this unit, it is emphasized that evaporation occurs as an effect of heat. Students are expected to conduct experiments and make observations on phase changes of matter, including melting, freezing, evaporation, and condensation, all driven by heat transfer. While performing experiments, students are required to take necessary safety precautions. They are also guided to record the qualitative data they collect during experiments and observations related to phase changes. Based on the collected data, students are expected to interpret and evaluate which phase change occurs because of heat absorption or heat release, using cause-and-effect reasoning. In the 5th grade, phase changes driven by heat are addressed under the Nature of Matter unit. In this unit, it is emphasized that there is continuous heat exchange between substances in nature (thermal equilibrium), that evaporation can occur at any temperature, and that while evaporation can happen at any temperature, boiling occurs only at a certain temperature. At the middle and high school level, the curriculum assumes that students have prior knowledge of the concept of evaporation, so no particular emphasis is given to this concept at these grade levels.

**Scientific Explanation**

Various perspectives on scientific explanation have emerged within the philosophy of science, including the Covering Law Model proposed by Hempel and Oppenheim in 1948, Probabilistic Explanation by Hempel in 1966, Explanatory Unification put forth by Friedman in 1974 and later by Kitcher in 1997, and the Causal Model presented by Salmon in 1978, among others. This diversity in definitions arises from the different ways scientists explain phenomena in practice. Scientists often utilize laws to explain natural occurrences. In such cases, the explanation consists of a series of explanans (a set of covering laws or nomological explanations) and an explanandum (a description of the phenomenon). The explanans offer causal reasons for the occurrence of the explanandum, expressed through statements as natural laws. For instance, consider why someone feels cool as they dry off after getting wet. The thin layer of water left on the skin after getting wet evaporates, which is a cooling process (explanan). This evaporation leads to a drop in body temperature, resulting in a sensation of coolness (explanandum). In a valid scientific explanation, certain logical conditions must be met: the explanandum must logically stem from the explanans, causal relations must be met, and the explanans must involve general laws that are true and empirically testable.

However, not all natural phenomena can be explained solely through laws, but probability. Scientific explanations for phenomena like weather patterns, the likelihood of a baby's gender, or the risk of cancer involve different kinds of explanations. For instance, medical professors often use statistical data to explain scientific phenomena.

Imagine a doctor explaining to a patient the effectiveness of a particular drug for a specific disease by stating, "If you take two pills of this drug daily for seven days after infection, there's a 92% chance of relief." Unlike the law model, this probabilistic explanation doesn't guarantee the truth of the explanandum; rather, it suggests a high probability of its occurrence.

Furthermore, scientific explanations might also encompass theories. For instance, consider why an earthenware pot keeps water cool. A typical explanation might entail the pot's clay composition, rendering it permeable (explanan 1). Consequently, a small quantity of water consistently seeps through its walls (explanan 2), forming a thin layer on the pot's surface (explanan 3). The water molecules within this layer exhibit random motion (explanan 4), colliding with varying speeds and exchanging kinetic energy (explanan 5). When they acquire adequate energy to overcome intermolecular forces, the molecules evaporate, entering the space above the liquid (explanan 6). This process reduces the average kinetic energy of the remaining liquid molecules (explanan 7), ultimately maintaining the coolness of the water inside the pot (explanandum). Thus, a scientific explanation may incorporate theories that offer insightful interpretations of imperceptible natural phenomena. As evident in this explanation, the tenets of the kinetic molecular theory (explanans 4-7) furnish a thorough rationale and foundational mechanism for the evaporation process. Accordingly, both explanatory unification and causal models suggest that the integration of robust theories like this facilitates comprehensive explanations.

In summary, there's a wide range of scientific explanations in the philosophy of science literature, making it challenging to establish a universally accepted model. However, drawing from causal and unificationist models, Braaten and Windschitl (2011) proposed a mixed model called the Explanation Tool. This model, suitable for assessing explanations of elementary school chemistry concepts, distinguishes three levels of explanation: (1) a low level describing what happened without theoretical components, (2) a medium level describing how something happened with limited theoretical elements, and (3) a high level explaining why something happened using theoretical components within a causal narrative. According to this model, a high-level explanation must involve causally linked theoretical premises presented in the form of a coherent story. In the present work, this approach has been used as a frame for the evaluation of students' explanations.

### The Research Question

The following research question represents the central inquiry of this study.

