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Integrating augmented reality into intelligent tutoring systems to enhance science education outcomes

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Abstract
Integrating Augmented Reality (AR) technology into Intelligent Tutoring Systems (ITS) has the potential to enhance science education outcomes among middle school students. The purpose of this research was to determine the benefits of an ITS-AR system over traditional science teaching methods regarding science learning outcomes, motivation, engagement, and student confidence in science education. Using a quasi-experimental setup with a pretest–posttest and a control group, the research compared the effects of the ITS-AR system with conventional science teaching. In the experiment, the ITS-AR system offered tailored feedback, adaptable learning routes, and targeted assistance to students based on their requirements and advancement. It also helped them visualize intricate scientific notions and experiments using AR technology. The findings indicated that the ITS-AR system significantly improved science learning outcomes compared to the conventional teaching method. Additionally, the students using the ITS-AR system were more motivated, engaged, and confident in their science education than those in the control group. These results point towards the benefits of combining AR with ITS to boost science education results and heighten student involvement and enthusiasm in science studies. This research highlights the potential for incorporating artificial intelligence into science teaching and the creation of efficient ITS-AR tools for science education.

Keywords Augmented reality · Intelligent Tutoring systems · Science education

1 Introduction

Science education plays a crucial role in a student's academic growth as it lays the foundation for comprehending and interpreting the world (Driver et al., 2000). Given its significance, there is a continuous need to advance science education outcomes

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and explore new methods to engage students in the learning process (Oliveira et al., 2019; Struyf et al., 2019). Technology providing new methods plays a crucial role in contributing science education. It has the potential to make learning more interactive, engaging, and effective (Hanif, 2020; Mead et al., 2019). Technology also allows for the use of multimedia resources such as videos, animations, simulations, and interactive tools that can help students better understand scientific concepts (Barrow et al., 2019; Bogusevschi et al., 2020; Chai et al., 2019). It can also provide access to a wide range of educational resources that are not otherwise available, such as online databases and virtual labs (Bogusevschi et al., 2020; Chatterjee, 2021). In addition, technology enables the use of innovative tools and approaches such as Augmented Reality (AR) and Intelligent Tutoring Systems (ITS), which can provide personalized and adaptive learning experiences for students in science education (Arici et al., 2019; Fidan & Tuncel, 2019; Hillmayr et al., 2020). These technologies can also help teachers to monitor student progress and provide feedback in real-time, which can help students to learn more effectively (Jho, 2020; Mousavinasab et al., 2021; Taub et al., 2021; Xu et al., 2019). Recent studies underscore the accelerating adoption of AR and ITS technologies, highlighting significant advancements in their application across various educational settings. These technologies are increasingly recognized not just for their potential to individualize learning experiences but also for their ability to deliver complex scientific content such as the periodic table more effectively (Camara Olim et al., 2023, 2024; Nazar et al., 2024). Furthermore, current research emphasizes the critical role of integrating cutting-edge technologies like AR and ITS to meet the diverse learning needs of students, particularly in dynamic and visually dependent science subjects (Lampropoulos, 2023). These studies validate the necessity of our approach, reinforcing the potential of AR and ITS to revolutionize science education through enhanced interactivity and engagement.

AR technology integrated in ITS in middle school classrooms is a promising approach towards enhancing science education outcomes. AR technology offers a unique and engaging way for students to learn about complex scientific concepts and experiments (Arici et al., 2019; Arslan et al., 2020; Fidan & Tuncel, 2019; Moro et al., 2021; Sahin & Yilmaz, 2020; Salar et al., 2020; Sırakaya & Alsancak Sırakaya, 2022). Particularly for teaching the periodic table—a central element in science education—the use of AR technology offers a unique and engaging way for students to grasp its complex and abstract nature (Câmara Olim et al., 2024). By using AR, students can visualize 3D models of atoms, molecules, and other scientific structures, which can help them to better understand the material (Ateş & Garzon, 2023). This visual interaction can help demystify the relationships and properties of elements, which are often challenging for students to comprehend through traditional teaching methods (Macariu et al., 2020). Additionally, AR can be used to create interactive simulations of chemical reactions and other scientific processes, which can further enhance students' engagement and understanding (Sahin & Yilmaz, 2020; Salar et al., 2020). On the other hand, ITS systems are undergoing transformative advancements, with the latest iterations increasingly leveraging cutting-edge technologies such as artificial intelligence, machine learning, and natural language processing (Vujinović et al., 2024). These innovations are not just incremental; they are revolutionizing the field by enabling ITS to offer highly personalized, adaptive, and deeply engaging educational experiences. Such systems are now capable of dynamically adjusting instructional strategies based on real-time analysis of individual student performance and engagement levels. This evolution marks a significant departure from traditional models, offering unprecedented precision in personalizing education and enhancing student learning outcomes in science education (Jho, 2020; Rau et al., 2015; Shin, 2020). These developments are particularly crucial as they provide practical solutions to long-standing educational challenges and open up new avenues for research and application in the educational technology space.Furthermore, ITS can provide targeted feedback, personalized support, and adaptive learning paths to help students improve their understanding of scientific concepts (Dolenc et al., 2015; Hillmayr et al., 2020; Shin, 2020). ITS can also provide teachers with valuable data on student progress, allowing them to identify areas where additional support or guidance may be necessary (del Olmo-Muñoz et al., 2023; Dutt et al., 2022; Kochmar et al., 2022; Sharma & Harkishan, 2022). Together, AR and ITS not only enhance the understanding of science topics such as the periodic table but also significantly improve overall science learning outcomes by providing a more engaging, interactive, and personalized learning experience.

By incorporating AR into ITS, students can receive personalized feedback on their understanding of the material, as well as additional support and resources to improve their knowledge and skills (Ahuja et al., 2022; Alam, 2022; Papakostas et al., 2022). Additionally, ITS can adapt to each student's unique learning needs and progress, providing a more individualized learning experience (Kochmar et al., 2022; Sharma & Harkishan, 2022; Singh et al., 2022). The integration of ITS-AR technology in middle school science education is poised to significantly enhance learning outcomes, boost engagement, and spark interest in scientific subjects. More importantly, it equips students with the technological literacy and critical thinking skills essential for their future academic and professional success. These recent insights directly align with the objectives of our study, which seeks to explore the effectiveness of AR and ITS not only in boosting academic performance but also in enhancing students' engagement and self-efficacy in science education. This alignment ensures that our research is rooted in the latest educational trends and technological advancements.

