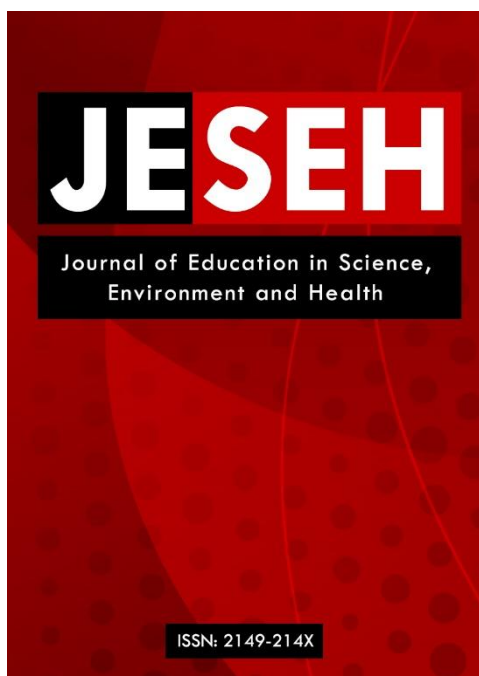




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Students' Experiences of an Artificial Intelligence-Supported Virtual Learning Environment in Science Lessons: A Case Study

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Abstract

The purpose of this study was to examine students' learning experiences and their awareness of AI literacy during the instruction of the *Energy Transformations and Environmental Science* unit in the eighth-grade Science course through an AI-supported virtual learning environment. This study employed a qualitative embedded single-case study design. The study group consisted of 20 students (12 girls and 8 boys) selected through criterion sampling. Data were collected using an open-ended questionnaire following a 16-class-hour instructional implementation and analyzed through content analysis. The findings revealed that the AI-supported virtual learning environment facilitated students' understanding of abstract concepts through instant feedback and interactive learning materials while also enhancing their motivation toward the Science course. Furthermore, the students developed a critical awareness of AI by recognizing not only its benefits but also its limitations, including the potential to generate hallucinated responses and conceptual errors. Overall, the findings suggest that AI-supported virtual learning environments are not only effective instructional support tools but also valuable learning environments that contribute to the development of students' AI literacy.

Introduction

Rapid advances in science and technology have brought about significant changes in educational systems. Science education, in particular, is a dynamic discipline that continually evolves and interacts with emerging technologies rather than remaining static (Geldi & Orhan, 2025). The integration of artificial intelligence (AI) into education enhances students' engagement with academic content and maximizes the pedagogical potential of virtual learning environments. Highly interactive virtual environments, in particular, provide immersive learning experiences that encourage students to actively engage with instructional materials. Recent studies have highlighted two primary functions of integrating AI technologies into educational settings: (a) personalizing instruction according to students' individual learning pace and needs (Chen et al., 2020; Temur, 2025), and (b) increasing student engagement through real-time interactions facilitated by algorithms and AI-powered chatbots (Karsenti, 2019; Turhan & Nas, 2025). From this perspective, AI-supported virtual learning environments are emerging as pedagogical learning environments that promote students' active participation in the learning process rather than positioning them as passive recipients of information.

Contemporary educational approaches aim to cultivate individuals who not only acquire knowledge but also actively seek, question, and critically evaluate information while effectively using current technologies as learning tools. Within this context, the Science course plays a crucial role in helping students understand both their immediate environment and the broader world. However, science is also recognized as a discipline that includes abstract concepts, complex processes, and phenomena that cannot be directly observed, making it challenging for many students to learn. These challenges are particularly evident in units such as Energy Transformations and Environmental Science, where students are expected to develop conceptual understanding of complex scientific processes. Consequently, there is a growing need to investigate how students interact with virtual learning environments while learning such content.

Recent research suggests that students' interactions with digital systems produce not only academic outcomes but also multidimensional experiences that shape their cognitive and psychosocial perceptions (Liu et al., 2026). Evaluating these learning experiences solely through academic achievement tests may be insufficient to explain the nature of students' interactions with AI and how they make sense of these interactions during the learning process. The educational quality of students' dialogues with algorithms and AI-powered chatbots, the ways they interpret immediate feedback, and the cognitive transformations they experience throughout this process can be more effectively explored through qualitative inquiry. Accordingly, there is an increasing need for qualitative

studies that move beyond examining how much students learn and instead focus on how they experience, interpret, and make sense of AI-supported learning processes within science education.

A review of the literature indicates that students experience considerable difficulties in learning and understanding concepts related to photosynthesis and respiration (Bacanak et al., 2004). Traditional instructional approaches, two-dimensional visuals, and static learning materials are often insufficient for helping students concretize such abstract concepts and dynamic processes and for addressing existing misconceptions. Developing an understanding of cellular processes such as photosynthesis or multistep processes such as energy transformations requires interactive learning tools that actively support knowledge construction. This highlights the growing pedagogical need for innovative, dynamic, and interactive educational technologies. Accordingly, the development of AI-supported digital learning environments has been recommended to facilitate students' understanding of such abstract concepts in science classrooms (Pektaş et al., 2026).

These AI-supported digital technologies, which are transforming traditional instructional practices, demonstrate their greatest educational potential in virtual learning environments that provide instant feedback and opportunities for interactive dialogue. The interactive learning process that takes place in these environments closely aligns with Kolb's (1984) Experiential Learning Theory. Students' direct engagement with simulations represents the Concrete Experience stage, while reflecting on the immediate feedback they receive corresponds to Reflective Observation. Constructing an understanding of abstract processes, such as photosynthesis, through the guidance of the AI assistant reflects the Abstract Conceptualization stage. Subsequently, testing this newly acquired understanding through continued dialogue with the AI corresponds to Active Experimentation. In this way, technology moves beyond serving merely as a medium for information delivery and instead provides a foundation for an experiential learning cycle.