> What are the scientific explanation levels of preservice primary school teachers when explaining the evaporation process?

## Method

### Design and Procedures

This is a case study. The study was conducted with fourteen first-year university students enrolled in a primary school teacher education program. Of these students, ten were female and four were male. One-on-one interviews were conducted with the students, and after each interview, the interviewees were asked not to share the interview content with other students who would participate later. Prior to the actual interviews, the interview protocol was piloted, leading to revisions in the wording and sequencing of the questions. The pilot also helped determine the duration needed for each interview.

Students were particularly asked when some water is spilled on the table, after a while, we see that the spilled area dries up and the water disappears. What do you think happened to the water?' A qualified explanation expected was: Spilled water gets heat from its surroundings, such as the room air, the table, or sunlight if present (1). The absorbed heat makes the water molecules move faster (2). As they move faster, their kinetic energy increases (3). Water molecules constantly bump into each other and exchange energy (4). Some molecules gain enough energy to overcome the attraction holding them in the liquid (5). The molecules at the surface can then break free from the liquid (6). Once free, they escape into the air as water vapor (7). And this process of liquid molecules turning into gas is called evaporation (8).Top of Form Each interview lasted approximately 15 minutes or less. Participation in the interviews was voluntary. The students were attending a state university in Turkey and had qualified for this program by successfully passing the national university entrance exam. All participants had completed high school prior to beginning their university studies. At the time of the research, the students had not yet received any university-level instruction on the concept of evaporation. However, in the Turkish education system, the concept of evaporation is included in the science curriculum at the primary, middle, and high school levels.

## Results

### The Analysis of Students' Expressions

The students' expressions were deductively analyzed (Patton, 2001). In other words, the expressions were analyzed based on the operational definitions provided in Table 1.

Table 1. Operational Definitions for Codes adapted from the Study by Braaten & Windschitl (2011).

| Codes | Definitions |
|---|---|
| Level 1 *(What)* | • Student describes *what* happened.<br>• Student describes, summarizes, or restates a pattern or trend in data without making a connection to any unobservable/ theoretical components. |
| Level 2 *(How)* | • Student describes how or partial *why* something happened.<br>• Student addresses unobservable/ theoretical components *tangentially.* |
| Level 3 *(Why)* | • Student explains *why* something happened.<br>• Student can trace a full *causal* story for why a phenomenon occurred.<br>• Student uses unobservable/ theoretical components of a model to explain an observable event/ phenomenon<br>• Student uses powerful science ideas (*like kinetic molecular theory*) to explain observable events. |

Below is a dialogue between the researcher and the *student 1* regarding the evaporation process. In the following and subsequent dialogues, the letter *R* stands for the researcher and *S* stands for the student.

R: When some water is spilled on the table, after a while, we see that the spilled area dries up and the water disappears. Is that right?

S: Yes.

R: What do you think is the reason?

S: It is evaporation.

R: What happens to water?

S: Water can evaporate at any temperature.

R: What happens to the water?

S: It mixes with the air.

R: Do you know how it mixes? How does that process work?

S: I don’t know that.

In this dialogue, the student’s responses remain primarily at *Level 1 (What).* When asked about the reason for the disappearance of the spilled water, the student simply states, “It is evaporation,” which names the phenomenon but does not provide an explanation of how or why it occurs—this fits Level 1. When asked again what happens to the water, the student answers “Water can evaporate at any temperature,” which repeats a general fact but does not build a causal link—again. The statement “It mixes with the air” also remains descriptive, indicating only what happens, not how the process works on a molecular level. When the researcher probes further about how the mixing happens, the student responds “I don’t know that” showing that they do not yet connect the phenomenon to any underlying theoretical ideas, such as energy transfer, particle motion, or the kinetic molecular theory. Therefore, no parts of the dialogue reach Level 2 (How) or Level 3 (Why). Overall, the student demonstrates a basic descriptive understanding of evaporation but lacks any mechanistic or theoretical reasoning.

Below is another dialogue between the researcher and the student 9 regarding the evaporation process.

R: When some water is spilled on the table, after a while, we see that the spilled area dries up and the water disappears. What do you think happened to the water?

S: It evaporated. We can explain it through evaporation.

R: What does evaporate mean?

S: It means the transition from liquid to gas by absorbing heat.

R: How does this happen?

S: It absorbs heat from outside.

R: Okay. From where?

S: From the sun. From a natural source.