Despite these promising developments, the existing literature still presents significant gaps, particularly regarding the detailed impact of ITS-AR integration on middle school students' academic achievement, motivation, engagement, and self-efficacy. These critical areas of student development are crucial yet underexplored, with most existing studies offering only a surface-level exploration that focuses primarily on short-term outcomes. These studies often fail to capture the nuanced ways in which such technologies affect students' long-term academic behaviors and attitudes, or the complex interplay between technology use and educational achievement over time. Additionally, while current research has touched upon various aspects of student interaction with technology, there is a noticeable lack of depth in studies that examine the specific pedagogical mechanisms through which ITS-AR systems influence learning processes and outcomes. This oversight means that educational technologists and curriculum developers are missing valuable insights into how these tools can be optimized to support different types of learners. Moreover, the variability in technology implementation across different educational contexts has not been thoroughly examined, leaving a significant gap in our understanding of the scalability and adaptability of ITS-AR systems in diverse educational settings. This variability includes differences in school resources, teacher readiness, and student demographics, which can all influence the effectiveness of technology-integrated learning environments. Without a comprehensive examination of these factors, the broader applicability of research findings remains questionable, and the potential for ITS-AR systems to be effectively integrated into varied educational landscapes is limited. Understanding these gaps is essential not only for advancing academic knowledge but also for practical applications in educational technology deployment. Filling these gaps could lead to more tailored and effective educational practices that leverage ITS-AR systems to their fullest potential, thereby ensuring that all students benefit regardless of their individual learning needs or the specific educational contexts in which they are situated. To address these gaps, this study aims to investigate the effectiveness of an ITS integrated with AR technology in improving science learning outcomes among middle school students. The study also explore how the integration of ITS-AR technology in science education can improve students' science engagement, self-efficacy beliefs and motivation to learn science. By doing so, our research contributes to filling the critical voids in the literature by providing empirical evidence on the long-term effects of these technologies and their potential for broad application across various educational environments. Overall, this study seeks to contribute to the growing body of research on the use of ITS-AR technology in science education and its potential to enhance student learning outcomes. By identifying the strengths and limitations of ITS-AR integration and providing insight into best practices for implementation, this study can inform future efforts to improve science education outcomes through technology. The findings of this study can inform the development of policies and practices related to the implementation of technology in middle school classrooms, and demonstrate the effectiveness of the ITS-AR approach in enhancing learning outcomes, providing evidence-based support for the use of technology in education.

In the context of this study, following research questions are stated:

1. How does the integration of intelligent tutoring system and augmented reality in science instruction affect middle school students' learning outcomes?
2. To what extent does the combination of intelligent tutoring system and augmented reality improve students' engagement, motivation, and self-efficacy in science education?

The structure of this paper is organized as follows: first, a comprehensive literature review is presented, which examine the current state of research on the use of AR and ITS in education, and highlight the gap that this study aims to fill. Second, the methodology section describes in detail the research design, including the sample, measures, data collection process, and data analysis plan. Third, the results section presents the findings of the study, followed by a discussion of the implications of the results for theory and practice. Finally, the paper concludes with a summary of the main findings, limitations of the study, and suggestions for future research.

2 Literature review

2.1 Intelligent tutoring systems

Intelligent Tutoring Systems (ITS) are computer-assisted learning software designed to personalize and adapt instruction to individual learners by modeling their cognitive and emotional states (Chrysafiadi et al., 2022; Nesbit et al., 2014). These systems employ artificial intelligence and machine learning techniques to create dynamic and adaptive learning environments tailored to the needs and abilities of each student (Paladines & Ramírez, 2020; Tsihrintzis et al., 2021; Virvou et al., 2020). The primary goal of ITS is to enhance student learning outcomes by providing immediate feedback, targeted guidance, and individualized support to students (Erümit & Çetin, 2020; Khazanchi & Khazanchi, 2021; Kochmar et al., 2020). ITS can analyze students' responses to questions and activities, and based on that analysis, provide feedback on areas where they may need additional support or guidance (Clancey & Hoffman, 2021; Sotiropoulos et al., 2019). This personalized approach to feedback can help students to identify and correct errors in their understanding of the material, and provide additional resources and guidance to improve their knowledge and skills (Graesser et al., 2018; Kochmar et al., 2020; Ostrander et al., 2020). It can be designed to support a range of subjects and learning goals, such as mathematics, science, learning foreign language, sustainable education, and social studies (Ni & Cheung, 2023; Parrisius et al., 2022; Rau et al., 2015; Rebolledo-Mendez et al., 2022; Singh et al., 2022). In the context of science education, ITS can be particularly effective in helping students to understand complex scientific concepts and processes (Jho, 2020; Rau et al., 2015; Shin, 2020). For example, ITS can help students to visualize the structure of atoms and molecules, understand the relationship between different elements in the Periodic Table, or learn about the processes involved in photosynthesis or cellular respiration.

Recent advancements in ITS technology have introduced several groundbreaking features that are transforming educational approaches. For example, the integration of Natural Language Processing allows ITS to engage in more sophisticated dialogues with students, offering explanations and answering questions in a more human-like manner (Alam, 2023; Shaik et al., 2022). Furthermore, the development of emotion-sensitive ITS, which can detect and respond to students' emotional states, has shown promise in maintaining engagement and reducing frustration during learning sessions (Dutt & Ahuja, 2024; Zheng et al., 2024). These systems utilize affective computing techniques to adapt instructional strategies based on detected emotional states, thereby enhancing the overall learning experience (Vujinović et al., 2024). Additionally, the incorporation of advanced data analytics and learning analytics into ITS enables more precise tracking of student progress and performance, allowing for the identification of learning patterns and the customization of learning paths to cater to the unique needs of each student (Alam, 2023). Recent research has also focused on developing ITS that facilitate collaborative learning environments, which encourage peer-to-peer interaction and group problem-solving (Stamper et al., 2024). These technological innovations underscore a significant shift towards more dynamic and responsive educational tools.

Reflecting these transformative advancements, the ITS International Conferences stand at the forefront of exploring cutting-edge applications and the latest research in ITS and related fields. These conferences, initiated in Montreal in 1988, have continuously evolved to address emerging trends and technologies in computer and cognitive sciences, artificial intelligence, and enhanced learning environments. Notably, the introduction of the Brain Function Assessment in Learning series has bridged intelligent systems with neuroscience, illustrating interdisciplinary approaches that enhance understanding and learning experiences. The conferences cover a broad spectrum of topics, including the integration of AR and virtual reality in learning technologies, and the use of artificial intelligence to foster inclusive and personalized learning environments. Discussions at these conferences highlight the development of models for emotions, motivation, and metacognition within ITS, the application of machine learning techniques for educational data mining, and innovative uses of brain-computer interfaces in tutoring systems. These topics not only highlight the progressive nature of research within the ITS community but also emphasize the practical implications of these technologies in diverse educational settings—from classrooms to informal learning spaces and professional training modules.

