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Fostering Scientific Communication in Elementary Science Learning Through Game-Based Toulmin Argumentation

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Abstract: This study aims to investigate the potential of science-themed educational games in improving the scientific communication skills of elementary school students. The main focus lies in examining the development of students' ability to express ideas, build arguments, and use scientific vocabulary in an authentic and engaging learning context. This study used a naturalistic qualitative approach with a case study design. Data were collected through participatory observation, audio-video recordings of classroom activities, and documentation of students' work in grade V of a public elementary school. Thematic analysis was used to interpret the data, supported by the application of the Toulmin Argumentation Pattern (TAP) framework. This framework facilitates the identification of key argument components, including claims, data, guarantees, qualifications, and rebuttals. The findings show that the game "Science Monopoly" effectively stimulates various forms of scientific communication in a natural way. Students presented claims and backed them up with data relevant to the science topic being discussed. However, this study also reveals significant limitations in the development of justification and the use of capital markers, which appear to be less prominent in student discourse. The word cloud analysis further highlights that the scientific vocabulary used by students is primarily concerned with themes such as the water cycle, the Earth's rotation, and the solar system. These results suggest that integrating science content into educational game formats can significantly increase student engagement and deepen their conceptual understanding of scientific phenomena. Based on these findings, the study recommends integrating science literacy-oriented educational games into formal instructional settings. Such integration should be supported by the use of multimodal representations and the structured scaffolding of educators to develop students' scientific communication skills further. This research contributes to the advancement of participatory and meaningful science learning strategies that encourage critical thinking from an early age.

Keywords: verbal interaction, educational games, science literacy, scientific communication, Toulmin Argumentation Pattern, basic education.

▪ INTRODUCTION

Introduction Educational transformation in the 21st century demands more complex learning skills, such as critical thinking, scientific communication, collaboration, and problem-solving (Agaoglu et al., 2025; Oanh & Dang, 2025; Wei et al., 2025). Science education at the elementary school level is an important foundation in cultivating these skills, not only in the form of factual knowledge, but also contextual argumentative skills (Le Blanc, Freire, and Vierro 2017; León-Reyes et al., 2025; Mercer-Mapstone & Kuchel, 2017; Qablan et al., 2025). Unfortunately, according to Jensen, (2008), Michael & Modell (2003), and Mintzes & Wandersee (2005) science learning model which is still dominated by lecture methods and emphasis on memorization makes learning less meaningful and tends to be passive for students In line with the change in learning paradigm, various innovative approaches are being explored to answer these challenges (Kulgemeyer & Schecker, 2013).

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One of them is game-based learning that has been proven to integrate cognitive, affective, and social aspects in a balanced manner. For instance, a study by Cheng, Pang, & Kong (2025) developed a virtual reality (VR) game called Brainland, which successfully integrated cognitive, affective, and social dimensions in the context of immersive learning for older adults. The game included six mini-games set in a simulated home environment, designed to train various independent living and cognitive skills such as memory, logical thinking, motor coordination, and even creativity through art-making. Participants reported high engagement, perceived realism, and the relevance of game tasks to daily life. They highlighted improvements not only in memory and attention but also in emotional well-being, sense of accomplishment, and even social connectedness. This study illustrates how game-based learning, when designed with user-centered and immersive approaches, can holistically develop multiple dimensions of learning, including those crucial in scientific and everyday contexts. Educational games provide students with a space to experience active, collaborative, and reflective learning, while allowing them to convey ideas, answer challenges, and develop logical mindsets in a fun setting (DiCesare et al., 2025; Haneklaus, Kaggwa, and Misihairabgwi, 2025; Kantorski et al., 2025; Wu et al., 2025). Nevertheless, although educational games have been widely studied in the context of motivation and learning interest, few studies have specifically examined the dimensions of scientific communication that emerge in students' verbal interactions during play, let alone those that use structural frameworks such as the Toulmin Argumentation Pattern (TAP) (van Antwerpen et al., 2025; Ldokova, Frumina, and Alwaely 2025; Madu et al., 2025).

The TAP approach offers significant advantages that make it particularly relevant for analyzing students' scientific communication skills in verbal interaction during science learning. By deconstructing arguments into their core components, such as claims, data, warrants, backings, qualifiers, and rebuttals, TAP allows educators and researchers to evaluate not only the presence of argumentation but also its complexity, explicitness, and depth of reasoning. As demonstrated by Rapanta, Macagno, and Jenset (2025), this framework is effective in capturing developmental progressions and individual differences in argument quality, including the use of evidence (backing), acknowledgment of alternative viewpoints (rebuttal), and epistemic caution (qualifiers). These indicators are crucial in understanding how students construct and communicate scientific knowledge in dialogic settings, making TAP a robust methodological tool for examining learning processes in culturally diverse and age-variant classrooms. This allows researchers to identify the dimensions of students' critical thinking, such as how they support claims with evidence, connect reason with statements, and consider exceptions and alternatives.

In addition, TAP has proven to be flexible and can be applied at various levels of education, ranging from elementary education to higher education. This flexibility is not only theoretical but has been proven by numerous studies that explicitly test the application of TAP to different age groups and educational backgrounds. For example, Kaya (2018) shows that TAP can be used effectively to analyze the argumentative abilities of elementary school students in the context of science learning. Although early childhood students still struggle with crafting complex written arguments, they can effectively demonstrate the basic structure of arguments verbally, such as claims and reasons, during classroom interactions. Research by Ezgeta-Balić & Balić, (2024), Ogegbo & Aina (2024) and Rapanta et al. (2025) reinforced the findings through cross-border studies involving children aged 5 to 11 years, and found that elementary school students were able to construct argument structures that followed the TAP pattern With the right pedagogical interventions, students even show the use of more complex elements such as backing and rebuttal, signaling that TAP can capture the development of critical thinking gradually.

Furthermore, research by Mafugu, Nzimande, & Makwara (2024) utilized TAP to assess the scientific argumentation skills of prospective elementary school teachers. The results showed that most students were at levels 2 and 3 (claims, data, warrants, backing), although not many had reached the highest level, which included strong rebuttals. This demonstrates that TAP is an effective evaluative tool in the education of prospective elementary school teachers.

Finally, a study by Chang, Tsai, & Meliana (2023) and Oh (2014) that focused on prospective middle school science teachers shows how TAP can uncover erroneous presuppositions in the understanding of complex scientific concepts such as tides. This study shows how the use of unscientific backing can be an indicator of misconception, and TAP can be a sensitive tool in detecting and directing understanding in a more scientific direction. Overall, these findings suggest that TAP is not only a systematic argumentation framework, but also adaptive and relevant for various age groups, including primary school students. Thus, TAP is a very valuable instrument in analyzing and developing students' scientific communication skills from an early age. Levels of education, from elementary to tertiary. For primary school students, the TAP can still be used, focusing on basic components such as claims, data, and rebuttals. At a higher level, the analysis can be extended to support and qualifications. This makes TAP an adaptive tool in evaluating argumentative skills according to students' cognitive levels (Wambsganss et al., 2020). TAP is also highly effective in authentic learning contexts, such as group discussions, educational games, or project-based learning, as it can capture the natural scientific thinking process of students' verbal interactions (Erduran et al., 2004). What's more, TAP can be combined with a quantitative approach through the assessment of the frequency and complexity of arguments, or with visualisations such as argument mapping, making it a powerful analytical method for mixed-methods approaches. Thus, TAP is not only an analytical tool but also a pedagogical guide that helps teachers understand and guide the development of students' scientific communication in a more directed and structured manner.

In Indonesia, research on the argumentative structure of elementary school students in science learning is still very limited. A relevant study by Tenriawaru & Putra (2021) investigated the argumentation skills of senior high school students in biology learning using Toulmin's Argumentation Pattern (TAP). The study revealed that while most students could construct claims and provide some supporting grounds or warrants, they generally struggled with producing complete arguments, particularly lacking in the components of rebuttal and backing. Specifically, 68.63% of students remained at level 3 argumentation, with 0% achieving levels 4 or 5, which require clear rebuttals and complex argument chains. However, their study was conducted at the high school level within formal instructional settings. To date, no study has explored how younger students, particularly at the elementary level, construct scientific arguments in more naturalistic, game-based learning contexts. This study addresses that gap by examining the development of argumentative structures among elementary school students engaged in science learning through educational games. By focusing on real-time dialogue during gameplay, this study provides a novel perspective on how early scientific reasoning and communication skills can develop in informal learning settings.