In the present study, AI literacy is conceptually integrated with Kolb's Experiential Learning Theory rather than treated as a separate technological competency. AI literacy encompasses interconnected competencies related to understanding AI systems, using AI effectively, critically evaluating AI-generated outputs, and engaging with AI in ethical and responsible ways (Ng et al., 2021). Recent research suggests that experiential learning can provide a meaningful pedagogical framework for developing AI literacy by engaging learners in direct interaction with AI, reflection on their experiences, conceptual development, and application in new situations (Gnoth & Novak, 2025). Research conducted with secondary school students has also demonstrated the applicability of experiential learning principles to AI-related learning (Hsu et al., 2022).

Accordingly, this study establishes a conceptual relationship between the four stages of Kolb's experiential learning cycle and different dimensions of AI literacy. During the Concrete Experience stage, students interact directly with simulations and the AI assistant, providing opportunities to develop awareness of AI capabilities and functions while gaining practical experience in using AI-supported learning tools. During Reflective Observation, students examine simulation outcomes and reflect on the feedback provided by the AI assistant, creating opportunities to recognize and critically consider the strengths and limitations of AI-generated responses (Delanoy, 2026). During Abstract Conceptualization, students use AI-supported explanations and dialogue to construct scientific concepts while evaluating whether these explanations are consistent with their observations and existing scientific understanding. Finally, during Active Experimentation, students test their emerging understanding through continued interaction, follow-up questions, and the application of explanations to new situations. This process also provides opportunities for students to recognize the importance of verifying AI-generated information and to develop more critical and responsible practices in their use of AI (Delanoy, 2026; OECD, & European Commission. (2026).

These environments go beyond functioning as passive platforms that merely digitize information. Instead, they serve as dynamic learning ecosystems that interact directly with students, adapt to their level of understanding and learning pace, identify learning gaps in real time, and provide immediate instructional support. The use of AI in education has been reported to generate positive outcomes for both students and educators. While AI-supported tools foster interactive learning environments by enhancing students' motivation and classroom engagement, preservice teachers have also demonstrated positive attitudes toward the potential of these technologies to facilitate personalized learning and provide innovative educational solutions. This suggests that educators are becoming increasingly prepared to pedagogically integrate emerging AI technologies into future teaching and learning practices (Eltahir & Babiker, 2024).

The increasing integration of AI technologies into educational settings requires students not only to use these systems effectively but also to evaluate them from a critical perspective. Accordingly, AI literacy is regarded as a multidimensional competency that encompasses awareness, use, evaluation, and ethical considerations.

Supporting this perspective, Kazancı Tınmaz and Atmaca (2026) reported that preservice teachers demonstrated high levels of awareness, use, evaluation, and ethical responsibility regarding AI applications. Their findings also indicated that preservice teachers were able to critically evaluate AI technologies while recognizing the ethical responsibilities associated with their use.

Given the large class sizes in today's schools, it is often difficult for teachers to provide immediate feedback to every student and personalize instruction according to individual learning needs. Furthermore, many existing digital learning materials position students as passive recipients of information. Previous research has consistently shown that AI-supported learning environments enhance students' academic achievement (Almasri, 2024; Bayram & Çelik, 2023), support personalized learning experiences (Holmes et al., 2019), and positively influence students' attitudes toward the Science course (Arduç, 2025). Despite these advantages, most existing AI-supported learning tools primarily focus on delivering information or providing standardized feedback. Therefore, it is important to investigate the potential contribution of AI-supported conversational assistants, designed in accordance with curriculum learning outcomes and students' developmental characteristics, to eighth-grade students' learning processes in complex science topics such as Energy Transformations and Environmental Science.

Previous research on AI-supported learning has primarily examined its effects on students' motivation, academic achievement, and active participation in learning processes (Alkan, 2025). For example, Güneş and Yılmazlar (2025) examined the integration of ChatGPT with the REACT strategy in science education and reported a significant effect on students' academic achievement. Most existing studies have focused on the quantitative effects of AI-supported learning environments on academic achievement (Almasri, 2024; Dong et al., 2025) and motivation (Alkan, 2025). However, relatively little attention has been paid to how eighth-grade students construct an understanding of abstract scientific processes, respond to Socratic dialogue, or develop critical AI literacy when confronted with inaccurate AI-generated responses, including AI hallucinations.

Against this background, the present study seeks to move beyond examining how much AI contributes to science learning by exploring how students experience and make sense of their interactions with AI. Specifically, the study qualitatively investigates the cognitive processes underlying student–AI interaction and the development of AI literacy within the framework of Kolb's (1984) Experiential Learning Theory. To address the identified gap in the literature, an AI-supported virtual learning environment was specifically developed for eighth-grade students. Rather than functioning as a conventional chatbot, this web-based learning environment was designed as an interactive AI-supported conversational assistant that guides students through pedagogically structured dialogue, provides personalized real-time feedback, and supports the construction of abstract and complex concepts in the *Energy Transformations and Environmental Science* unit.

Within this context, qualitatively examining how AI-supported virtual learning environments influence eighth-grade students' science learning experiences is essential for understanding the pedagogical dimension of technology integration. Accordingly, the primary purpose of this study is to explore students' learning experiences, their conceptual understanding, and the nature of their interactions with AI in science education from a qualitative perspective. In doing so, the study demonstrates how AI-supported virtual learning environments can function not merely as tools for information delivery but as environments that foster meaningful knowledge construction.