Despite the potential benefits of ITS, there are also some limitations and challenges that must be addressed. One of the primary challenges of ITS is the development and implementation process (Holstein et al., 2017). Creating an effective ITS requires a significant investment of time, resources, and expertise (Burgess, 2017; Chen et al., 2020; Holstein et al., 2017). The system must be able to accurately analyze student performance (Chan & Zary, 2019), identify areas where additional instruction or guidance is needed, and provide personalized feedback in real-time (Chen et al., 2021; Tsai et al., 2020). Achieving this level of accuracy and personalization requires a sophisticated design and a substantial amount of data (Chen et al., 2022). Another challenge of ITS is the need for continuous maintenance and updating (Albacete et al., 2019; Holstein et al., 2018). As new research and developments emerge in the field of education, ITS must be updated and adapted to ensure that they continue to provide an effective learning experience (Chen et al., 2020; Ijaz et al., 2017). Failure to update and maintain ITS may result in outdated content, inaccurate feedback, and reduced efficacy (Albacete et al., 2019). Furthermore, there are challenges associated with the assessment of the effectiveness of ITS (Chen et al., 2022). While ITS are designed to improve learning outcomes, accurately measuring their impact can be difficult (Albacete et al., 2019; Zawacki-Richter et al., 2019). This may be due to the complex nature of the learning process, as well as the many variables that can influence learning outcomes. To accurately measure the effectiveness of ITS, rigorous studies must be conducted that consider a wide range of factors and control for extraneous variables. Finally, there are concerns about the potential for overreliance on ITS (Luan et al., 2020). While ITS can provide valuable support and guidance to students, they are not a substitute for human interaction and engagement. Overreliance on ITS may limit students' ability to think critically, problem-solve, and develop their own ideas and perspectives.

Despite these challenges and limitations, ITS continue to be an important tool for enhancing the learning experience (Chen et al., 2022). By providing personalized support and guidance, ITS have the potential to improve learning outcomes and increase student engagement in the educational process (Huang et al., 2022). As research in the field of ITS continues to develop, it is likely that these systems will become even more sophisticated and effective, providing an increasingly valuable resource for educators and students alike (Zhang et al., 2022).

2.2 Augmented reality in science education

Augmented Reality (AR) is a technology that overlays digital information onto the real world, creating a new environment that blends physical and virtual reality (Mozumder et al., 2022). AR has the potential to enhance science education by providing students with a more interactive and engaging learning experience (Arici et al., 2019; Ateş & Garzon, 2023). By using AR, students can visualize and interact with scientific concepts in a more dynamic and immersive way (Jiang et al., 2022; Martins et al., 2022), increasing their understanding of complex topics and making learning more enjoyable (Lee, 2022). Despite its potential benefits, there are also some challenges associated with using AR in science education. One of the main challenges is the cost and availability of AR hardware and software (Furió et al., 2013; Danielsson et al., 2020). While the technology has become more accessible in recent years, it still requires a significant investment in terms of time, money, and technical expertise (Ateş & Garzon, 2023). Additionally, not all schools and educational institutions have the resources to provide their students with access to AR technology, which can create disparities in learning opportunities (Wu et al., 2013). Another challenge associated with AR in science education is the need to develop high-quality AR content that is aligned with educational standards and objectives (Zhan et al., 2020). The development of AR content requires a significant amount of time and expertise (Gavish et al., 2015), and the content must be carefully designed to ensure that it is both engaging and educational (Chang et al., 2014). Additionally, the development of AR content requires a deep understanding of the subject matter, as well as the technical skills to create and integrate the digital assets (Iqbal et al., 2022).

Despite these challenges, the use of AR in science education is becoming increasingly popular, as educators and researchers recognize its potential to enhance student learning outcomes. As technology continues to evolve, it is likely that AR will play an even more significant role in science education in the future. AR has already been used in a variety of science education settings, including chemistry, physics, and biology (Ivan et al., 2022; Lai & Cheong, 2022; Mazzuco et al., 2022). In chemistry, for example, AR can be used to visualize molecular structures and chemical reactions, making it easier for students to understand how atoms and molecules interact with each other (Mazzuco et al., 2022; Sakshuwong et al., 2022; Tarng et al., 2022). In physics, AR can be used to demonstrate concepts like motion, electricity, and force of gravity, providing students with a more intuitive and interactive way to learn these topics (e.g., Fidan & Tuncel, 2019; Ibáñez et al., 2015; Vidak et al., 2021). In biology, AR can be used to explore the structures of Cell and Cell Division, organs, and organisms, providing students with a more engaging and interactive way to learn about living systems (e.g., Arslan et al., 2020; Özeren & Top, 2023; Yapici & Karakoyun, 2021). One of the key benefits of AR in science education is its ability to make abstract concepts more concrete and tangible (Arici et al., 2019; Sahin & Yilmaz, 2020). By overlaying digital information onto the real world, AR can also provide students with more opportunities to explore and experiment with scientific concepts, which can help to foster their curiosity and creativity (Kennedy et al., 2021; Yilmaz & Goktas, 2017). The effectiveness of AR in science education has been demonstrated in several studies. For example, Sahin & Yilmaz (2020) found that using AR technology resulted in higher levels of academic achievement and positive attitudes towards the course among middle school students. Similarly, Arici and Yilmaz (2023) showed that problem-based learning supported by AR is more effective than traditional teaching methods in improving students' problem-solving and decision-making abilities, as well as academic achievement in a science course. Tarng et al (2022) demonstrated that an AR system is effective in improving high school students' understanding of chemical reactions. In Çetin and Türkan's (2022) study, the use of AR-based applications significantly improved students' achievement and attitudes towards science in a distance education setting.

In conclusion, these studies suggest that AR has great potential in enhancing student learning outcomes in science education and can provide a more engaging and interactive learning experience for students. Therefore, AR should be considered as a valuable tool in science education, and further research should be conducted to explore its full potential.

2.3 Transforming the learning experience: a course material with augmented reality and intelligent tutoring system integration

The periodic table, a cornerstone of chemical education, encapsulates the essence of chemical properties and the relationships between elements (Joag, 2014). Mastering this table is crucial for students, not only for chemistry but across various scientific disciplines. However, its abstract nature and the vast amount of information it contains can often seem daunting to students, which can hinder effective learning (Bierenstiel & Snow, 2019). In response to these challenges, a learning course material developed in this study leverages ITS and AR to provide comprehensive instruction on the principles of the periodic table. The integration of AR materials offers an interactive and engaging learning experience that transforms the periodic table from a static chart to a dynamic, interactive model. For example, 3D models and interactive simulations help students visualize the structure of atoms and molecules, enhancing their understanding of complex scientific concepts and the relationships within the periodic table. These visual aids are not merely illustrative but are designed to facilitate a deeper engagement with the material, helping students to see and interact with the elements in ways that traditional teaching methods cannot achieve.