Especially those that integrate games as a natural learning context (Prastika et al., 2025). There has been limited research on how verbal interaction during play activities can form the basis of scientific communication skills. These skills are crucial as part of science literacy, which is emphasized in international curriculum standards, such as the *Next Generation Science Standards (NGSS)* (Tomovic et al., 2017). Addressing this gap, this study aims to explore students' verbal interactions when playing the Monopoly educational game with a science literacy theme. The research focus is directed at identifying emerging argumentative structures, including challenges and opportunities in the development of the scientific argumentation component among elementary school students. This research not only contributes to the development of learning media but also strengthens the theoretical foundation for understanding how educational games can serve as a vehicle to foster natural, reflective, and contextual scientific communication in children.

▪ METHOD

Participants

This study involved grade V students from one of the public elementary schools in Pekanbaru as participants. The sample was purposively selected, i.e., three small groups of students (each comprising five students) who demonstrated active involvement in science learning and readiness for the topics to be explored (the water cycle, earth rotation, and the solar system). The students involved in this study were in the age range of 10–11 years, which corresponds to the transitional phase from the concrete operational stage to the early formal operational stage, according to Piaget’s theory of cognitive development (Samad, Osman, & Nayan, 2023). At this stage, children begin to develop logical reasoning, understand cause-and-effect relationships, and can engage in more structured and abstract thinking. These cognitive abilities make this age group particularly suitable for studying the development of scientific communication and argumentation skills. Furthermore, using educational games as a learning context aligns with their developmental needs, as it combines playfulness with structured thinking, fostering engagement and deeper learning in a natural and meaningful way. The criteria for active involvement are determined through the results of the teacher's observation and the track record of student activity in class discussions, as well as the value of previous assignments. Meanwhile, the readiness of the topic was measured through the results of daily tests and the students’ ability to explain concepts orally during pre-observation.

Research Design and Procedures

This study employed a naturalistic qualitative approach with an exploratory case study design (Stevens & Wrenn, 2013) to obtain an in-depth understanding of how science-themed educational games facilitate students’ scientific communication skills. The research was conducted over a period of two weeks and comprised three main stages. The first stage was the preparation phase, which involved validating the design of the “Science Monopoly” game by science education experts. This validation ensured the game's alignment with targeted scientific concepts and intended learning objectives.

The second stage involved implementing the game. Each student group participated in a 45–60-minute gameplay session within a classroom environment structured to support interactive and student-centered learning. This duration was considered sufficient for a full round of the Science Monopoly game, allowing all students multiple turns. Within each round, students generally engaged in 3–4 cycles of argumentation, which included presenting claims, supporting them with data, and responding to peers' rebuttals. The allocated time also facilitated active participation from each member, ensuring balanced group dynamics. This time frame was informed by developmental psychology literature concerning the attention span of children aged 10–11 years, as well as findings from preliminary pilot tests. The pilot results indicated that a 45–60-minute session was optimal for maintaining engagement, fostering critical thinking, and supporting the emergence of complex argumentation within a collaborative learning setting.

The third stage involved the researcher assuming the role of a neutral facilitator and participant observer during gameplay. The researcher's intervention was deliberately restricted to technical aspects only, such as explaining game instructions, reminding students of time constraints, and ensuring adherence to the rules of turn-taking and card usage. The researcher was prohibited from influencing or guiding the content of students' arguments. To uphold consistency and neutrality, a facilitation protocol was developed. This protocol specified the instances in which the facilitator was permitted to speak (e.g., at the beginning of the game, during rule clarification, or when addressing confusion about game mechanics), included standardized responses for typical situations (e.g., "Please refer to the instruction card" instead of providing content-based hints), and established a passive observation stance during argumentation to avoid any verbal or nonverbal cues that might shape student responses. To minimize bias, all sessions were audio- and video-recorded, and the facilitator maintained structured field notes without interpretation during the activity. During data analysis, the researcher's role and potential influence were explicitly acknowledged and critically examined. To ensure objectivity, argumentation data were independently coded by two researchers who had not been involved in facilitating the game. Discrepancies in coding were resolved through consensus, and triangulation with student artifacts and observational data was employed to enhance the credibility and validity of the findings.

Instruments

Several instruments were used in this study to facilitate the collection and analysis of comprehensive data regarding students' scientific communication skills and arguments. These instruments include both teaching tools and analytical frameworks designed to capture the complexity of students' discourses and reasoning processes during games (Daya et al., 2025). The first instrument is the Science Monopoly Game, an educational board game designed to integrate content from the Indonesian science curriculum (Natural Sciences/IPA) into an interactive, game-based learning format. The game utilizes a series of special cards designed to elicit scientific arguments through various cognitive challenges. These include: (a) Concept Question Cards, which ask open-ended questions such as "Why does it rain?", "What happens if the Earth stops spinning?", or "How does the water cycle work?" These questions aim to activate students' conceptual understanding and stimulate explanatory thinking. (b) Argumentation Cards, which require players to provide real-life evidence or examples to support their answers, encourage structured reasoning. (c) Rebuttal Challenge Cards, which encourage students to criticize or challenge their peers' responses, promote critical evaluation and counter-arguments. All components of the game have been reviewed and validated by two experts in basic science education to ensure alignment with learning objectives, content relevance, and developmental appropriateness. The second instrument consists of guidelines and structured participatory observation sheets. The tool is designed to systematically record verbal and non-verbal interactions during the game, including aspects such as speaking turns, the use of scientific vocabulary, and indicators of collaboration or rebuttal among students. Third, Student Work Artifacts are collected as an additional data source. This includes students' written notes, answer sheets, and narrative responses, which are analyzed to assess their ability to craft coherent scientific arguments outside the verbal domain of the game. The fourth instrument is the TAP-Based Coding Sheet, adapted from the Toulmin Argumentation Pattern (TAP), which serves as the primary analytical tool for evaluating students' arguments. This framework combines the key components of claim structure, including data, assurances, endorsements, qualifications, and rebuttals. It is operationalized into a rubric used to systematically code each unit of student speech or written argument. To ensure the validity and reliability of the instruments, all coding items and schemes are reviewed by two independent specialists in the field of science education. The reliability between the assessors was assessed by having two researchers independently code the data using the TAP rubric. Discrepancies are addressed through consensus-building discussions. The reliability between the raters results in a Kappa Cohen coefficient of K = 0.82, showing a high level of agreement and consistency in the coding process.

Data Analysis

The data analysis in this study was carried out through a structured and multi-layered approach to examine the various dimensions of scientific communication and argumentation. The process includes three main analytical lenses: thematic analysis, argumentative analysis based on the TAP, and linguistic analysis through word cloud visualization, all of which are supported by rigorous triangulation and validation procedures to ensure the credibility and strength of the findings. Thematic analysis is used as an initial stage to explore the patterns of interaction and thematic content that emerge during student play. The transcript text of the recorded session was read repeatedly and inductively coded to identify recurring themes and discussion trajectories. This analysis aims to reveal how students construct, negotiate, and respond to scientific concepts in the context of educational games. With a focus on the natural flow of discourse, the theme of the analysis provides a comprehensive view of students' engagement with science content, including how they collaborate, ask questions, and build knowledge together.

Furthermore, argument analysis was carried out using the TAP framework. This framework allows for a detailed examination of the structure and quality of students' arguments by identifying the existence of certain argumentative components: claims, data, guarantees, supports, qualifiers, and rebuttals. Each unit of analysis is defined as a complete argumentative turn, which can consist of a single expression or a series of interrelated statements that form a coherent argument. The segmentation of these units adheres to operational rules that ensure analytical consistency: a new unit begins with the introduction of a different idea or response to a science prompt. It ends at a disconnect, re-topic, or facilitator's intervention. Arguments that are revealed through consecutive short phrases but still have an integrated focus are treated as a single unit of analysis.