The principal contribution of this study lies in the development of a web-based integrated virtual learning environment specifically designed for middle school science education. Unlike the conventional use of general-purpose generative AI systems, which are not inherently designed around specific pedagogical goals, education-oriented AI can be intentionally structured to support learning through context-sensitive guidance, feedback, and pedagogically meaningful interactions OECD, & European Commission. (2026). In the present study, a large language model was integrated directly into curriculum-aligned interactive science simulations rather than being used as a separate, general-purpose information source.

The AI assistant was designed not merely to provide information but to function as a pedagogical guide during students' interaction with the simulations. Accordingly, it provided immediate feedback, posed guiding questions, supported students in interpreting simulation outcomes, and encouraged them to reconsider and test their understanding. This design is consistent with recent research showing that generative AI pedagogical agents can provide contextualized and adaptive guidance during simulation-based science learning (Chao et al., 2026; Wen et al., 2026). In particular, Chao et al. (2026) demonstrated the potential of generative AI pedagogical agents to provide proactive and context-sensitive scaffolding by connecting AI support with students' ongoing interactions within simulation-based learning environments.

In addition, the AI assistant in the present study was restricted to the learning outcomes addressed in the target unit through a customized pedagogical system prompt. Thus, the proposed environment brings together interactive science simulations, curriculum-aligned LLM-supported dialogue, and immediate pedagogical feedback within a single learning environment. Rather than positioning generative AI as a standalone source of information, the environment integrates AI support into the students' ongoing exploration and interpretation of scientific phenomena. This integration is consistent with emerging research emphasizing the value of contextualized AI guidance during simulation-based learning (Wen et al., 2026; Chao et al., 2026) and with the broader emphasis on designing AI-supported educational experiences that enable learners to interact with AI in purposeful and responsible ways OECD, & European Commission. (2026). Consequently, the study contributes to the literature by illustrating how an LLM can be embedded within an interactive, curriculum-aligned science learning environment to provide pedagogically structured support rather than functioning solely as a general-purpose conversational tool.

To achieve the primary purpose of the study, the following research questions were addressed:

1. What are students' views on how the interactions and immediate feedback provided by the AI-supported virtual learning environment contributed to their construction of abstract concepts, such as energy transformations?
2. What are students' views regarding the ease of use, challenges, and overall satisfaction they experienced while using the AI-supported virtual learning environment?

Method

Research Design

This study adopted a qualitative embedded single-case study design to examine eighth-grade students' interactions with an AI-supported virtual learning environment during their learning of the Energy Transformations and Environmental Science unit in the Science course. According to Merriam and Tisdell (2016), a case study is a qualitative research approach that aims to provide an in-depth description and analysis of a bounded system. Likewise, Yin (2009) argued that a case study is the most appropriate research strategy when the boundaries between a phenomenon and its real-life context are not clearly defined.

Following the framework proposed by Yıldırım and Şimşek (2021, pp. 304–305), the study was conducted through the following stages: (a) formulating the research questions, (b) developing the research sub-questions, (c) identifying the unit of analysis, (d) defining the case to be investigated, (e) selecting the study participants, (f) collecting the data and relating them to the research sub-questions, (g) analyzing and interpreting the data, and (h) reporting the case study.

An embedded single-case study design was considered appropriate because students' perspectives on abstract scientific concepts in innovative learning environments, such as AI-supported virtual learning environments, are multidimensional and cannot be adequately explained through quantitative data alone. In an embedded single-case study, the case includes multiple embedded units of analysis, enabling different aspects of the same case to be examined in depth (Yıldırım & Şimşek, 2021, p. 313).

Study Group

The study group was determined using purposeful sampling, a non-probability sampling strategy that is consistent with the nature of qualitative research. Purposeful sampling involves selecting information-rich cases or individuals that are expected to provide in-depth insights into the phenomenon under investigation (Patton, 2015). Among the purposeful sampling strategies, criterion sampling was employed to select the participants. In criterion sampling, participants are selected based on predetermined criteria established by the researcher (Yıldırım & Şimşek, 2021, p. 120).

The inclusion criteria for participation in the study were as follows:

1. Being enrolled in the eighth grade at a public middle school affiliated with the Turkish Ministry of National Education.

2. Actively participating in the instruction of the Energy Transformations and Environmental Science unit in the Science course.
3. Voluntarily agreeing to participate in the study and obtaining parental consent.
4. Having access to adequate computer and Internet facilities provided by the school throughout the implementation process.

Based on these criteria, the study group consisted of 20 eighth-grade students (12 girls and 8 boys) enrolled in a public middle school located in the Southeastern Anatolia Region of Türkiye during the 2025–2026 academic year. Prior to implementation, preliminary interviews were conducted to determine whether the participants had previous experience with similar educational technologies and AI applications. The interviews indicated that the students had comparable levels of AI and technology readiness. Most participants reported having limited prior experience with simulation-based learning activities in science classes and being familiar with generative AI tools such as ChatGPT and Gemini. To ensure participant confidentiality and comply with research ethics, each student was assigned a unique identifier (e.g., S1, S2, S3), and no real names were used at any stage of the study.

Prior to data collection, ethical approval was obtained from the Ethics Committee for Social and Human Sciences Research of Kırıkkale University, and official permission was granted by the Provincial Directorate of National Education responsible for the participating school. In addition, before the implementation began, both the participating students and their legal guardians were informed about the purpose of the study, the research procedures, and the confidentiality of the collected data. Written informed consent was obtained from both the students and their parents or legal guardians. These procedures were undertaken to ensure the ethical integrity, transparency, and trustworthiness of the study.