By incorporating an ITS into the course material, instructors can deliver personalized guidance and feedback tailored to the individual learning needs of each student. The ITS analyzes students' interactions and performance, adapting the instructional content in real-time to suit their learning pace and style. This personalized approach not only improves comprehension and retention of information but also addresses the diverse learning needs within a classroom, ensuring that all students can progress. This course material also includes the use of a learning management system integrated with ITS and AR, creating a comprehensive educational tool that manages course content, tracks student progress, and assesses learning outcomes through quizzes, assignments, and exams. This system allows for a thorough evaluation of the effectiveness of ITS and AR in enhancing student engagement with the periodic table. Furthermore, instructor training is a critical component of this initiative, ensuring that educators are equipped with the necessary skills and knowledge to effectively deploy AR materials and utilize ITS. Technical support is provided continuously to both students and instructors, ensuring the smooth operation of the AI-AR system and addressing any challenges that arise during its use. Students who participated in this course material were not only engaged but were able to apply what they learned through a project focused on the periodic table. Throughout the project, they received continuous feedback from the ITS, which helped them identify and correct misunderstandings, thus solidifying their knowledge and enhancing their skills in using the periodic table practically.

Table 1 below displays the project suggestions and the feedback provided by the ITS, illustrating the practical applications of the knowledge acquired and the effectiveness of the personalized instructional approach..

3 Method

3.1 Sample

In this study, convenience sampling was employed to recruit participants from a single public school. While convenience sampling is a commonly used method in educational research due to logistical constraints and limited access to diverse participant pools, it inherently poses limitations concerning the generalizability of the results to other educational settings or populations. This method was chosen primarily for its practicality and feasibility within the school setting, where securing participant involvement can often be challenging. Participants in this study were volunteers who expressed interest in participating, thus ensuring a high level of engagement and compliance with study procedures. All volunteers were provided with detailed information about the study's purpose, procedures, potential risks, and benefits. Informed consent was obtained from each participant, which addressed the ethical concerns related to volunteer participation. Furthermore, stringent ethical

Table 1 The project proposal suggested by the students and the feedback received from the Intelligent Tutoring System

Project Components	Project Summary	Provided Feedback
Title	Designing the Future Periodic Table: An Augmented Reality Project for Eighth-Grade Students	
Objective	In this project, we will use Augmented Reality technology to design a futuristic Periodic Table that includes new elements that do not currently exist. We will work collaboratively to research and create 3D models of these new elements, and integrate them into an interactive AR experience. We will also learn about the properties and potential uses of each element and the skills required to work with AR technology	The objective does not seem to align with the learning goals related to the actual Periodic Table, its elements, and their properties
Materials	We will need access to textbooks and online resources to research the properties and uses of existing elements. We will also use 3D modeling software to create 3D models of new elements, and an AR app to create the final experience	The materials listed are insufficient for the project, and more resources could be included to support research and the creation of new elements. There is no mention of how the 3D modeling software or AR app will be accessed or whether they will be provided by the school or students
Process	We will work in teams to research and design new elements that we imagine could exist in the future. We will use 3D modeling software to create 3D models of these new elements. Next, we will use an AR app to integrate the new elements into an interactive Periodic Table experience. The AR experience will include visual aids that explain the properties and potential uses of each element, as well as interactive simulations of chemical reactions involving the new elements	While the project encourages collaboration and the development of important skills such as research and presentation, the steps are not well-defined, and the project lacks a clear plan of action. The process can be broken down further into specific steps, such as identifying existing gaps in the Periodic Table, researching potential new elements, and designing and creating 3D models
Assessment	The project will be assessed based on the quality and accuracy of the research, the design and functionality of the AR experience, and the level of creativity and innovation demonstrated in the new elements and their integration into the Periodic Table. We will also present our work to the class and receive feedback from our peers. We will reflect on the skills and knowledge we developed throughout the project, such as critical thinking, collaboration, and technological literacy	The project assessment lacks specificity and does not provide clear guidelines for grading or evaluating the project's success. There is no mention of how the assessment will be conducted, what criteria will be used, or how feedback will be provided

Table 1 (continued)

Project Components	Project Summary	Provided Feedback
Expected Outcomes	Through this project, we will develop a deeper understanding of the Periodic Table and its properties, as well as the ability to think creatively about its future. We will also develop important skills, such as research, 3D modeling, AR design, and presentation, which will prepare us for future academic and professional pursuits. The project will be a fun and engaging way to learn about science, technology, engineering, and math, and will inspire us to be more creative and innovative in our approach to learning	The expected outcomes seem unrealistic, as the project is not directly related to the actual Periodic Table and its properties. Additionally, the outcomes do not provide a clear understanding of what students will learn, and how their skills will be developed

considerations were meticulously adhered to concerning data collection, management, and dissemination, including the maintenance of confidentiality, anonymity, and privacy to safeguard participants' rights and welfare.

The study was conducted in a single public school located in a densely populated area with a low percentage of immigrants. This specific demographic setting was chosen due to its potential to reflect the educational experiences of similar urban schools, albeit with acknowledged limitations in representing more diverse or rural educational contexts. The participants comprised 58 eighth-grade middle school students enrolled in the school's science course. The sample included an almost equal gender distribution of 28 female and 30 male students, aged 13 to 14 years, thereby mirroring the school's demographic profile in terms of gender and age. The selection of students was strategically based on their academic performance in the science course, ensuring a broad spectrum of abilities was represented, from high achievers to those who might struggle with scientific concepts. This stratification was intended to provide insights that are relevant across various levels of academic aptitude, enhancing the applicability of the study's findings within the academic context of the chosen school. The students' diverse levels of prior knowledge and experience with the scientific concepts under investigation also allowed for a rich collection of perspectives and insights during the data collection and analysis phases, thus adding depth to the study's findings.

3.2 Instruments

In the study, data collection tools provided a comprehensive set of data that allowed the researchers to examine the impact of the ITS-AR system on the students' academic achievement, engagement, motivation, and self-efficacy in science learning.

3.2.1 Academic achievement

The responsibility of creating the pre-test and post-test for measuring the science success of the students in this study was given to two experienced science teachers. The pre-test was administered to assess the baseline knowledge of the two groups of students before they started the science course. The test was designed to assess the students' understanding of scientific concepts through a variety of question types. These included yes-or-no items, multiple-choice questions, matching questions, and short answer questions. The test consisted of a total of 40 questions, with each question carrying equal weight towards the total score of 100. The use of different question types allowed the researchers to evaluate the students' knowledge from multiple angles and assess their ability to apply their knowledge in various contexts. The purpose of the pre-test was to determine if the two groups had equivalent basic knowledge before the start of the intervention. In contrast, the post-test was designed to evaluate the students' scientific knowledge after they completed the science course. The objective of the post-test was to determine whether the science course had a positive impact on the students' knowledge and understanding of the scientific concepts covered in the study.