Each unit was then independently coded by two researchers using rubrics that were colored in harmony with the TAP model. Reliability between raters was measured using Kappa Cohen, which yielded a value of 0.82, indicating a high level of agreement and consistency in coding practices. In addition to structural and thematic analysis, linguistic analysis is conducted to investigate the use of scientific vocabulary among students. This analysis leverages the Word Cloud function in Voyant Tools to visualize the frequency and distribution of key scientific terms used during the game. This visualization highlights dominant conceptual terms such as "evaporation," "rotation," and "gravity," thus providing insight into students' conceptual focus and the depth of their engagement with science topics. The use of word clouds offers a complementary lens for understanding the patterns of language and terminology that are repeated in large qualitative datasets. To reinforce the validity of the analysis, data triangulation was employed across three primary sources: participatory classroom observations, audio-video recordings of game sessions, and student-generated artifacts, including answer sheets and notes. Expert validation is carried out by two independent science education specialists who review data analysis procedures and their interpretation. In addition, member checks were carried out with student participants to confirm the accuracy and resonance of the interpretation of the sequence of arguments. Through these joint efforts, the study ensures analytical diligence and increases the credibility of findings related to scientific communication and student argumentation development.

The analysis instrument was compiled based on the TAP indicator (see Table 1), and inter-rater reliability was tested using the Cohen's Kappa coefficient (K = 0.82), indicating high consistency. Word Claud visualisation was done with Voyant Tools to assess the distribution of scientific vocabulary. Data validity is guaranteed by source triangulation, expert validation, and member checking.

Table 1. TAP Analysis indicator

TAP Components	Indicators	Example Speech
Claim	Scientific statement	"The Earth revolves from west to east."
Data	Fact support	"Because the shadow changes"
Warrant	Logical linkages	"If the shadow changes, it means that there is movement."
Backing	Additional support	"The science book says..."
Qualifier	Conditional	"Usually... except during eclipses"
Rebuttal	Denial of arguments	"But not the sun that moves"

▪ RESULT AND DISSCUSSION

Based on the results of the analysis of student conversations during the implementation of the Science Monopoly educational game, two dominant types of communication emerged: (1) scientific communication, and (2) general or off-task communication.

1. Scientific Communication

This type of communication reflects students’ efforts to convey scientific concepts, construct arguments, and explain processes related to curriculum topics (e.g., the water cycle, Earth's rotation, the solar system). The data revealed multiple instances where students formulated complete argumentative structures based on the Toulmin Argumentation Pattern (TAP), such as:

Claim : "*The sun causes the water to evaporate*."
Data : "*Because when it is hot, puddles disappear*."
Rebuttal : "*But clouds can also form from cold places like mountains*."

These interactions show that the game effectively stimulated the use of scientific vocabulary and reasoning. Each student typically engaged in 3–4 argumentative cycles per session, indicating active participation and conceptual engagement.

2. General or Off-Task Communication

This includes unrelated or playful conversations such as teasing, storytelling, or asking about game tokens. Although not directly related to learning content, this type of interaction contributed to peer bonding and relaxed classroom climate, which are important in socio-constructivist learning environments.

Negative Case Analysis and ZPD Insights

To deepen the understanding of learning dynamics, negative case instances where students struggled or failed to construct coherent arguments were identified and analyzed. One notable example involved a student who attempted to explain why the moon causes tides:

"*The moon makes waves… because it is up there… and... water likes it*?"

This response lacked clear data and a warrant, showing confusion between correlation and causation. Peer intervention was hesitant, and no effective scaffolding was provided by group members. This case illustrates the student's position within the Zone of Proximal Development (ZPD), the space between what the student can do independently and what they can achieve with guidance. Another negative case occurred when a student refused to challenge a peer's argument, stating:

"*I do not know, it is probably right… I do not want to argue.*"

This reflects a lack of confidence in using counter-arguments and indicates that while the student understood the factual content, they had not yet developed the social cognitive skill to engage in rebuttal, another marker of ZPD. These cases underscore the importance of teacher scaffolding and the explicit modeling of argumentation strategies, particularly for students who are still developing their reasoning and language skills. They also support the idea that educational games need to be supported by teacher prompts and metacognitive reflection to fully activate learning potential. The distribution of communication types in educational monopoly games is presented in Table 2.

Table 2. Distribution of communication types in educational monopoly games

Types of Communication	**Examples of Interactions**	**Number of Speeches**	**Percentage (%)**
Science Communication	Answering scientific questions, explaining the water cycle, and answering questions about the rotation of the Earth, the planets	310	77.5

General or off-task communication	Telling stories about the experience of going to the lake, joking, asking about the location of the river, and playing around	90	22.5
Total		400	100

Table 2 presents the results of interaction analysis, illustrating the division of communication types during the use of educational games. Of the total interactions analyzed, 77.5% were science-based, while 22.5% were general or joking in nature. The predominance of science communication indicates that the educational game effectively stimulated students to engage in meaningful scientific discussions in a natural and enjoyable setting. Interestingly, joking or off-topic communication typically emerged during transitional moments, such as while waiting for turns, after answering challenging questions, or following minor disagreements during gameplay. These moments served as social buffers, reducing tension, fostering peer bonding, and maintaining a psychologically safe learning environment. Far from being distractions, these interactions contributed to creating a relaxed classroom atmosphere that was conducive to sustained engagement.

Overall, the findings underscore the dual function of educational games: not only as a pedagogical tool to support the integration of science concepts, but also as a social context that promotes inclusivity, emotional comfort, and collaborative learning through participatory and contextual experiences.

Critical Analysis of Patterns, Trends, and Significant Relationships of Students' Scientific Arguments in the Educational Monopoly Game

The Monopoly educational game applied in the context of science learning in elementary schools has resulted in a significant pattern of scientific communication. Using the Toulmin Argumentation Pattern (TAP), this analysis identifies conceptual trends and relationships in the topics of the Water Cycle, the Solar System, and the Earth's Rotation. Its primary focus is on how students shape scientific claims, present data, and develop assurances and rebuttals in the context of game-based learning. Research in elementary schools shows that Monopoly's educational games significantly facilitate students' scientific communication on the topics of the Water Cycle, the Solar System, and the Earth's Rotation. Using the TAP, this analysis focuses on how students develop scientific claims, present supporting data, and formulate warrants (justifications) and rebuttals.

These games create an active and collaborative learning environment that encourages students to engage in critical thinking and logical reasoning. The integration of Monopoly and TAP is effective in developing 21st-century skills such as critical thinking and scientific communication, while demonstrating the adaptation of TAP in the context of game-based learning. Overall, the study highlights the innovative potential of educational games in promoting scientific reasoning and communication in primary education. aligns with research by Kantorski et al. (2025), which suggests that educational games create an interactive and immersive learning environment where students can actively explore and understand complex topics in an engaging and enjoyable way. These games have been shown to increase engagement and participation, encouraging critical thinking, collaboration, and information retention through simulated real-world scenarios. Game-based learning specifically facilitates the balanced integration of cognitive, affective, and social aspects.

Common Argumentation Patterns

In general, the findings show that in the context of the Monopoly educational game, a dominant argumentative pattern is characterised by the explicit presentation of claims and data. It indicates that students can state their scientific position or view (claim) and back it up with evidence or information they have obtained (data) from relevant gaming experience or knowledge. Clarity in the presentation of claims and data is a crucial foundation in scientific communication, as it enables the validity of the initial argument to be evaluated.

However, further analysis revealed that there are challenges in articulating other components of TAP, such as *warrants* and *qualifiers*, that are often not directly stated by students. *Warrant* (*warrant* serves as a logical bridge that explains why the data supports a claim). The absence of a direct warrant expression can imply that even if students have an intuitive understanding of the relationship between data and claims, they may not yet be fully able to formulate them into explicit general principles or reasons. This can be due to cognitive limitations at that age, a lack of practice in articulating abstract reasoning, or a focus on learning that has not been intensively emphasizing the justification aspect. *Qualifier* (*a qualifier* indicates the level of strength or limitation of a claim). The absence of a qualifier may indicate a student's tendency to make absolute claims without considering specific exceptions or conditions. This is an area that could be improved to develop more nuanced and scientific thinking.