Data Collection

For this study, a web-based AI-supported virtual learning environment was developed to facilitate students' learning of the *Energy Transformations and Environmental Science* unit. The environment was organized into separate modules corresponding to all curriculum learning outcomes included in the unit. Students were able to access the AI-supported learning interface either by following the instructional sequence of the course or by freely selecting any module according to their individual learning preferences.

Within each module, the intended learning outcomes were supported through interactive simulations integrated with an AI-powered conversational assistant. This integrated learning environment enabled students to receive immediate feedback, ask content-related questions, interpret scientific data and simulation outputs, and generate practice questions for assessment purposes. Consequently, the system provided students with a personalized and interactive learning experience throughout the instructional process.

The integration of the large language model (LLM) into the simulation environment served a pedagogical function beyond that of a general-purpose conversational AI tool. Rather than operating as an independent source of information, the AI assistant was used in direct connection with the students' interactions with the simulations. When students examined a simulation, they could ask questions about their observations, receive immediate feedback, request clarification, and obtain guiding prompts that encouraged them to reconsider their observations and construct scientific explanations. In this way, the LLM supported the interpretation of simulation outputs and provided a continuous dialogue between students' concrete experiences and their emerging conceptual understanding.

The pedagogical integration of generative AI into an interactive science learning environment is consistent with Wei et al. (2025), who incorporated generative AI-enhanced pedagogical agents into an augmented reality-based 5E learning environment to scaffold students' science learning. The integration therefore positioned the LLM as a pedagogical guide embedded within the learning process rather than as a separate tool used primarily for information retrieval. An example of the interaction between a student and the AI assistant within the virtual learning environment is presented in Figure 1.

The AI-supported virtual learning environment used in this study was developed by the researcher to enable students to interact simultaneously with an AI-powered conversational assistant and interactive science simulations. The system was designed as a web-based learning environment using HTML and JavaScript for the user interface. The AI component was implemented through the OpenAI API, using the GPT-3.5-Turbo large language model (OpenAI, 2024).

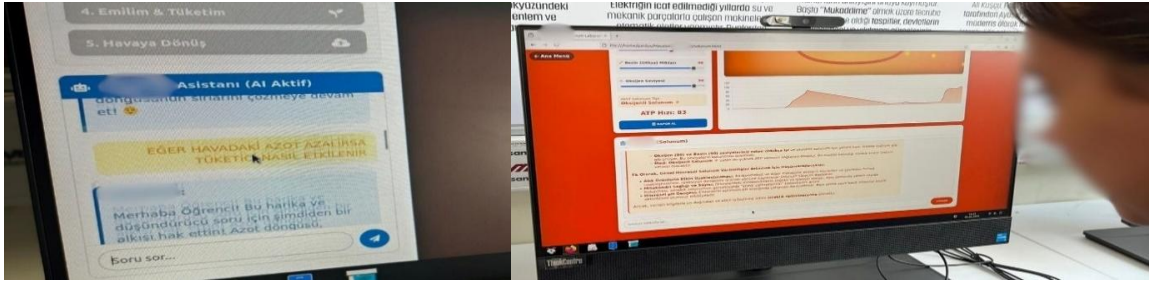


Figure 1. Student interaction with the AI-supported virtual learning environment during the *Energy Transformations and Environmental Science* unit.

To ensure that the AI assistant operated within clearly defined pedagogical boundaries and to minimize the risk of AI hallucinations commonly associated with generative AI systems, a customized system prompt was developed. The model was instructed as follows: You are an educational assistant developed for the eighth-grade Science course, specifically for the Energy Transformations and Environmental Science unit. Rather than providing students with direct answers, you should guide them to examine the on-screen simulations, provide hints, encourage inquiry through questioning, and support them in constructing scientific understanding. Communicate in a friendly and engaging manner while encouraging students to think critically and reach conclusions independently. In addition, the model was restricted to answering only questions related to the curriculum learning outcomes addressed in the study. Questions outside the scope of the curriculum were intentionally excluded through appropriate system instructions to ensure that the AI assistant remained focused on the instructional objectives.

The AI assistant was integrated into the web-based learning environment through the OpenAI API using an API key. In large language models, the temperature parameter controls the degree of randomness in text generation, with lower values generally producing more focused and deterministic outputs (Tophel et al., 2025). Low temperature settings have also been employed in educational applications to control output variability; for instance, Kwak and Pardos (2024) set the temperature of GPT-3.5-turbo to 0.2. Accordingly, in the present study, the temperature parameter was set to 0.2 to promote response consistency and limit unnecessary variability in AI-generated explanations. This configuration was considered appropriate for an educational context in which consistency and scientific accuracy were prioritized over creative variation.

Despite these precautions, it was observed that, consistent with the nature of generative AI models, the system occasionally produced incomplete or inaccurate responses. This observation was also reflected in the study findings. Several students reported that AI systems should not always be regarded as completely reliable sources of information and emphasized the importance of verifying AI-generated responses using additional sources. These experiences contributed to the development of students' AI literacy, encouraging them to view AI not as an unquestionable source of information but as a learning tool that should be critically evaluated.

The implementation and data collection process was conducted concurrently with the instructional schedule of the *Energy Transformations and Environmental Science* unit in the eighth-grade Science curriculum. The implementation lasted 16 class hours, during which students actively interacted with the AI-supported virtual learning environment. Throughout the implementation, instructional techniques such as the Predict–Observe–Explain (POE) strategy and the station technique were employed to promote active learning and student engagement. These techniques enabled students to interact with the AI-supported learning environment, examine simulations, discuss their observations, and construct scientific concepts through inquiry and guided feedback. Examples of the implementation process are presented in Figure 2.