R: Okay. Then what happens?

S: (No response)

R: What happened when heat was absorbed?

S: I don't know.

Based on the provided coding scheme, the student’s responses primarily fall within the *Level 2 (How)* code. At the beginning, the student simply identifies that the water evaporates without offering any causal explanation, which aligns with Level 1 as it describes what happened. When prompted to elaborate, the student explains that evaporation is a transition from liquid to gas by absorbing heat, which indicates a partial understanding of the underlying mechanism—thus matching Level 2 (How). The student further mentions that the heat comes from the sun, which provides contextual information but does not extend into a full causal explanation. There is no evidence that the student constructs a complete causal story or applies theoretical models such as the kinetic molecular theory to explain why the phenomenon occurs; therefore, there is no Level 3 (Why) explanation present in the dialogue. Overall, the dialogue demonstrates a surface-level understanding with basic descriptive and partial mechanistic reasoning but lacks deeper theoretical connections.

Below is another dialogue between the researcher and the *student 11* regarding the evaporation process.

> R: When some water is poured onto the table, after a while, we see that the area is dried up and the water is gone. What's the reason for this?
>
> S: I think the water evaporates by interacting with the air. Heated water is expanded into the air.
>
> R: Where does the heat come from?
>
> S: I think it's from the heat in the room, or it could be from the sun if it is outdoors. It could be from windows.
>
> R: Okay.
>
> S: The energy is coming in. Through energy (or) heat, I think the water loses its weight and rises into the air, so it evaporates.
>
> R: Okay.

In this dialogue, the student again demonstrates *Level 2* reasoning. The initial response, "the water evaporates by interacting with the air," describes what happens and introduces the idea of interaction with air, showing some awareness of the process—this is mainly Level 1 with a hint of Level 2. The statement, "Heated water is expanded into the air," reflects an attempt to describe how the process occurs by linking heat and expansion, indicating partial mechanistic reasoning that fits Level 2 (How). When asked about the heat source, the student correctly identifies multiple possible sources (room temperature, sunlight, windows), which shows context awareness but still remains at a descriptive level. The follow-up explanation, "The energy is coming in. Through energy (or) heat, I think the water loses its weight and rises into the air," again demonstrates partial understanding of the process. The student tries to link energy input to the observable change (evaporation) but does not articulate a complete molecular explanation or use a scientific model like the kinetic molecular theory. Therefore, the student does not reach Level 3 (Why) because they do not provide a full causal story with unobservable components such as particle motion or energy transfer at the molecular level. Overall, the student combines descriptive observations with partial mechanistic reasoning, showing an emerging understanding but lacking a fully developed theoretical explanation.

Below is another dialogue between the researcher and the *student 14* regarding the evaporation process.

> T: When some water is spilled on the table, after a while, we see that the spilled area dries up and the water disappears. What do you think happened to the water?

S: Most likely, the water evaporated.
T: How did it evaporate?
S: Since it was spilled onto the surface, initially, the water particles evaporated due to heat energy, either from the sun or any other heat source. The energy between them increased, temperature increased, and evaporation occurred.
T: You mentioned kinetic energy earlier (Referring to the first dialogue).
S: The kinetic energy between particles increased. Heat energy increased.
T: Where did it get the heat from?
S: It got the heat from external sources. Like the sun.
T: Wouldn't evaporation occur without the sun?
S: No, evaporation would still happen. After a certain time, evaporation would occur because it's on the surface. Usually, evaporation occurs on the surface. That's what I know.
T: What if there's no sun?
S: It would still occur.
T: Where would it get the heat from?
S: I don't know.
T: Have you ever thought about it?
S: No. I hadn't thought about it.

In this dialogue, the student's explanations mostly reflect *Level 2 (How).* The student's explanation does not fully articulate a complete causal story. Initially, the student correctly identifies that the water "most likely evaporated," which is descriptive and aligns with Level 1 (What) since it simply states what happened. When asked how evaporation occurs, the student explains that heat energy causes water particles to evaporate, referencing external heat sources like the sun. This demonstrates Level 2 (How) reasoning, as they connect an unobservable component (energy transfer) to the observable phenomenon. The student also mentions that the "kinetic energy between particles increased," which shows an attempt to use a theoretical concept, hinting at Level 3 (Why) reasoning. However, this explanation remains superficial and does not develop into a full causal chain that links the kinetic molecular theory to particle motion, energy transfer, and phase change in detail. Furthermore, when asked whether evaporation would occur without the sun, the student acknowledges that it still would, indicating an understanding that other heat sources can supply the necessary energy. Yet, when prompted to elaborate on what these other sources might be, the student is unable to explain, showing a gap in the theoretical depth required for a true Level 3 explanation. Overall, the student's reasoning goes beyond simple description by incorporating partial mechanistic ideas about energy transfer and particle motion, thus achieving Level 2 understanding. However, the lack of a coherent, scientifically grounded causal model limits the response from reaching Level 3, which would require fully connecting the kinetic molecular theory to the observed evaporation process.