The academic achievement test administered in this study aimed to measure the students' mastery of the scientific concepts covered in the unit of 'Matter and Industry'. The test was designed to assess the students' understanding of the classification of elements as metals, nonmetals, and noble gases, and their ability to classify changes in matter as physical and chemical changes, as per the Turkish National Ministry of Education (2018)'s guidelines. The questions in the test were formulated to test the students' comprehension of scientific concepts, accuracy of scientific explanations, clarity and coherence of written responses, and use of scientific terminology.

To determine the reliability of the achievement test, the researchers used data obtained during the pilot implementation. They calculated the Cronbach's Alpha coefficient, which is a statistical measure of internal consistency. Typically, this coefficient ranges from 0 to 1, with higher values indicating greater internal consistency or reliability (Pallant, 2020). A Cronbach's alpha coefficient of less than 0.40 is generally considered unreliable, indicating that the items on the scale are not measuring the same thing or that there is too much error in the responses. A value between 0.40 and 0.59 is considered to be less reliable, while a value between 0.60 and 0.79 is considered reliable. Finally, a coefficient between 0.80 and 1.00 is considered extremely reliable, indicating a high level of internal consistency and precision in measuring the construct of interest (Nacar et al., 2021). In this study, the achievement test's Cronbach's Alpha coefficient was found to be 0.82 indicating that the test is quite good and has a high degree of internal consistency.

3.2.2 Student engagement scale

In this study, researchers utilized the student engagement scale to better understand how students interact with learning activities. The scale, developed by Wang et al. (2016), consists of 33 items that are presented as both positively and negatively worded questions on a 5-point Likert scale, where 5 indicates strong agreement and 1 indicates strong disagreement.

The study focused on four dimensions of engagement, including behavioral engagement, emotional engagement, cognitive engagement, and social engagement, as defined by the original scale developers (Wang et al., 2016). The first dimension, cognitive engagement, evaluated the students' ability to regulate their learning, implement deep learning strategies, and apply cognitive strategies to comprehend complex ideas. The second dimension, emotional engagement, measured both positive and negative emotional reactions towards teachers, peers, and classroom activities. It also evaluated the students' interest in learning and their appreciation for the learning content. The third dimension, social engagement, assessed the quality of social interactions with peers and adults, and the students' willingness to form and maintain relationships while learning. Finally, the fourth dimension, behavioral engagement, evaluated the students' participation in academic and class-based activities, specifically focusing on positive conduct and the absence of disruptive behavior.

To assess the reliability of the engagement dimensions, Cronbach's alpha was calculated for each dimension. The results showed that the behavioral, emotional, and cognitive, and social engagement dimensions had high reliability, with alpha values of 0.85, 0.91, and 0.92, 0.88, respectively.

3.2.3 Science motivation scale

The Science Motivation Scale, developed by Glynn and Koballa (2006), has been widely used to measure the intrinsic and extrinsic motivation of individuals to engage in science learning and related activities. In this study, the scale was used to gain a better understanding of the motivational factors that influence middle school students' learning outcomes in science education. The Science Motivation Scale used in this study is a comprehensive psychometric instrument consisting of 30 items, with a 5-point Likert-type scale ranging from 'never' to 'always'. The scale comprises six distinct components of motivation, which are believed to impact students' willingness to engage in science learning and related activities.

The scale included a series of questions designed to assess their personal motivations for learning science. The first set of questions delves into students' intrinsic motivation, measuring their innate curiosity and passion for the subject matter. The second set of questions focuses on extrinsic motivation, examining the external factors that influence students' interest in science. As the assessment progresses, students encountered questions related to their personal goals and aspirations. The third set of questions measures the perceived relevance of learning science to these goals, helping to identify potential areas for improvement in the curriculum. The next set of questions explores students' sense of responsibility and self-determination in learning science. This component of the assessment provides valuable insights into students' attitudes toward learning and their approach to academic challenges. Finally, students were asked about their level of anxiety when it comes to science assessment. This information can be used to identify potential stressors and to develop strategies for helping students manage test-related anxiety. Cronbach's alpha was calculated as 0.90 for The Science Motivation Scale.

3.2.4 Self-efficacy scale

Self-efficacy is a powerful concept that captures an individual's belief in their ability to successfully perform a particular task or achieve a specific goal. In the field of education, self-efficacy can play a critical role in determining a student's level of motivation, engagement, and academic performance. The Self-Efficacy for Learning Form, developed by Zimmerman and Kitsantas (2007), has become a widely used tool for measuring self-efficacy in educational research. The SELF scale, consists of 19 items that assess students' self-efficacy beliefs across three factors: test-taking, studying, and note-taking. To respond to each item, students use a rating scale that ranges from 0 to 100 points, with 0 indicating they definitely cannot do the task, 30 meaning they probably cannot do it, 50 indicating they are unsure if they can do it, 70 meaning they probably can do it, and 100 indicating they definitely can do it.

Based on the internal reliability results, the Cronbach Alpha coefficients of the factors were found to range from 0.78 to 0.92. The high correlation coefficients suggest that the items are internally consistent, meaning that they are measuring the same thing and are not contradictory.

3.3 Experimental process

The study was based on the idea that while ITS can provide personalized feedback, adaptive learning paths, and individualized support to students based on their learning needs and progress, traditional lacks the ability to provide students with an immersive and interactive learning experience that can improve their understanding and retention of scientific concepts. The education activities corresponding to each week are listed below and Fig. 1 illustrates these activities.

Week 1: Introduction to the education system At the beginning of the intervention, the students in the control group were introduced to text-based instruction, while the students in the experimental group were introduced to the ITS-AR system. The instructor provided an overview of the system's features, discussed its potential to enhance learning outcomes in science education, and introduced the scientific concepts that would be covered in the study. Furthermore, the instructor explained how the ITS-AR system functioned and demonstrated its use to the students.

Week 2–3: Pre-test/questionnaire During the second and third week of the intervention, comprehensive pre-tests and pre- questionnaires were conducted to evaluate the students' baseline knowledge of the scientific concepts and their overall engagement, motivation, and self-efficacy in science education. The pre-tests and pre-questionnaires were administered to both the experimental and traditional groups to ensure that they had similar levels of baseline knowledge and engagement in science education. The students were given ample time to complete the test, and the instructor closely monitored the testing process to ensure that there were no distractions or interruptions.