Figure 2. Classroom implementation of the AI-supported virtual learning environment.

Throughout the implementation, the AI-supported virtual learning environment was used to help students develop a deeper understanding of abstract scientific concepts, such as photosynthesis, respiration, and energy transformation processes, through the immediate feedback provided by the AI assistant (Hwang et al., 2020). Rather than serving as the primary source of information, the teacher assumed the role of a facilitator by observing students' interactions with the AI-supported virtual learning environment, managing the instructional process, and providing technical guidance when necessary (Zawacki-Richter et al., 2019).

Following the completion of the implementation period, an open-ended questionnaire developed by the researcher was administered to obtain an in-depth understanding of students' experiences with the AI-supported virtual learning environment. The questionnaire consisted of six open-ended questions, three of which focused on students' experiences with artificial intelligence and three on their learning experiences and perceived learning outcomes in science.

The questionnaire was designed to enable students to freely express, in their own words, their cognitive and psychosocial perceptions, as well as the opportunities and challenges they encountered during the implementation process (Yıldırım & Şimşek, 2021, p. 85). To establish the content validity of the instrument, the questionnaire was developed based on a review of the relevant literature and revised in accordance with expert feedback.

After the instructional implementation had been completed, the questionnaires were distributed to all participants, and their written responses regarding the effects of the AI-supported virtual learning environment were collected. Before completing the questionnaire, students were informed that their responses would remain confidential, that there were no right or wrong answers, and that their responses would not affect their academic evaluation. They were therefore encouraged to answer the questions honestly and reflect on their experiences as accurately as possible.

Data Analysis

The qualitative data collected through the open-ended questionnaire were analyzed using content analysis. Content analysis is a systematic analytical method that aims to identify codes and reveal the relationships among them in order to explain the collected data. During this process, similar data are organized into meaningful concepts, categories, and themes, enabling complex qualitative data to be presented in a form that is more understandable and interpretable for readers (Büyüköztürk et al., 2018, p. 259). The analysis began by transferring the written responses of the 20 participants regarding their experiences with the AI-supported virtual learning environment into Microsoft Excel, where the raw dataset was compiled. During this process, the originality of the data was carefully preserved, and no modifications were made to the participants' responses.

Subsequently, the responses were read line by line, and meaningful words, phrases, and sentences reflecting students' experiences with the AI-supported virtual learning environment and their science learning were identified and coded (Creswell & Creswell, 2018). Related codes were then grouped together to generate broader and more comprehensive themes. These codes and themes are presented in the Findings section together with representative quotations from the participants, without interpretive commentary, in accordance with the principles of qualitative data reporting. To ensure the reliability of the coding process, intercoder reliability was established. Intercoder reliability refers to the degree of agreement between independent coders regarding how qualitative data should be coded (O'Connor & Joffe, 2020). Accordingly, the data initially coded by the researcher were independently reviewed and coded by a second researcher with expertise in qualitative research methods and science education.

Although previous studies have suggested that reviewing approximately 30–40% of the dataset is generally sufficient for establishing intercoder reliability, the second coder analyzed the entire dataset in the present study because the number of participants was relatively small. The codes and themes generated by the two coders were then compared, and the intercoder reliability coefficient was calculated using the formula proposed by Miles and Huberman (1994): $\text{Reliability} = \frac{\text{Agreement}}{\text{Agreement} + \text{Disagreement}} \times 100$. Based on the comparison of 120 coded responses, the intercoder reliability coefficient was calculated as 89.16%. According to Büyüköztürk et al. (2018), an agreement rate of 70% or higher indicates acceptable reliability in qualitative research.

In addition to intercoder reliability, the study was conducted in accordance with the trustworthiness criteria proposed by Lincoln and Guba (1985). Credibility was enhanced by collecting data immediately after students had completed the instructional implementation, supporting the findings with direct participant quotations, and developing the data collection instrument based on expert feedback. Transferability was strengthened through

detailed descriptions of the study group, research setting, and implementation process. Dependability was ensured by systematically documenting all stages of the research process and by incorporating independent coding conducted by a second researcher. Confirmability was established by linking the findings to direct participant quotations, calculating intercoder agreement, and providing a transparent description of the data analysis procedures (Lincoln & Guba, 1985). The resulting codes, themes, and their corresponding frequencies are presented in the Findings section.

Findings

Findings Related to the First Research Question

The findings related to the first research question, namely "How do the interactions and immediate feedback provided by the AI-supported virtual learning environment influence students' construction of abstract concepts such as energy transformations?", are presented in Tables 1 and 2.

Table 1. Codes and frequencies of cognitive factors related to the energy transformations and environmental science unit

Sub-theme	Codes	Frequency (f)
Cognitive Factors	Easier Understanding of the Subject	15
	Contribution to Academic Achievement	10
	Visualization	5
	Concretization	3
	Modeling	2
	Reinforcement and Rapid Access	5
Total		40

As shown in Table 1, students' cognitive evaluations regarding their learning experiences during the implementation of the Energy Transformations and Environmental Science unit were organized under a single sub-theme, with a total of 40 coded statements ($f = 40$). Analysis of the students' responses revealed that the most frequently emphasized code was "Easier Understanding of the Subject" ($f = 15$). This finding suggests that the AI-supported virtual learning environment facilitated students' conceptual understanding by presenting complex scientific processes, such as photosynthesis and respiration, through dialogue tailored to their cognitive level. Three representative excerpts illustrating this code are presented below.