In order to determine the reliability of the coding, a randomly selected video transcript together with the coding definition table (Table 1) was given to two different researchers. These researchers were asked to code the transcripts independently based on the definition table. They then re-coded the transcripts using the definition table, and subsequently, experts compared the codes identified by the coders with their own codes to calculate the coding reliability. Coding reliability was calculated by dividing the number of agreed codes by the total number of codes (Miles & Huberman, 1994, p. 69; Saglam & Kanadlı, 2019). The reliability coefficient was obtained by taking the average of the resulting ratios. The coding of the independent researchers demonstrated complete agreement (100%), indicating, according to Miles and Huberman (1994, p. 69), that the codes were assigned with a high level of reliability.

The deductive analysis of students' verbal expressions regarding the evaporation phenomenon revealed that all responses fell within Level 1 (What) and Level 2 (How) categories, with no student demonstrating Level 3 (Why) reasoning. Further, the responses that qualified as Level 2 were superficial. In these responses, students mostly stated that temperature or heat leads to evaporation, but none provided a coherent or sufficiently detailed causal chain to explain the evaporation process. Table 2 depicts the codes emerging from the students' explanations and their percentages.

Table 2. Codes emerged from Student Responses and their Percentages

| Codes | Number of Students | Percentage (%) |
|---|---|---|
| Level 1 *(What)* | 5 | 36 |
| Level 2 *(How)* | 9 | 64 |
| Level 3 *(Why)* | 0 | 0 |

The data then transformed into the following graph.

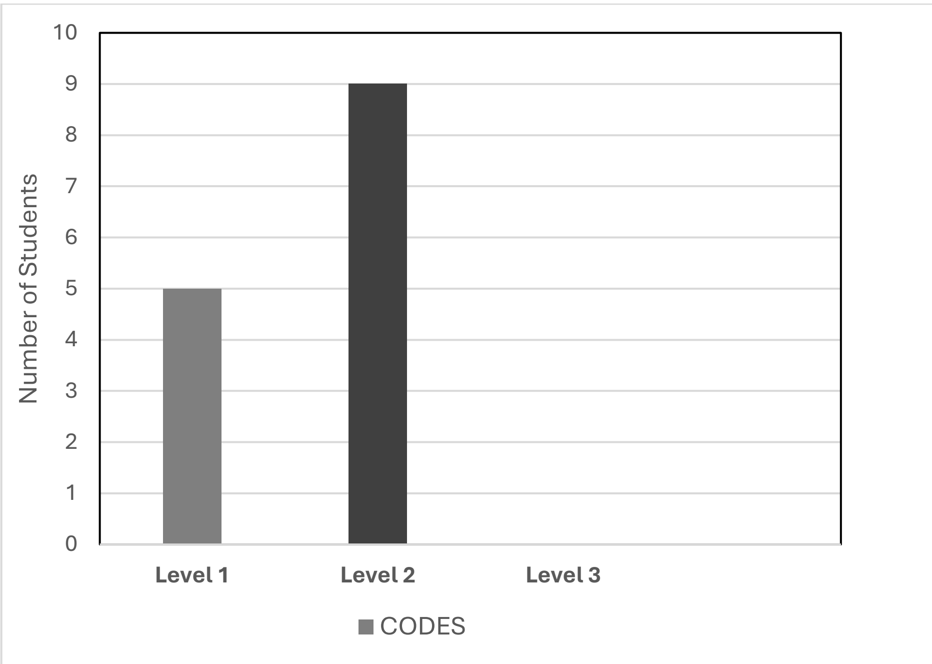


Figure 1. Codes Emerged from Students' Responses

Figure 1 displays the distribution of codes derived from the students' explanations. Of the 14 students analyzed, 5 (36%) provided Level 1 responses that primarily involved naming or describing what happened without connecting to underlying processes. Meanwhile, 9 students (64%) gave responses categorized as Level 2, indicating a partial, but incomplete, understanding of how evaporation occurs. The lack of Level 3 responses (0%) underscores the current absence of fully developed causal explanations among the student sample.