Nonetheless, there are significant positive indicators of critical and collaborative thinking seen in student discussions, particularly through the many rebuttals that emerge. The emergence of rebuttals shows that students not only passively receive information, but are also able to:

1. Identifying weaknesses in arguments: They may find gaps or points that require further clarification or consideration in claims or data presented by their peers.
2. Presenting alternative perspectives: Rebuttals often stem from different understandings or additional information that other students have, enriching discussions and encouraging the construction of shared knowledge.
3. Engage in a dialogical process: The ability to refute and respond to rebuttals is at the heart of productive scientific discussions, where ideas are tested and refined through interaction.

Overall, these findings reflect that Monopoly's educational game can stimulate argumentative thinking processes with a fun and contextual approach. The immersive and interactive environment provided by the game reduces barriers to participation and encourages the exploration of ideas. While there is room for further development in the articulation of warrants and qualifiers, the existence of explicit claims, data, and rebuttals signals the great potential of educational games as tools to facilitate scientific communication and develop high-level thinking skills in elementary school students. In line with Roza, Siregar, and Solfitri (2020), who demonstrate that game-based learning can serve as an effective bridge between enjoyable learning and the development of complex cognitive skills.

TAP Analysis: Water Cycle

On the topic of the Water Cycle, a striking pattern is the power in mastering the sequence of processes (evaporation, condensation, precipitation). Students can submit scientific claims independently, supported by observational data. The rebuttal seems to be an answer like 'addition', which indicates a corrective process. Warrants are often implied, while qualifications are rarely visible. This topic is strong in building sequential logic and is highly contextual with students' daily experiences.

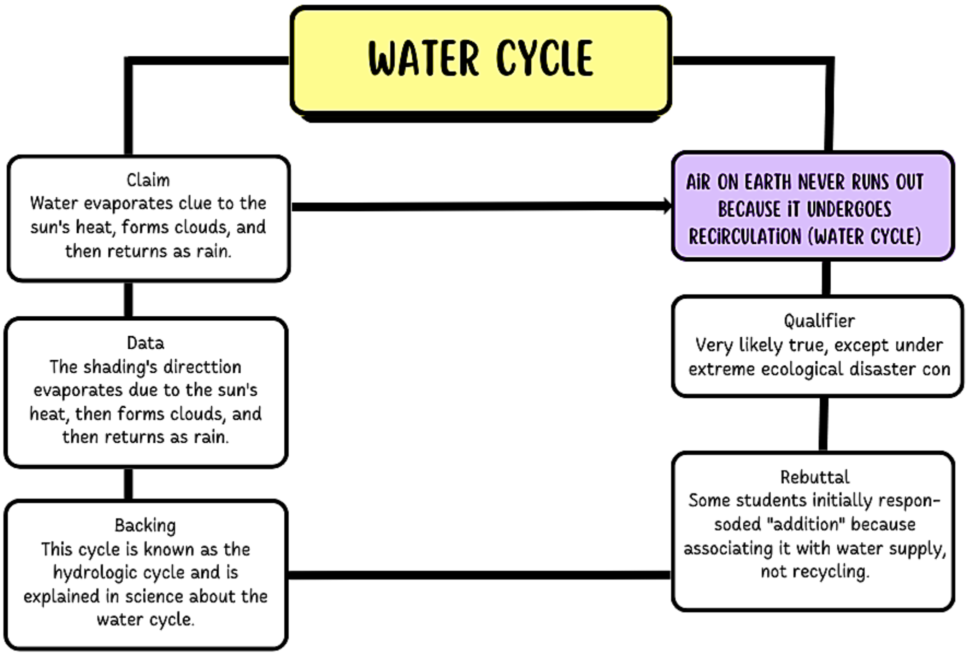

Figure 1. TAP analysis: water cycle

Figure 1 presents a scientific argument analysis regarding the water cycle using the TAP framework. This model is used to structure arguments logically and comprehensively. The main claim asserts that water on Earth is replenished continuously through the water cycle, ensuring it never runs out. This claim is supported by data explaining how water changes form: it evaporates due to the sun’s heat, condenses into clouds, and returns to Earth as precipitation. This process repeats in a natural recycling system. The backing reinforces this explanation with scientific justification, stating that this process is known as the hydrological cycle, which is commonly taught in science lessons. The argument also includes a qualifier, which acknowledges that the claim is likely to be true except under extreme ecological disaster conditions that might disrupt the cycle. The rebuttal section addresses a common misconception, where some students initially interpreted the term “addition” as referring to water availability, assuming that water increases through external supply rather than through internal recycling.

In this context, the term “addition” refers to the introduction of new water into a local water cycle from sources outside the natural recycling process. These internal processes typically include evaporation, condensation, precipitation, infiltration, and transpiration, which together form a relatively closed-loop system of water reuse. However, in reality, local water systems can receive external inputs. Examples of addition include surface water from upstream regions (such as river flow), rainfall that originates from water vapor produced in other ecosystems and transported by wind, and human-generated sources such as desalinated water, supplementary irrigation from external areas, or urban runoff entering natural systems. Thus, “addition” not only signifies an increase in water volume but also highlights that not all water within a system is generated from local recycling. Understanding this distinction is critical in environmental education, especially when discussing the dynamics and sustainability of water resources in a specific area.

TAP Analysis: Solar System

On the theme of the Solar System, students face conceptual challenges in distinguishing terms such as 'solar system' and 'galaxy'. The objections that emerge suggest a rich conceptual discussion. Claims and data are often precise, but warrants and endorsements are less explicit. Because the topic is abstract, it is natural for students to demonstrate a more declarative understanding than an analytical argumentative one.

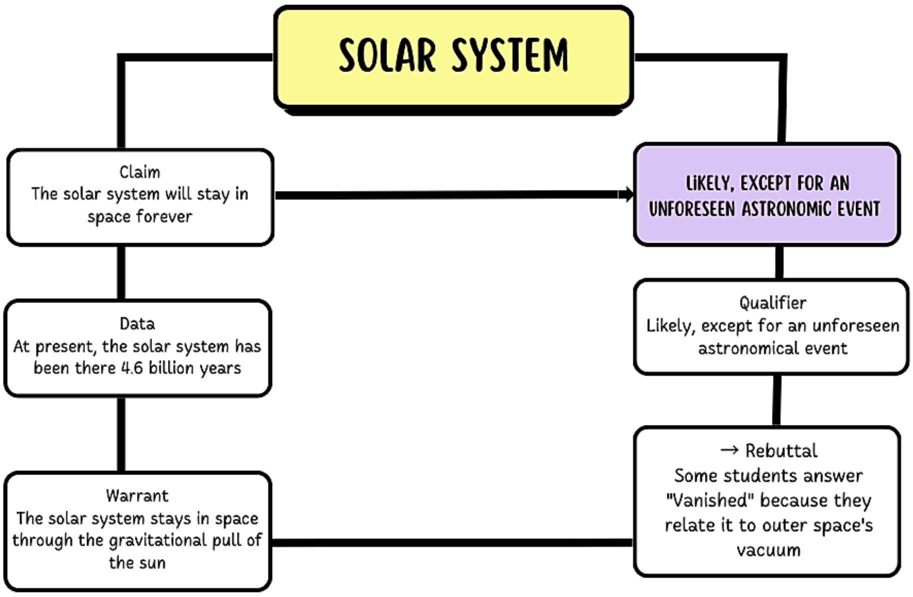

Figure 2 TAP analysis: solar system

The statement "The solar system will stay in space forever" reflects a main claim or conclusion proposed by students regarding the sustainability of the solar system in space. To support this claim, the students presented data indicating that the solar system has existed for 4.6 billion years, demonstrating its stability and sustainability over a very long period. This argument is strengthened by the warrant stating that the solar system remains in space due to the Sun's gravitational force, which keeps the planets attached to their orbits. However, the student also included a qualifier stating that it was "likely, except for an unforeseen astronomical event," indicating that the claim is not absolute, but rather probabilistic and open to possible changes due to unexpected astronomical events. On the other hand, some students provided a rebuttal, answering "vanished," because they attributed the existence of the solar system to the condition of a vacuum in space. This rebuttal highlights a misconception that some students still hold about the relationship between the vacuum of space and the existence of celestial bodies, underscoring the need for educators to clarify and reinforce the concept. Overall, this argument structure shows a fairly complex student understanding as well as active involvement in scientific discussions through the application of elements of the Toulmin Argumentation Pattern.