"For example, instead of reading the lengthy notes in our science textbook, we can ask the AI in the application and receive shorter, easier-to-understand explanations. This makes learning both easier and faster." (S7)

"While using the application, it explained the science topics that I did not understand in a fun and easy way. For example, one of the topics I struggled with was the food chain, and now I can understand it easily." (S9)

"I told the AI about a topic in the matter cycle that I did not understand. It explained the key concepts to me, and then it gave me practice questions. After answering those questions, I understood the topic much better." (S20)

In addition, students frequently emphasized the positive impact of the application on their academic performance through the codes "Contribution to Academic Achievement" ($f = 10$) and "Reinforcement and Rapid Access" ($f = 5$). Representative excerpts from students' responses are presented below.

"I think it helped me learn more quickly and easily. Instead of spending two hours preparing summaries, I just asked the AI, which gave me more time to study. It also helped me while preparing for the High School Entrance Examination (LGS) by providing practice questions and summaries." (S5)

"In every lesson, I can easily and quickly access the information I need whenever I want." (S15)

"It was helpful because we could access information more logically and easily. We could also reach it much faster, which was especially useful when studying for exams and similar tasks. It helped me understand the food chain better by using videos that allowed me to visualize the topic." (S2)

Further examination of Table 1 indicates that students also referred to the codes "Visualization" ($f = 5$), "Concretization" ($f = 3$), and "Modeling" ($f = 2$) in relation to the mental construction of abstract processes

addressed in the unit. Students reported that the explanations and feedback provided by the AI-supported virtual learning environment helped them develop mental models of scientific concepts, thereby making abstract processes easier to understand. Representative excerpts supporting these codes are presented below.

"The application was very helpful because we could see everything visually. It presented the content in three dimensions, and the topic I understood best was the matter cycles." (S18)

"I had always struggled to study the matter cycles effectively. Thanks to the AI, I understood the topic much better through both the visuals and the explanations." (S19)

"What contributed most to my science learning was being able to see and examine everything in a three-dimensional way. It also helped me understand the lessons much more effectively." (S8)

Students' perceptions of their learning experiences with the AI-supported virtual learning environment during the Energy Transformations and Environmental Science unit were not limited to the cognitive dimension; affective reflections on the learning process also emerged. These findings are presented in Table 2.

Table 2. Codes and frequencies of the affective factors related to the energy transformations and environmental science unit

Sub-theme	Codes	Frequency (f)
Affective Factors	Increased Interest in Science	14
	Learning Through Enjoyment	9
	Arousing Curiosity	2
Total		25

As shown in Table 2, a total of 25 statements ($f = 25$) were coded under the sub-theme of Affective Factors. Within this sub-theme, the most frequently emphasized code was "Increased Interest in Science" ($f = 14$). This finding indicates that the AI-supported virtual learning environment positively influenced students' intrinsic motivation and attitudes toward science. It also suggests that abstract scientific concepts, which are often perceived as challenging when taught through traditional instructional approaches, became more engaging through the dynamic interactions and immediate feedback provided by the AI-supported virtual learning environment. Three representative student excerpts illustrating this code are presented below.

"Science has become easier and more enjoyable for me. I have become much more interested in science." (S17)

"It changed a lot. I understood the topics much better, and my interest in science increased." (S13)

"After using the application, my interest in science increased. I understood the science topics much better and performed more successfully on my exams." (S20)

In addition, students reported that interacting with the AI extended beyond a purely academic requirement by providing opportunities for "Learning Through Enjoyment" ($f = 9$) and "Arousing Curiosity" ($f = 2$). Their responses indicated that, rather than acting as passive recipients of information, they enjoyed the learning process, felt comfortable asking questions without experiencing stress, and were encouraged to explore new scientific concepts independently. Representative student excerpts illustrating these codes are presented below.

"I couldn't really say that I liked science before, but afterward I started coming to class more willingly. My science test scores also improved, and science became much more enjoyable." (S4)

"You could say that my curiosity about science started to increase. For example, being able to view the matter cycle in three dimensions was a great advantage." (S2)

"...Learning becomes more enjoyable, and we can learn with the AI even without the teacher explaining the topic first. We understand the concepts more quickly, and the whole learning process feels more comfortable." (S7)

Findings Related to the Second Research Question

The findings related to the second research question, *"What are students' perceptions of the conveniences, challenges, and overall satisfaction they experienced while using the AI-supported virtual learning*

environment?", were organized into two main sub-themes: "Attitude and Perspective Change," reflecting students' overall satisfaction with the learning experience, and "Awareness of the System's Limitations and Functioning," reflecting the limitations and challenges they encountered during the implementation. The findings are presented in Table 3 and Table 4.

Table 3. Codes and frequencies of the attitude and perspective change sub-theme in the ai-supported virtual learning environment

Sub-theme	Codes	Frequency (f)
Attitude and Perspective Change	Willingness to Use AI in the Future	13
	Perceived Usefulness of AI	8
	Exploring AI	5
Total		26

As presented in Table 3, a total of 26 statements ($f = 26$) were coded under the sub-theme "Attitude and Perspective Change," which reflects students' positive experiences with and satisfaction toward the application. Within this sub-theme, the most frequently emphasized code was "Willingness to Use AI in the Future" ($f = 13$). This finding indicates that students' experiences with the AI-supported virtual learning environment resulted in a high level of satisfaction and fostered their willingness to adopt AI as a sustainable learning tool in future stages of their education. Representative student excerpts illustrating this code are presented below.