This finding indicates that while students can identify and describe the observable aspects of evaporation, they struggle to articulate a comprehensive scientific explanation that addresses the underlying causal mechanisms at a molecular or theoretical level. More specifically, the majority of the students' responses were classified as Level 2; however, these Level 2 explanations were generally superficial. In these responses, students frequently acknowledged that temperature or heat plays a role in causing evaporation, which reflects a partial understanding of the process. Despite this, none of the students provided a detailed or coherent causal chain that connects heat energy to molecular motion, and the phase changes from liquid to gas. This suggests a gap in their grasp of how temperature influences kinetic energy at the molecular scale, ultimately enabling molecules at the surface of the liquid to escape into the gaseous phase. The absence of any Level 3 responses is noteworthy because Level 3 represents the highest form of conceptual understanding in this coding scheme, an explanation that fully integrates observable phenomena with unobservable theoretical constructs, such as molecular kinetic theory and intermolecular forces. The fact that no students reached this level highlights a limitation in their conceptual models and suggests that further instructional intervention may be necessary to support students in developing deeper mechanistic reasoning about phase changes.

## Discussion and Conclusion

The results indicate that no student constructed a good mechanistic understanding of evaporation process. That is, while pre-service primary teachers can identify evaporation as a natural process, their explanations overwhelmingly remain at descriptive or partially mechanistic levels, lacking the theoretical depth necessary for Level 3 causal reasoning. In other words, the data suggests that while students have some awareness of the factors influencing evaporation (such as heat), their explanations remain largely descriptive or surface-level. According to McNeill and Krajcik's (2006) framework, a robust scientific explanation requires not only a claim but also evidence and reasoning that connect observable phenomena to scientific theories. However, participants in this study often provided claims (e.g., "evaporation occurs when water disappears") without incorporating sufficient evidence or theoretical reasoning, particularly at the molecular level.

The 2024 Turkish Science Curriculum outlines a carefully sequenced introduction of evaporation and related phase changes, presenting them as phenomena that occur through the transfer of heat. At the elementary level, beginning in the 4th grade, students are introduced to evaporation within the broader framework of matter and its changes, with a focus on conducting experiments, making observations, and drawing cause-and-effect conclusions based on qualitative data. In the 5th grade, this foundation is reinforced by addressing the relationship between evaporation and boiling, as well as introducing the principle of thermal equilibrium, thereby expanding students' awareness of the continuous exchange of heat in nature. This scaffolding reflects an intentional pedagogical strategy designed to help learners gradually construct a coherent understanding of how matter behaves under varying thermal conditions. However, a significant limitation emerges when examining the treatment of evaporation in the upper grade levels. At both middle and high school, the curriculum presupposes that students already possess sufficient prior knowledge of evaporation and thus provides no explicit reinforcement or extension of the concept. This omission is noteworthy, as the phenomenon of evaporation cannot be fully understood without reference to molecular explanations grounded in kinetic theory. While early exposure at the primary level helps students to recognize evaporation as a macroscopic effect of heat, the absence of a structured return to the topic in later grades results in a missed opportunity to connect students' developing knowledge to a deeper, molecular-level framework.

In particular, the kinetic theory of matter, which explains evaporation as the escape of high-energy particles from the surface of a liquid, is an essential conceptual bridge that allows learners to transition from descriptive observations to mechanistic scientific explanations. However, this aspect of the concept is never conveyed to students. In this sense, the curriculum's treatment of evaporation highlights both strength and weaknesses. On one hand, it succeeds in laying an accessible foundation for young learners by linking evaporation to everyday experiences and experimental inquiry. On the other hand, by overlooking the need to revisit the concept through the lens of kinetic theory in middle and high school, it risks leaving students with a fragmented or incomplete understanding. Therefore, while the curriculum contributes to early scientific literacy, its long-term effectiveness in fostering advanced scientific reasoning may depend on supplementing these omissions with targeted instructional interventions at higher grade levels.