The data collected served as the baseline for the study and provided valuable information on the students' level of understanding, motivation, engagement, and self-efficacy in science education before the intervention. This data was used to evaluate the effectiveness of the ITS-AR system and the traditional instructional approach in improving the students' learning outcomes and to identify areas where further support may be necessary. The data was also used to control for any pre-existing differences between the experimental and traditional groups, ensuring that any differences in learning outcomes were solely attributable to the intervention.

Week 4–7: Text based and ITS-AR instructions For the traditional group, the fourth to seven week of the intervention involved providing science instruction through the use of textbooks, lectures, and demonstrations, as well as practice exercises and assessments. During this phase, the instructor assigned readings from the textbook covering the scientific concepts that were covered in the study. The students were expected to read and study the textbook on their own to gain an understanding of the scientific concepts. In addition to the readings, the instructor delivered lectures and demonstrations in the classroom. The lectures covered the key scientific concepts, and the demonstrations showed the students how these concepts are applied in real-life situations. The instructor used visual aids such as diagrams, charts, and videos to help the students understand the concepts. After each lecture and demonstration, the students were given practice exercises to complete. These exercises tested the students' understanding of the scientific concepts and provided an opportunity for them to apply what they had learned. The exercises were designed to challenge the students and encourage them to think critically about the concepts. The students were also given assessments to evaluate their understanding of the scientific concepts covered in the study. These assessments consisted of multiple-choice questions and short answer questions that tested the students' understanding of the scientific concepts. The assessments were designed to be challenging but fair, and were based on the material covered in the readings, lectures, and demonstrations. Throughout the fourth to seven week of the intervention, the instructor was available to answer any questions that the students may have had and to provide feedback on their progress. The instructor used the feedback to identify areas where the students may have been struggling and to provide additional support and guidance as needed. At the end of the seven week, the students had completed a range of practice exercises and assessments. The instructor evaluated the progress of the students and provided feedback on their learning outcomes. This feedback helped the students to identify areas where they needed to improve and to build on their strengths. The data collected during this phase of the intervention was used to assess the effectiveness of the traditional instructional approach in improving science learning outcomes and to identify areas for further improvement.

The periodic table is fundamental to science education, serving as the framework through which students understand chemical properties and behaviors. Its complexity and the abstract nature of its content, however, pose significant challenges for students trying to grasp and retain this crucial information. To address these challenges, our study specifically aimed to enhance the learning experience of the periodic table through innovative technological integration. During weeks four to seven of the intervention, the experimental group received science instruction using the ITS-AR system, a period critical for engaging students with the core elements of the periodic table beyond traditional learning methods. Figures 2 and 3 display interface designs that utilize AR, developed by The Australian Nuclear Science and Technology Organisation (ANSTO), to help users explore and learn about the periodic table. These designs demonstrate how AR can transform the static information of the periodic table into a dynamic and interactive visual experience, making complex concepts more accessible and engaging. Furthermore, the ANSTO XR mobile application, utilized in this study, offered a range of educational resources, including interactive posters designed to facilitate the learning of the periodic table across diverse age groups. This app employs a novel approach by integrating AR technology to teach atomic structures, providing users with an interactive and immersive experience that effectively illustrates the scale and complexity of atomic structures. This not only deepens understanding of the properties of protons, neutrons, and

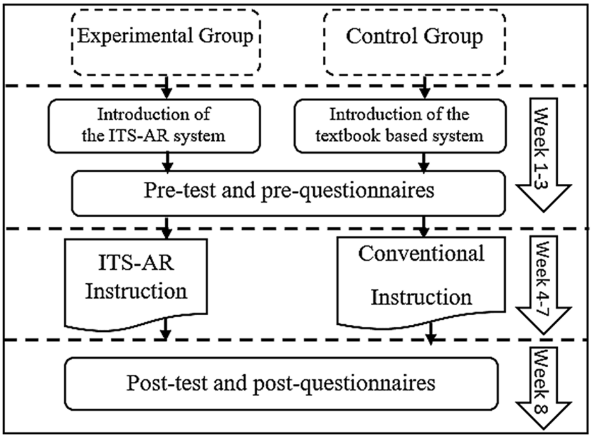

Fig. 1 A visual representation outlining the structure and procedures of the experiment

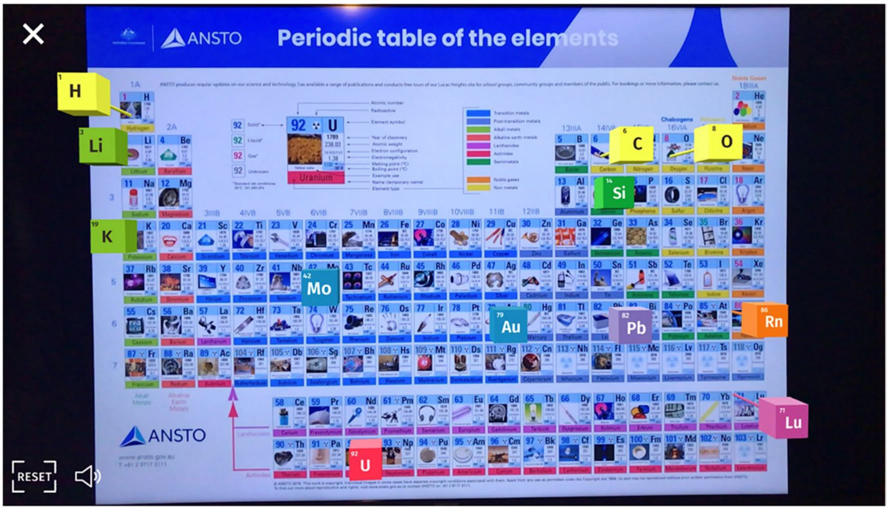

Fig. 2 an example of augmented reality interfaces for studying the periodic table

electrons but also enhances student curiosity and engagement by allowing them to visualize and interact with these elements in a virtual space. This targeted approach using AR and ITS technologies specifically addresses the educational challenges associated with the periodic table and leverages the strengths of interactive digital tools to enhance student learning outcomes. By offering a more engaging, interactive, and personalized learning experience, these technologies significantly improve comprehension and retention of the periodic table, thereby contributing to broader science learning outcomes.

During this phase, the instructor assigned learning activities to the students that integrated AR technology to help them visualize complex scientific concepts and experiments. The AR technology provided students with a more interactive and immersive learning experience, enabling them to better understand the scientific concepts covered in the study.

Throughout the fourth to seven week of the intervention, students were encouraged to actively engage with the ITS-AR system and to take ownership of their learning. At the end of the seven week, the students had completed a range of learning activities using the ITS-AR system. The instructor evaluated the progress of the students and provided feedback on their learning outcomes. This feedback helped the students to identify areas where they needed to improve and to build on their strengths. A sample of feedback provided by ITS-AR system is involved in Table 1. The data collected during this phase of the intervention was used to assess the effectiveness of the ITS-AR system in improving science learning outcomes and to identify areas for further improvement.