"I had been interested in AI before, but I had never thought about using it in the future. However, after using this application and other AI tools, I started thinking that I might even choose a technology-related career in the future." (S14)

"I now think AI can be used in almost every field and in many aspects of daily life. It can make people's lives easier and be especially useful for students preparing for exams." (S19)

In addition, students' responses coded as "Perceived Usefulness of AI" ($f = 8$) and "Exploring AI" ($f = 5$) further confirmed the benefits provided by the virtual learning environment. Representative excerpts reflecting these perceptions are presented below.

"I really enjoy using AI, and incorporating it into my lessons made learning much more enjoyable. I think similar applications could also be developed for many other subjects." (S16)

"If I had known that AI could be this helpful, I would have used it to study much earlier and learned the topics more effectively." (S12)

"I would also like to explore other AI tools that have been developed." (S17)

In addition to these positive attitudes, students also developed an awareness of the challenges they encountered and the technological limitations of the system throughout the implementation. The findings related to the sub-theme "Awareness of the System's Limitations and Functioning" are presented in Table 4.

Table 4. Codes and frequencies of the awareness of the system's limitations and functioning sub-theme in the AI-supported virtual learning environment

Sub-theme	Codes	Frequency (f)
Awareness of the System's Limitations and Functioning	Learning to Use AI	18
	Understanding the Limitations of AI	10
	Recognizing the Potential Risks of AI	1
Total		29

Within this sub-theme, which comprised a total of 29 coded statements ($f = 29$), the most frequently emphasized code was "Learning to Use AI" ($f = 18$). Students reported that, unlike traditional learning methods, they learned how to interact effectively with AI through hands-on experience. Representative student excerpts are presented below.

"Yes, I learned how to use AI and how to ask my questions more effectively, and that was really helpful. When the AI's answers were incomplete, I learned how to guide it and obtain better responses. I also learned how to create images and videos." (S2)

"What I learned was how to use computers and AI more effectively, along with many new things. This allowed us to experience better learning environments." (S8)

In addition, the most noteworthy findings regarding the challenges associated with the learning experience emerged under the codes "Understanding the Limitations of AI" ($f = 10$) and "Recognizing the Potential Risks of AI" ($f = 1$). Through firsthand experience with the system, students realized that AI cannot interpret every question perfectly and occasionally requires appropriate guidance from users. These experiences fostered technological awareness and contributed to the development of foundational AI literacy. Representative student excerpts illustrating these perceptions are presented below.

"As we continue using different AI tools, we will learn how they work by exploring them with curiosity. I also think that AI does not always provide completely accurate or definitive information." (S11)

"After using this application, I realized that it does not always produce completely accurate results, and I think this applies to other AI systems as well. Instead of relying on a single AI tool, we should verify information using multiple sources." (S7)

"Yes, I know that chatbots are probably the easiest and most enjoyable part of AI, but unfortunately they do not always provide completely accurate information. That is why we should sometimes conduct our own research." (S16)

"AI provides many important benefits, and that makes it valuable. However, it also has potential risks. It may sometimes give incorrect answers, and excessive use may lead to health-related problems. Therefore, it is important to learn how to use AI safely." (S15)

Taken together, these findings demonstrate that the AI-supported virtual learning environment had a multidimensional impact on the learning experiences of eighth-grade students. The application made a substantial contribution to students' ability to conceptualize abstract scientific concepts related to the *Energy Transformations and Environmental Science* unit and enhanced their motivation toward science learning. Furthermore, the findings indicate that students did not remain passive users of the technology. Rather, by recognizing the pedagogical limitations, underlying functioning, and potential constraints of AI systems, they developed a foundational level of AI literacy.

Conclusion and Discussion

This study investigated the cognitive and affective reflections of eighth-grade students, as well as their experiences with an AI-supported virtual learning environment implemented in the teaching of the *Energy Transformations and Environmental Science* unit in science education. The findings demonstrate that AI integration functions not only as an instructional tool but also as a multidimensional learning environment that effectively enhances students' learning processes, technological awareness, science learning experiences, and critical awareness of AI.

Examination of the findings related to the first research question revealed that the AI-supported virtual learning environment enabled students to conceptualize abstract scientific concepts, such as photosynthesis, respiration, and energy transformations, thereby facilitating a deeper understanding of the unit content. Furthermore, students reported increased interest in science and indicated that the learning process became more enjoyable compared with traditional instructional approaches. These findings are consistent with previous studies demonstrating that AI-supported virtual learning environments positively influence students' academic achievement and learning motivation in science education (Bayram & Çelik, 2023; Dong et al., 2025).

The findings suggest that students' improved understanding of these abstract concepts was attributable not merely to the provision of information by the AI-supported virtual learning environment, but more importantly to its immediate feedback mechanism, which adapted to each student's learning pace and level of conceptual understanding. By connecting their observations from the simulations with the AI-generated instructional feedback, students were able to identify and reconstruct misconceptions within the same learning session, thereby promoting meaningful conceptual change. This interpretation is supported by Turhan and Nas (2025), who argued that AI can function as a teaching assistant by providing immediate feedback that makes abstract scientific concepts more comprehensible in classroom settings. Similarly, Yin et al. (2025) reported that immediate feedback delivered through AI chatbots produced positive effects on students' learning outcomes and brain activity.