TAP Analysis: Earth's Rotation

The topic of Earth's Rotation generates arguments that are most closely related to students' real-life experiences, such as changes in shadows and day-night times. This strengthens students' ability to relate observations to scientific claims. The warrant often seems implicit, and the refutation is particularly active due to common misconceptions regarding the movement of the sun. This topic has high potential to introduce the concept of qualifiers and alternative reasoning.

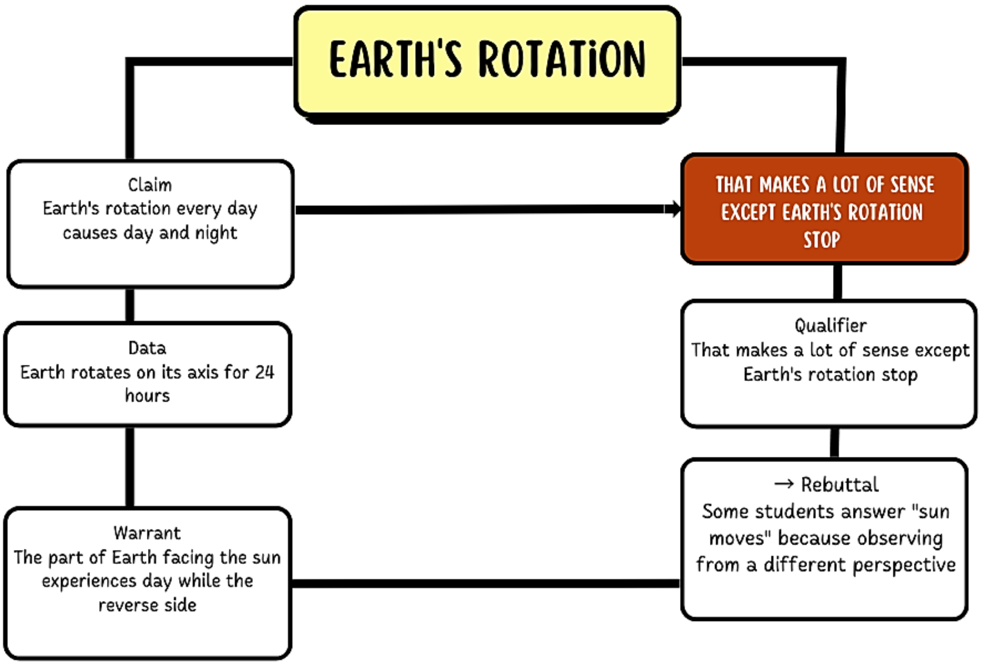

Figure 3. TAP analysis: earth's rotation

Figure 3 illustrates a scientific argument using the Toulmin Argumentation Pattern (TAP) to explain the phenomenon of day and night as caused by the Earth's rotation. The claim presented is that the Earth's daily rotation causes the alternation between day and night. This claim is supported by data stating that the Earth rotates on its axis once every 24 hours. This rotation serves as the foundational fact upon which the argument is built. To strengthen the logical connection between the data and the claim, the warrant is provided: the side of the Earth facing the Sun experiences daylight, while the opposite side remains in darkness. This logical explanation connects the process of rotation with the experience of day and night.

Furthermore, the argument includes a qualifier to acknowledge the condition under which the claim may not hold. It states that the explanation is valid unless the Earth's rotation were to stop, a hypothetical but scientifically meaningful scenario that establishes the limits of the claim's validity. The rebuttal addresses a common misconception among students, who often believe that the Sun moves around the Earth. This misunderstanding arises from the everyday observation that the Sun appears to rise and set, leading to an incorrect interpretation based on perspective rather than scientific reasoning.

Overall, this TAP analysis helps clarify the cause of day and night through a structured argument that is both scientifically accurate and pedagogically useful. It not only reinforces correct scientific understanding but also anticipates and corrects common errors in reasoning. This kind of analytical framework is especially effective in science education, as it encourages students to think critically about how evidence supports explanations and to recognize the role of perspective in shaping misconceptions.

The analysis of the three learning topics shows a significant relationship between students' real experiences and their ability to construct scientific arguments. Some important patterns that emerge include concrete topics, such as the rotation of the Earth, which tend to encourage direct observation and deep reflection from students. Meanwhile, abstract topics such as the solar system are more prone to misunderstandings, but they open up space for discussions about scientific classification. In transitional topics, such as the water cycle, students can combine sequential observations with a more organized conceptual framework. Additionally, there is a tendency for students to communicate data more easily than to construct warrants or qualifiers in their arguments. Rebuttals most often arise in the context of the Earth's rotation, indicating that misconceptions can actually serve as an important starting point to enrich scientific discussions in class. These patterns emphasize the importance of experience-based and dialogic approaches in strengthening students' scientific communication skills.

Table 3. Analysis of the conceptual strength of the three TAPs

Conceptual Aspects	Water Cycle	Solar	Earth's Rotation
Argumentative Arguments	Strong in *data*, *claims*, and *rebuttals*	Strong in *claims* and *warrants,* but *often weak* in backing	Strong in *data* and *warrants,* weak in *qualifiers*
Connection to Experience	High (rain, drinking water, heat)	Low (abstract, not directly visible)	Medium-high (day and night, direction of the sun)
Cognitive Complexity	Intermediate process sequences and visual representations	High involves classification and macro structure	Highly demanding changes in perspective and the mental rotation model
Rebuttal Clarity	Corrective to literal answers (addition vs turnover)	Term correction (solar system vs galaxy)	Conceptual rebuttal (the sun moving vs the Earth rotating)
Potential for Qualifier Strengthening	High (example: "water remains except in times of extreme drought")	Medium (can be discussed from long-term changes in the solar system)	Height (e.g., "during rotation, undisturbed

Monopoly educational games are not only a fun means but also an effective tool for forming scientific argumentative structures. The pattern suggests that elementary school students can build claims and submit data, as well as naturally correct misunderstandings through rebuttals. The challenge remains in the explicit components of warrants and qualifications.

Therefore, the teacher's assistance in rearranging the logic of arguments and providing trigger sentences is highly recommended to enrich students' scientific communication at the elementary level. The use of TAP shows that students are able to construct the "claims" and "data" components spontaneously and contextually. However, the components of "warrant" and "qualifier" are still very limited, both in frequency of occurrence and verbal explicitness. Claud's Word analysis corroborates these findings with a high frequency of descriptive terms but a lack of explicit cause-and-effect expression. To clarify the distribution of argumentative ability, we construct the following schema showing the distribution of TAP on three main topics:

Table 4. Distribution of argumentative skills

TAP Components	Water Cycle	Solar	Earth's Rotation
Claim	Very Often	Often	Very Often
Data	Very Often	Often	Very Often
Warrant	Sometimes It Appears	Infrequently	Sometimes It Appears
Backing	Infrequently	Infrequently	Infrequently
Qualifier	Almost None	Almost None	Almost None
Rebuttal	Frequent (corrective)	Frequent (definitive)	Very Frequent (conceptual)

From the table above, it can be seen that *rebuttals* are a component with potential for further exploration, as they actively arise when students experience misunderstanding s. Argumentative depth seems to be stronger on topics that have a direct relationship to the student's real experience, such as "the rotation of the Earth." For example, students easily associate changes in shadows and day-night time with rotational movements, thus sparking corrective discussions. In contrast, on topics such as the abstract concept of the "solar system," students have a harder time building an analytical understanding and tend to use declarative answers. These findings confirm the importance of teacher scaffolding in strengthening students' argumentative structures, especially for the "warrant" and "qualifier" components. In this context, scaffolding is conceptualized as a step-by-step support system, like a staircase, that helps students gradually move from simple expressions of opinion toward more complete and structured scientific arguments. To implement this scaffolding concretely, we recommend the following:

1. In-game trigger question cards, such as “*Why do you think that is the case*?”, “*What supports your idea*?”, and “*Under what conditions might this not apply*?” These serve as early steps that prompt students to expand beyond basic claims and begin justifying their ideas.
2. Post-game reflective sessions, where students are guided to reconstruct their arguments. Teachers can use this opportunity to identify missing reasoning

components and provide targeted prompts, thereby helping students ascend to more complex argumentation levels (e.g., including qualifiers and rebuttals).