Week 8: Post-test The eighth week of the intervention involved administering a post-test to measure the effectiveness of the ITS-AR system in improving science learning outcomes. The post-test measured the students' understanding of the scientific concepts. A post-questionnaire was also administered to collect data on the students' motivation, engagement, and self-efficacy in science education following the intervention.

3.4 Data analysis

Academic data, including academic achievement test scores, student engagement scale scores, science motivation scale scores, and self-efficacy scale scores, were

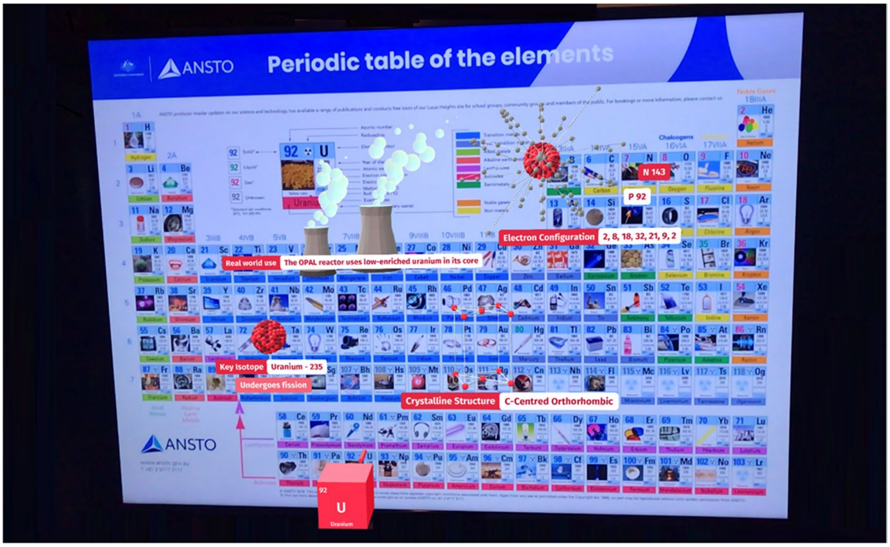

Fig. 3 Discovering the Periodic Table through Augmented Reality: Interface Design Example

collected for both the experimental and control groups prior to and following the learning activity.

The analysis was performed using the Statistical Package for the Social Sciences (SPSS) software. Descriptive statistics were used to summarize and describe the data collected from the pre- and post-tests, as well as the surveys. Measures of central tendency, such as means and medians, were used to describe the average scores of the participants on the various measures, while measures of variability, such as standard deviation, were used to describe the spread of the scores. The descriptive statistics were used to provide an overview of the data and to identify any outliers or unusual values. On the other hand, the effectiveness of the ITS-AR system approach in enhancing students' learning outcomes, engagement, motivation, and self-efficacy was evaluated through an analysis of covariance (ANCOVA) to determine if any significant differences were observed between the two groups.

4 Findings

The ITS-AR system was designed to provide personalized feedback, adaptive learning paths, and individualized support to students based on their learning needs and progress, and allow them to visualize complex scientific concepts and experiments through AR technology.

4.1 Learning outcomes

The present study aimed to investigate the effectiveness of integrating AR technology into ITS to improve science education outcomes among middle school students. The pre-test scores of the experimental and control groups were analyzed using t-test, and there was no significant difference between the experimental and control groups in their prior knowledge of the scientific concepts covered in the study ($F = 2.36$, $p = 0.459$). This result suggests that the two groups had equivalent learning outcomes before the intervention. To examine the post-test scores of the two groups, analysis of covariance (ANCOVA) was used to exclude the effect of their pre-test scores. As involved in Table 2, the findings revealed that the experimental group had significantly better learning outcomes than the control group ($F = 8.42$, $p < 0.01$). This result indicates that the adjusted mean score ($M = 87.92$) of the experimental group was higher than that of the control group ($M = 70.72$). Moreover, the standard deviation of the experimental group ($SD = 3.89$) was smaller than

Table 2 ANCOVA analysis comparing the learning outcomes between study groups

Variable	Study Groups	Mean	SD	Adjusted mean	F	p
Learning Outcomes	Experimental	87.98	3.89	87.92	8.42	0.006
	Control	70.76	5.45	70.72		

that of the control group ($SD = 5.45$), suggesting that the degree of dispersion for the experimental group was lower than that of the control group. This finding implies that the ITS-AR system approach was effective in improving students' learning outcomes in comparison to the traditional approach.

4.2 Student engagement

The pre-test scores of the two groups were not significantly different ($F = 3.46$, $p = 0.316$), indicating that the student engagement of the two groups was similar prior to the study. Namely, the lack of significant difference between the pre-test scores of the two groups suggests that any observed differences in student engagement between the experimental and control groups can be attributed to the ITS-AR system approach rather than pre-existing differences in student engagement. ANCOVA was used to assess the effectiveness of the ITS-AR system approach by examining the post-test scores of the two groups, with the pre-test scores being controlled for. The results presented in Table 3 showed that the experimental group had significantly higher student engagement than the control group ($F = 13.47$, $p = 0.003$). This indicates that the adjusted mean ($M = 4.23$, $SD = 1.02$) of the experimental group was superior to that of the control group ($M = 3.78$, $SD = 1.14$) in terms of student engagement. The results suggest that the ITS-AR system approach was effective in enhancing student engagement.

4.3 Science motivation

Analysis of Covariance (ANCOVA) was employed, with pretest scores as a covariate, posttest scores as dependent variables, and ITS and AR system approaches as independent variables. The test of homogeneity showed that the regression slopes of the two groups' science motivations are homogeneous with $F = 0.43$ and $p > 0.01$, indicating that ANCOVA is appropriate for data analysis. To get a more in-depth understanding, we analyzed the descriptive statistics data of the pretest and posttest scores for science motivations. ANCOVA results revealed that there is a significant difference in post-performance ratings of the two groups, with $F = 10.42$ ($p < 0.01$). This implies that the use of the ITS-AR technology approach has been beneficial for students, particularly those in the experimental group, who had significantly better motivation (adjusted mean = 4.29) than those in the control group (adjusted mean = 3.78). Therefore, we conclude that integrating ITS-AR technology was an effective way of improving students' motivation towards science education. A

Table 3 ANCOVA analysis indicating the results of the student engagement between groups

Variable	Study Groups	Mean	SD	Adjusted mean	F	p
Student Engagement	Experimental	4.21	1.02	4.23	13.47	0.003
	Control	3.80	1.14	3.78		

Table 4 ANCOVA results for posttest science motivation scores between experimental and control groups

Variable	Study Groups	Mean	SD	Adjusted mean	F	p
Student Engagement	Experimental	4.26	0.98	4.29	10.42	0.006
	Control	3.75	1.17	3.78		

detailed summary of the ANCOVA analysis of the posttest scores for science motivations, comparing the experimental and control groups, is presented in Table 4.