In conventional classroom settings, large class sizes often limit teachers' ability to provide individualized support to every student. The personalized interactions afforded by the AI-supported virtual learning environment may help mitigate this limitation while simultaneously fostering students' intrinsic motivation toward science learning. This finding is also consistent with Kolb's (1984) Experiential Learning Theory. Students' engagement in concrete experiences through simulations, their reflection on the immediate feedback provided by the AI, and their application of newly acquired knowledge to novel situations collectively correspond to the core stages of the experiential learning cycle. These stages also paralleled emerging aspects of AI literacy, as direct interaction supported AI awareness and use, reflection on inaccurate responses encouraged critical evaluation, and verification practices reflected more responsible use of AI.

The pedagogical contribution of the present environment lies in integrating the LLM directly with interactive science simulations rather than using generative AI as a separate information source. Pedagogically customized AI can support more structured and reflective interactions than general-purpose chatbot use (Su et al., 2026). In the present environment, students could discuss their simulation observations with the AI assistant, receive guidance, reconsider their interpretations, and continue exploring the scientific phenomenon. Thus, the LLM functioned as a pedagogical layer connecting students' direct experiences with simulations to reflection, conceptual understanding, and further experimentation. This approach is consistent with the view of generative AI as a dialogic learning partner rather than merely an information provider (Tang & Putra, 2026).

The second research question focused on students' experiences with AI, yielding several noteworthy findings. The results indicate that students perceived the AI-supported virtual learning environment not merely as a learning tool but also as a technology that they intended to continue using in the future, reflecting the development of positive attitudes toward AI. This finding is consistent with Eltahir and Babiker (2024), who suggested that both educators and students are increasingly prepared to adapt to transformative educational technologies.

Another important finding was that students did not accept AI as an unquestionable authority. Instead, through their own experiences, they recognized that AI may generate inaccurate information, has inherent limitations, and may occasionally fail to provide adequate responses. This finding is consistent with recent literature. Azizi et al. (2026) reported that although generative AI systems offer substantial advantages in supporting conceptual explanations and problem-solving processes, they also possess important limitations, including the generation of hallucinations, conceptual inaccuracies, and reduced performance on tasks requiring complex reasoning. From this perspective, students' recognition of AI as a learning tool whose outputs should be critically evaluated rather than accepted unquestioningly represents an important outcome in the development of AI literacy.

Notably, although students regarded AI as a valuable resource for learning, they also expressed the need to verify AI-generated information using multiple sources. This finding aligns with Walter's (2024) perspective that AI literacy encompasses not only the ability to use AI technologies effectively but also the capacity to critically evaluate, verify, and appropriately interpret AI-generated information. Pedagogically, however, such inaccuracies need not be viewed only as limitations. They can become productive learning opportunities when students are encouraged to question, evaluate, and correct AI outputs (Yan et al., 2026). In the present study, students' recognition of inaccurate or incomplete AI responses appeared to shift them from passive acceptance toward more critical engagement. Their statements about asking better questions, guiding the AI, and verifying information through multiple sources reflect questioning and verification practices. Similar activities that require students to evaluate AI-generated content against reliable sources have been shown to support critical evaluation skills (Oates & Johnson, 2025). Therefore, teachers can incorporate AI errors or uncertainties into classroom activities and encourage students to compare AI responses with simulation results, scientific evidence, textbooks, or other reliable sources. Such practices may support students' evaluative judgment and responsible use of AI.

Overall, the present study contributes to the literature by demonstrating that AI-supported learning environments are not merely tools for enhancing students' academic performance but also educational environments that foster awareness of AI's limitations and encourage the development of a critical perspective toward AI technologies. In particular, examining AI literacy through students' lived experiences within the context of science education represents one of the study's principal contributions to the field.

In conclusion, this study demonstrated that the AI-supported virtual learning environment supported eighth-grade students' science learning from both cognitive and affective perspectives while also fostering their ability to critically evaluate and verify AI-generated information. These findings suggest that AI-supported learning environments should not be viewed merely as technological tools for enhancing academic learning; rather, they can serve as pedagogical learning environments that promote the experiential development of students' AI literacy.

From this perspective, the present study contributes to the literature by emphasizing that the integration of AI into science education should be evaluated not only in terms of learning outcomes but also with respect to the quality of students' interactions with AI technologies. Accordingly, AI-supported learning environments are recommended to be integrated into instructional practices under teacher guidance and in alignment with clearly defined pedagogical objectives.

Limitations

Several limitations should be considered when interpreting the findings of this study. First, the study was conducted with 20 students enrolled in a single public middle school. Consistent with the nature of qualitative research, the study aimed to provide an in-depth understanding of a specific case rather than to produce findings that are generalizable to a broader population. Second, the research was limited to the Energy Transformations and Environmental Science unit of the science curriculum. Consequently, the effects of the AI-supported virtual learning environment on students at different educational levels or within other science units were beyond the scope of the present study. Finally, the data were collected exclusively through an open-ended questionnaire consisting of students' written responses. The absence of additional data collection methods, such as semi-structured interviews, classroom observations, or learning analytics, which could have provided a more comprehensive understanding of the learning process, represents a methodological limitation of the study.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Future research may comparatively examine the effects of different AI-supported virtual learning environments on students' conceptual learning and the development of their AI literacy.
2. Further studies may investigate the effectiveness of AI-supported virtual learning environments across different grade levels and science curriculum units.
3. Science curricula should place greater emphasis not only on knowledge acquisition but also on fostering students' digital competencies, particularly those related to AI literacy.
4. Professional development programs should be organized for science teachers to support the effective integration of AI-supported virtual learning environments into classroom instruction.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

* Ethical approval for this research was approved by the Scientific Research and Ethics Committee of Kırıkkale University with the decision dated February 20, 2026 (No: E.413527).

Conflict of Interest

* The authors declare that they have no conflicts of interest

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