The absence of molecular-level reasoning and the inability to connect macroscopic observations to underlying scientific principles point to a persistent gap in teacher preparation. Addressing this shortcoming requires targeted instructional interventions that emphasize the integration of scientific theories, such as the kinetic molecular theory, into everyday explanations of observable phenomena. Strengthening teacher candidates' ability to construct coherent and theory-driven scientific explanations is not only essential for their own conceptual development but also critical for fostering scientific literacy among future generations. Accordingly, both teacher education programs and national education policies must prioritize the cultivation of robust scientific reasoning skills, ensuring that pre-service teachers are adequately prepared to guide their students beyond surface-level descriptions toward deeper scientific understanding.

The scientific method, discovered in the 1600s, has carried humanity over the course of roughly 400 years into the eras of technology, space exploration, and artificial intelligence. Yet, even today, we have not succeeded in imparting a conceptual understanding of it to our youth—who will themselves become future teachers. It is therefore strongly recommended that the results of this study be carefully read and considered by policymakers at the head of the Turkish education system, by university academics engaged in this field, and most importantly by political leaders. They should reflect upon these findings, develop solutions to address the problem, and act swiftly to implement them. Due to the limited number of participants, the findings of this study cannot be considered generalizable. Nonetheless, they offer preliminary insights into the broader situation and may provide useful indications to guide future research.

## References


Boas, F. (1901). The Mind of Primitive Man. *The Journal of American Folklore, 14*(52), 1-11.

Braaten, M & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education, *Science Education, 95* (4), 639–669.

Burdge J. (2017). *Chemistry.* New York: McGraw-Hill Education.

Cinar, M. D. (Ed.). (2019). Aydınlanma Felsefesi (Rev. ed., unit: "Aydınlanma ve Bilim," B. B. Ozpek). Ataturk University, Open Education Faculty.

Cucen, A. K. (2005). The intellectual origins and critique of Western Enlightenment. In S. H. Bolay (Ed.), *Avrupa'da Aydinlanma* (pp. 115–122). Ankara: Gazi Kitabevi.

Friedman, M. (1974). Explanation and scientific understanding. *Journal of Philosophy, 71*, 5 – 19.

Hempel, C. G. (1966). *Philosophy of natural science*. Princeton University, NJ: Prentice-Hall.

Hempel, C. G., & Oppenheim, P. (1948). Studies in the logic of explanation. *Philosophy of Science, 15*(2), 135 – 175.

Hewitt, P. G. (2021). *Conceptual Physics*. Pearson Education.

Kitcher, P. (1997). Explanatory unification. In D. Rothbart (Ed.), *Science, reason, and reality: Issues in the philosophy of science* (pp. 167 – 186). Fort Worth, TX: Harcourt Brace.

Lévy-Bruhl, L. (1923). *Primitive mentality* (L. A. Clare, Trans.; 2018 ed.). Routledge.

McNeill, K. L., & Krajcik, J. (2008). Inquiry and scientific explanations: Helping students use evidence and reasoning. In *Science as inquiry in the secondary setting* (Ch. 11). National Science Teachers Association Press.

M.E.B. (Milli Egitim Bakanligi) (2024). *Fen Bilimleri Dersi Ogretim Programi (3, 4, 5, 6, 7 ve 8. Sınıflar).* Ankara

Miles, M.B. & Huberman, A.M. (1994). *Qualitative Data Analysis (2nd ed.)*. Thousand Oak, CA: Sage.

Saglam & Kanadlı (2019). *Nitel veri analizinde kodlama*. Kızılay, Ankara: Pegem Akademi

Patton, M.Q. (2002). *Qualitative Research& Evaluation Methods (3rd Ed.).* Thousand Oak:SAGE Publications. pp.453-455.

Russ, J. (2011). Avrupa Düşüncesinin Serüveni: Antik Çağlardan Günümüze Batı Düşüncesi (Özcan Doğan, Çev.). Doğu Batı Yayınları.

Sakyi-Hagan, N. A. (2024). Exploring the nature of scientific explanations: An interactive predict-observe-explain model-based intervention for pre-service science teachers. *Aquademia, 8*(2), ep24007.

Salmon, W. C. (1978). Why ask "Why?" An inquiry concerning scientific explanation. Proceedings and Addresses of the American Philosophical Association, 51(6), 683 – 705.

Strevens, M. (2013). No understanding without explanation. Studies in History and Philosophy of Science, 44(3), 510–515.

Zumdahl, S. S., and DeCoste, D. J. (2017). *Chemical Principles.* Boston: Cengage Learning.