Multimodal tools, such as argument maps, sentence starters, and visual templates, function as scaffolding “rungs” that support learners in organizing their thoughts, making connections between evidence and claims, and recognizing the limits or scope of their arguments. This staged support aligns with the concept of the Zone of Proximal Development (Vygotsky, 1978), helping students transition from what they can do independently to what they can achieve with structured guidance.

Strengthening Students' Scientific Communication

Educational game-based learning, such as Science Monopoly, is effective in encouraging natural, contextual scientific communication among elementary school students. Using the Toulmin Argumentation Pattern (TAP) approach, it was found that students are able to form claims and convey data, but still need guidance in the use of warrants and qualifiers. To reinforce this analysis, the Word Claud visualisation technique of students' verbal interactions is used in three main topics that arise during the game: the water cycle, the rotation of the Earth, and the solar system.

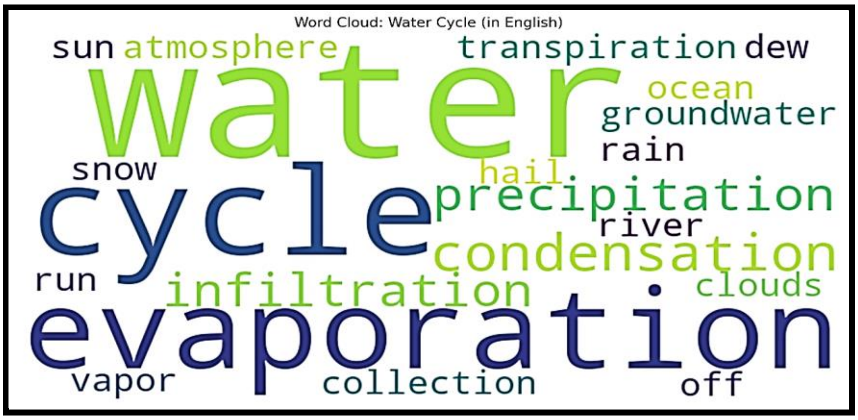

Figure 4. Word cloud: water cycle

Figure 4 illustrates the Word Cloud generated from students’ verbal interactions during the Science Monopoly game, specifically focusing on the topic of the water cycle. The most frequently occurring terms include water, evaporation, cycle, condensation, and sun, all of which are core elements of the water cycle concept. The prominence of these words in the Word Cloud suggests that students actively engaged with the topic and repeatedly referenced key ideas during the game-based discussions. In addition to these basic terms, the presence of more advanced scientific vocabulary, such as transpiration, infiltration, and precipitation, indicates that some students attempted to use more specific terminology, possibly reflecting recall of prior classroom learning. While the Word Cloud does not reveal the structure or depth of students’ reasoning, it offers a visual representation of the thematic salience and lexical engagement with scientific content.

We interpret these results with appropriate caution, avoiding direct assumptions about cognitive depth. However, as a complementary tool to argumentative analysis, the Word Cloud provides a useful overview of students’ linguistic focus and conceptual touchpoints within the water cycle domain.

This is an important indicator in the constructivism-based science learning process, where students build their knowledge through direct involvement and reflection on the learning experience. The students' success in not only mentioning but also integrating such terms into sentences, such as "water evaporates due to the heat of the sun", corroborates evidence of semantic and conceptual memory activation. It also supports information processing theory, which states that information encoding is more effective when it is associated with narrative context and causal reasoning. In addition, the use of these words in the form of argumentative sentences shows that students are beginning to practice scientific reasoning, a skill that is very important in the development of science literacy. From the perspective *of scientific discourse*, students' ability to use scientific vocabulary in an argumentative context signifies progress in internalizing the structure of scientific language necessary for the communication and exploration of natural phenomena in greater depth.

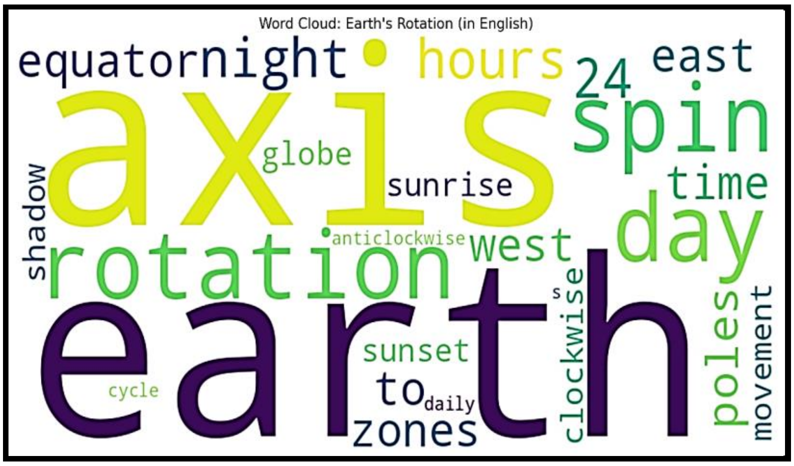

Figure 5. Word cloud: earth's rotation

Figure 5. shows the dominance of terms such as *earth*, *rotation*, *axis*, and *rotation*, reflecting students' focus on the mechanistic dimensions of the Earth's rotation. However, it is important to note that the emergence of these words reflects not only vocabulary mastery but also the potential involvement of students in high-level cognitive processes, especially in building scientific reasoning based on cause-and-effect relationships. For example, phrases that often come up from students, such as "the sun rises in the east because the earth rotates from west to east," are indications that they are beginning to understand the relationship between observational phenomena (sunrises) and the underlying scientific explanation (the direction of the earth's rotation). It reflects a *process of scientific reasoning* that involves understanding cause-and-effect relationships, a key component in the development of science literacy. However, a more critical analysis needs to be done to determine the extent to which this understanding is conceptual or merely reproductive. In many cases, students can assert such causal relationships without really understanding the spatial dynamics and underlying frame of reference. For example, the concept of "rotation of the earth from west to east" can be memorised without a visual or spatial understanding of how such movement results in a change in the position of the sun in the sky. *Paivio's dual-coding theory* suggests that the integration of verbal and visual representations is essential for building a complete conceptual

understanding, and in this context, relying solely on verbal pronunciation does not necessarily guarantee the depth of students' spatial understanding. Furthermore, the emergence of terms such as *axis* and *spin* suggests that students are beginning to associate the concept of rotation with the structural elements of the Earth; however, potential misunderstandings still need to be monitored. In science learning experiences, technical terms that are not explained through visual context or concrete practice can be a source of confusion. In constructivist-based teaching, it is essential to follow up on these findings with the exploration of model-based activities (e.g., the use of globes, light shadows, or digital simulations) that enable students to reframe their understanding through hands-on experience.

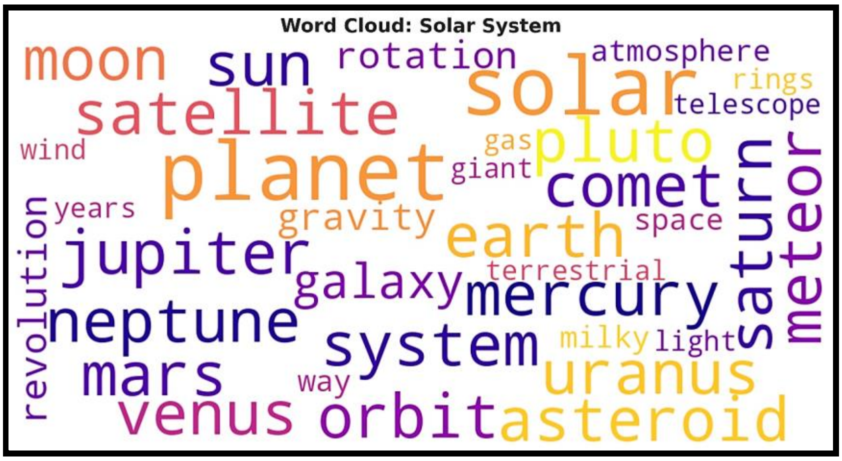

Figure 6. Word cloud: solar system

Figure 6 shows *the solar* system-themed Word Cloud, dominated by words such as *planet*, *sun*, *earth*, *orbit*, and *gravity*. The advent of these terms reflects that students have absorbed and activated some key concepts in basic astronomy, as well as being able to relate them in discussions during educational games. Most prominent here is the success of science-based Monopoly games as a contextual learning medium, where abstract concepts such as gravity and orbit are not taught expositorily, but rather emerge as the result of interaction and strategy in the context of the game. It supports a *place-based approach to cognition*, which emphasises that knowledge is best understood when it is learned in the context of its authentic use. Student statements such as "Jupiter is a large gaseous planet, so it has many satellites" became concrete evidence that students not only remembered isolated facts but also began to demonstrate the process of scientific thought through the relationship between the physical characteristics of planets and their structural impacts. This statement reflects a simple causal understanding rooted in the basic structure of scientific knowledge, as well as pointing *to the potential for* a more cohesive mental model of the solar system. Within the framework of science literacy, it is an important indicator that students begin to interpret science not only as a collection of definitions, but as a system of concepts that are interrelated and explain phenomena.

However, a critical approach needs to be applied to assess the depth of understanding. Although the students' arguments show valid conceptual linkages, most are still qualitative and have not demonstrated the use of empirical data or numerical amplification, such as the mass of planets, the number of satellites, or the orbital distance.

The absence of quantitative data shows that *data literacy* or *evidence-based reasoning* skills have not been fully developed, even though these two aspects are foundational in modern science learning that emphasises evidence-based reasoning. It is important for teachers to encourage the integration of real data in thematic learning like this, for example, through NASA infographic exploration, planetary characteristics tables, or simulation-based activities. In addition, *this Word Claud* can also serve as an indicator of students' cognitive representation of astronomy topics. Important concepts such as *asteroids*, *comets*, *satellites*, or *the Kuiper Belt have not yet* seemed striking, which could indicate that the scope of learning is still limited to the core of the solar system and has not yet reached a wider conceptual area. Therefore, teachers can use these outcomes as formative feedback to design follow-up activities that extend students' exploration to lesser-exposed aspects of play, for example, through dwarf planet case studies, exoplanet comparisons, or the impact of gravity in the trajectory of celestial bodies.

Thus, *this word cloud* is not just an overview of word frequency, but a window to understand the dynamics of students' cognitive development in understanding the solar system. He reflects on the integration between mastery of scientific vocabulary, the ability to connect concepts, and the potential to further develop evidence-based reasoning. Careful evaluation of what emerges and what does not emerge from these representations becomes an important cornerstone for designing more holistic, progressive, and transformative science learning.

Recorded results showing students' active involvement in scientific discussions during science-themed educational monopoly games show that game-based learning can be a powerful means of developing scientific communication. In this activity, students seem to be able to use scientific terms such as "evaporation", "rotation of the earth", and "planets" in the context of relevant discussions, indicating the transfer of knowledge from theoretical concepts to verbal practice. These findings are in line with Vygotsky's theory of the proximal developmental zone (ZPD)(Payong, 2020; Vygotsky, 1978), which states that social interactions, especially with peers, facilitate the development of new knowledge. In addition, effective scientific communication is an important aspect of an authentic science learning approach, where students not only memorise facts but also engage in the workings of scientists, including discussing, debating, and reflecting. However, the emergence of misunderstandings and inconsistencies in the use of terms confirms the importance of the presence of teachers as conceptual mediators. Teachers act as facilitators who assist students in purifying, defining, and consolidating scientific understanding in a systematic manner.

This educational game also opens up space for socio-scientific issue-based learning practices (SSI), which emphasise the importance of critical thinking, collaborative, and decision-making skills in the context of science. Through debates and discussions about answers or consequences in games, students not only express opinions but also learn to listen, evaluate the views of others, and build arguments based on logic and scientific evidence, essential skills in 21st-century science literacy (Mercer-Mapstone & Kuchel, 2017). This kind of interaction is in line with the principle of cooperative learning, where success is not only measured individually but also in groups. This kind of interaction aligns with the principles of cooperative learning, where success is shared collectively rather than individually. However, the data reveal that participation among students was not evenly distributed. Several factors contributed to this imbalance, including differences in confidence levels, verbal fluency, and prior familiarity with the science content. As a result, students who were already more vocal and assertive tended to dominate the discussion, while quieter students remained passive or only responded when directly prompted. Rather than leveling the playing field, the competitive and turn-based structure of the game sometimes amplified existing participation gaps, as dominant students were quicker to take the lead, articulate arguments, and challenge others. This highlights the need for deliberate scaffolding and facilitation strategies to ensure that every student has structured opportunities to speak, especially those who are typically less confident in verbal expression.

This reflects the challenges of implementing collaborative strategies, which are often dominated by specific students. Therefore, revisions to game design by adding role rotations or limiting talk time are important to ensure inclusivity and equitable distribution of learning opportunities. Game strategies that connect science concepts to students' daily lives support a domain-specific learning approach, which emphasises that effective learning occurs when content is presented in a context that is relevant and meaningful to students. Within this framework, students are seen as owners of initial knowledge that can be activated and developed through contextual and authentic experiences. For example, discussions about natural phenomena such as eclipses or daily water needs bridge conceptual understanding with students' empirical realities. However, technical terms such as "precipitation" or "revolution" that appear during the game must be explained in a multimodal way

▪ CONCLUSION

This study demonstrates that science-themed educational games, such as Science Monopoly, have the potential to facilitate meaningful scientific communication among elementary school students. Through the integration of curriculum-based content and the application of the TAP, students were able to construct claims and provide supporting data in an engaging, authentic learning environment. The findings affirm the role of educational games in promoting inquiry-based dialogue, especially when supported by scaffolding strategies that guide students toward using more complex argumentative elements such as warrants and qualifiers. The incorporation of Word Cloud analysis further enriched the study by identifying the thematic focus of student discussions, particularly on the water cycle, while revealing patterns of lexical engagement within scientific contexts.

The implications of this research highlight the importance of intentional design in educational games to ensure equitable participation and deeper cognitive engagement. While the game supported argumentation practice, participation was not evenly distributed; more confident students dominated the discourse, indicating a need for structured facilitation to empower quieter learners. The study also acknowledges its limitation in generalizability due to the small sample size and specific classroom context. Future research could explore the integration of teacher-led scaffolding during gameplay and the use of digital game platforms that allow adaptive support based on student responses. These directions align with Vygotsky's sociocultural theory, particularly the role of scaffolding within the ZPD, and provide a foundation for designing collaborative learning environments that strengthen scientific reasoning from an early age.

▪ REFERENCES

Agaoglu, F. O., Bas, M., Tarsuslu, S., Ekinci, L. O., & Agaoglu, N. B. (2025). The mediating digital literacy and the moderating role of academic support in the relationship between artificial intelligence usage and creative thinking in nursing students. *BMC nursing*, *24*(1), 484.

Chang, C. C., Tsai, L. T., & Meliana, D. (2023). "The concept of ocean sustainability in high school: measuring the ocean literacy of vocational high school students in indonesia." *Sustainability (Switzerland)* 15(2). doi: 10.3390/su15021043.

Cheng, L., Pang, W. Y. J., & Kong, A. (2025). "A virtual reality game for older adults' immersive learning." *Scientific Reports* 15(1):1–10. doi: 10.1038/s41598-025-07354-2.

Daya, Wawan, J., Ilham, Reza, H., Ugi, N., Alek, O., & Yusradinafi. (2025). "Integration of sports training and small games to improve the profile of pancasila students." *International Journal of Human Movement and Sports Sciences* 13(3):577–82. doi: 10.13189/saj.2025.130311.

DiCesare, D., Scheveck, B., Adams, J., Tassone, M., Diaz-Cruz, V. I., Van Dillen, C., ... & Walker, A. (2025). "The pit crew card game: a novel gamification exercise to improve ems performance in critical care scenarios." *International Journal of Emergency Medicine* 18(1). doi: 10.1186/s12245-024-00748-5.

Erduran, S., Simon, S., & Osborne, J. (2004). "TAPping into argumentation: development in the application of toulmin's argument pattern for studying science discourse." *Science Education* 88(6):915–33.

Ezgeta-Balić, D. A. R. I. A., & Balić, N. (2024). "Navigating through ocean literacy gaps: an analysis of elementary school textbooks in croatian education." *Mediterranean Marine Science* 25(1):1–13. doi: 10.12681/mms. 35378.

Haneklaus, N., Kaggwa, M., Misihairabgwi, J., Abu El-Magd, S., Ahmadi, N., Ait Brahim, J., ... & Lee, T. R. (2025). "The phosphorus negotiation game (p-game): first evaluation of a serious game to support science-policy decision making played in more than 20 countries worldwide." *Discover Sustainability* 6(1). doi: 10.1007/ s43621-024-00693-6.

Jensen, E. (2008). *Brain-Based learning: the new paradigm of teaching*. Corwin Press.

Kantorski, B., Bruzdewicz, K., Will, S., & Pollock, J. A. (2025). "Cards, Cubes, and Collaboration: A Case Study of the Development of an Educational Board Game." *Discover Education* 4(1). doi: 10.1007/s44217-025-00472-z.

Kaya, E. (2018). "Argumentation in elementary science education: addressing methodological issues and conceptual understanding." *Cultural Studies of Science Education* 13(4):1087–90. doi: 10.1007/s11422-017-9848-7.

Kulgemeyer, C., & Schecker, H. (2013). "Students explaining science assessment of science communication competence." *Research in Science Education* 43:2235–56.

Ldokova, G., Frumina, S., & Alwaely, S. A. (2025). "Taking into account students' psychotypes and using their neuropsychological maps when implementing digital educational technologies within the metaverse." *Smart Learning Environments* 12(1). doi: 10.1186/s40561-024-00344-3.

Le Blanc, D., Freire, C., & Vierros, M. (2017). "Mapping the linkages between oceans and other sustainable development goals: a preliminary exploration." *DESA Working Paper* 1(149):34.

León-Reyes, Bismark, B., Galeano-Rojas, D., Gámez-Vílchez, M., Farias-Valenzuela, C. , Hinojosa-Torres, C. & Valdivia-Moral, P. (2025). "Strength training in children: a systematic review study." *Children* 12(5):1–17. doi: 10.3390/children12050623.

Madu, G., Bei, K., Andreopoulos, S., & Steiner, M. (2025). "Design and execution of remote structured programming for students' summer undergraduate research experiences." *Discover Education* 4(1). doi: 10.1007/s44217-025-00515-5.

Mafugu, T., Nzimande, E., & Makwara, C. (2024). "Teachers' perceptions of integrative stem education in life sciences classrooms." *Eurasia Journal of Mathematics, Science and Technology Education* 20(11). doi: 10.29333/ejmste/15624.

Mercer-Mapstone, L., & Kuchel, L. (2017). "Core skills for effective science communication: a teaching resource for undergraduate science education." *International Journal of Science Education, Part B* 7(2):181–201.

Michael, J., & Modell, H. I. (2003). *Active learning in secondary and college science classrooms: a working model for helping the learner to learn*. Routledge.

Mintzes, J. J., & Wandersee, J. H. (2005). "Reform and innovation in science teaching: a human constructivist view." Pp. 29–58 in *Teaching science for understanding*. Elsevier.

Oanh, D. T. K., & Dang, T. D. H. (2025). "Effect of STEAM project-based learning on engineering students' 21st century skills." *European Journal of Educational Research* 14(3):705–21. doi: 10.12973/eu-jer.14.3.705.

Ogegbo, A. A., & Aina, A. Y. (2024). "Exploring young students' attitude towards coding and its relationship with STEM career interest." *Education and Information Technologies* 29(8):9041–59. doi: 10.1007/s10639-023-12133-5.

Oh, J.Y. (2014). "Understanding the alternative conceptions of pre-service secondary science teachers about tidal phenomena based on toulmin's argumentation." *International Journal of Science and Mathematics Education* 12(2):353–70. doi: 10.1007/s10763-013-9403-2.

Payong, M. R. 2020. *Zona perkembangan proksimal dan pendidikan berbasis konstruktivisme sosial menurut lev semyonovich vygotsky* [Zone of proximal development and social constructivism-based education according to lev semyonovich vygotsky]. *Jurnal Pendidikan Dan Kebudayaan Missio* 12(2):164–78.

Prastika, A. Y., Nadhifah, M., & Afkar, T. 2025. *Implementasi Dalam Pemanfaatan Aplikasi Wordwall Pada Pembelajaran Bahasa Indonesia Materi teks argumentasi kelas Xi di SMK Hasyim Asy'ari* [Implementation of the use of wordwall applications in indonesian language learning for argumentative text material for class XI at Hasyim Asy'ari Vocational School]. *Jurnal Pengembangan Dan Penelitian Pendidikan* 7(1).

Qablan, A., Nowfal, N., Al-Faiadh, T., Pearson, E., Alkaabi, A., Alhashmi, H., ... & Al Shamsi, A. Y. (2025). "Mapping the representation of four sdgs in international elementary science curriculum and textbooks." *Eurasia Journal of Mathematics, Science and Technology Education* 21(3). doi: 10.29333/ejmste/16042.

Rapanta, C., Macagno, F., & Jenset, G. (2025). "A close look at children's and adolescents' arguments: combining a developmental, educational, and philosophica perspective." *European Journal of Psychology of Education* 40(1):1–30. doi: 10.1007/s10212-024-00914-6.

Roza, Y., Siregar, S. N., & Solfitri, T. (2020). "Ethnomathematics: design mathematics learning at secondary schools by using the traditional game of melayu riau." *Journal of Physics: Conference Series* 1470(1). doi: 10.1088/1742-6596/1470/1/012051.
Samad, N. A., Osman, K., & Nayan, N. A. (2023). Computational thinking through the engineering design process in chemistry education. *International Journal of Educational Methodology*, *9*(4), 771–785.
Stevens, L. & Wrenn, C. (2013). "Exploratory (qualitative) research." *Concise Encyclopedia of Church and Religious Organization Marketing* 53.
Tenriawaru, A. B., & Putra, D. A. (2021, March). Profile of argumentation skills using Toulmin's argumentation pattern (TAP) in senior high school students in biology learning: preliminary research. In *Journal of Physics: Conference Series* (Vol. 1842, No. 1, p. 012065). IOP Publishing.
Tomovic, C., McKinney, S., & Berube, C. (2017). "Scientific literacy matters: using literature to meet next generation science standards and 21st century skills." *K-12 Stem Education* 3(2).
van Antwerpen, N., Green, E. B., Sturman, D., & Searston, R. A. (2025). The impacts of expertise, conflict, and scientific literacy on trust and belief in scientific disagreements. *Scientific Reports*, *15*(1), 11869.
Vygotsky, L. S. (1978). *Mind in society: the development of higher psychological processes*. Vol. 86. Harvard University Press.
Wambsganss, T., Niklaus, C., Cetto, M., Söllner, M., Handschuh, S., & Leimeister, J. M. (2020). "AL: An Adaptive Learning Support System for Argumentation Skills." Pp. 1–14 in *Proceedings of the 2020 CHI conference on human factors in computing systems*.
Wei, X., Wang, L., Lee, L. K., & Liu, R. (2025). "The effects of generative ai on collaborative problem-solving and team creativity performance in digital story creation: an experimental study." *International Journal of Educational Technology in Higher Education* 22(1). doi: 10.1186/s41239-025-00526-0.
Wu, J. H., Su, P. H., Wu, H. Y., Hsin, Y. M., Lin, C. H., & Lee, C. Y. (2025). "Educational board game for training dental and dental hygiene students in patient safety issues." *BMC Medical Education* 25(1). doi: 10.1186/s12909-025-07115-9.