4.4 Self-efficacy

To investigate the impact of the proposed teaching approach on students' self-efficacy, analysis of covariance (ANCOVA) was used to analyze the students' post-questionnaire ratings while controlling for the effects of their pre-questionnaire ratings. Prior to conducting the analysis, the homogeneity of regression on the pre-questionnaire of self-efficacy was examined to ensure its suitability. The results of the homogeneity test revealed no significant difference between the two groups of students for self-efficacy ($F = 5.68$, $p > 0.05$), suggesting that the two groups had similar levels of self-efficacy before the study. ANCOVA was then performed on the post-questionnaire scores to examine the effect of the ITS-AR approach on students' self-efficacy. The experimental group had an adjusted mean of 88.12 with a standard deviation of 5.68, while the control group had an adjusted mean of 70.77 with a standard deviation of 5.92. The results of the analysis indicated a significant difference in self-efficacy between the two groups, as determined by a statistically significant F-value of 21.68 ($p < 0.01$), as presented in Table 5. Thus, the proposed approach was found to have a positive impact on students' self-efficacy.

To sum it up, the results of this study imply that integrating AR technology into ITS can be a promising way to enhance learning outcomes, student engagement, motivation, and self-efficacy in science education among middle school students. The study found that the ITS-AR system approach was effective in improving students' learning outcomes and student engagement when compared to the traditional approach. It also revealed that the approach led to a significant improvement in students' motivation and self-efficacy, particularly among those in the experimental group. Therefore, the ITS-AR system approach can be an effective teaching strategy for science educators and educational institutions

Table 5 ANCOVA analysis of the posttest for the self-efficacy

Variable	Study Groups	Mean	SD	Adjusted mean	F	p
Self-Efficacy	Experimental	88.18	5.68	88.12	21.68	0.004
	Control	70.83	5.92	70.77		

seeking to improve student achievement, engagement, motivation, and self-efficacy in science education.

5 Discussion and implications

The present study investigated the effectiveness of an instructional intervention that combined Intelligent Tutoring Systems (ITS) and augmented reality (AR) technologies in enhancing learning outcomes, motivation, self-efficacy, and engagement in middle school students. The study findings revealed that the intervention had a positive impact on students' learning outcomes, motivation, self-efficacy, and engagement, as evidenced by the post-test/questionnaire results. The following discussion elaborates on the study findings and their implications for science education.

The first significant finding of our study was that the ITS-AR system considerably enhanced students' learning outcomes, as evidenced by the higher scores on the scientific concepts test achieved by students who received the intervention compared to those in the control group. This improvement aligns with previous studies, such as those by Arici et al. (2019) and Fidan and Tuncel (2019), which documented the beneficial effects of AR technology in science education settings. These studies reported that AR technology not only increases student engagement but also significantly improves comprehension of complex topics by making abstract content more tangible and accessible. Our findings extend the current understanding by demonstrating that the integration of ITS with AR can amplify these benefits. The AR component provided a visually rich and interactive environment that directly engaged students with complex scientific principles, enhancing their ability to internalize and apply what they learned. This is consistent with Lee's (2021) observation that AR-supported education creates immersive learning experiences that are particularly effective for teaching intricate scientific processes and concepts. Moreover, the personalized feedback and adaptive support features of the ITS were instrumental in furthering student learning outcomes. By continuously assessing each student's understanding and progress, the ITS tailored the educational content to meet individual learning needs, a capability that has been underscored by Erümit and Çetin (2020) and Khazanchi and Khazanchi (2021). These researchers found that adaptive learning environments significantly contribute to academic achievement by accommodating diverse learning styles and paces. Furthermore, the effectiveness of our ITS-AR system echoes the findings of Kochmar et al. (2020), who reported that intelligent tutoring systems that adapt to student responses can dramatically improve the learning process by providing timely, context-specific feedback. This not only aids in the retention of learned material but also fosters a deeper understanding by allowing students to explore concepts at their own pace and receive immediate clarification of doubts, thereby reducing frustration and enhancing motivation. In contrast to some studies which suggest limitations in the scalability of AR technologies in larger educational settings due to technical constraints or varying student tech proficiency (Al-Ansi et al., 2023; Cevikbas et al., 2023; Creed et al., 2024), our study's findings advocate for broader implementation as the benefits in engagement and understanding offset the initial challenges. This discrepancy may be attributed to advancements in AR technology and infrastructure that have reduced earlier barriers to access and usability. By comparing these results with the existing body of research, it is evident that while our study corroborates many findings on the efficacy of AR and ITS in enhancing educational outcomes, it also highlights the critical role of advanced, integrated systems in overcoming traditional educational challenges. These comparisons not only reinforce the validity of our results but also suggest that further exploration into combined ITS-AR systems could be highly beneficial for future educational technologies and methodologies.

The second significant finding of our study was that the ITS-AR system had a notable positive impact on students' motivation in science education. The results indicated that students who participated in the intervention exhibited higher levels of motivation to learn science compared to those in the control group. This enhancement in motivation aligns with the dynamic and interactive nature of the ITS-AR system, which transforms traditional science learning into an engaging, relevant, and enjoyable experience. The incorporation of AR technology played a crucial role in this increase in motivation. By providing a novel and visually engaging way to explore scientific concepts, AR technology not only made learning more appealing but also activated the students' curiosity and interest in science. This observation confirms findings from Önal and Önal (2021), who reported that AR environments significantly boost student engagement and interest by offering immersive experiences that are not possible in conventional educational settings. Similarly, Wang (2023) found that AR applications in science education increase student motivation by providing real-time, interactive simulations that allow for deeper exploration of scientific phenomena. Moreover, the ITS component of the system further enhanced student motivation by offering personalized and adaptive learning experiences tailored to individual student profiles. This customization addresses students' unique learning needs, abilities, and interests, making the learning process more relevant to each student. Such personalization is known to enhance intrinsic motivation as students feel their learning experience is directly aligned with their personal educational needs and goals (Alamri et al., 2020). Additionally, the adaptive nature of ITS helps maintain an optimal challenge level, keeping students engaged without causing frustration or disinterest. These results are supported by recent studies like those of Troussas et al. (2023), who found that personalized feedback mechanisms within ITS significantly contribute to increased motivation by helping students recognize their progress and understand their learning paths better. Conversely, studies by Abdelshiheed et al. (2023) suggest that while ITS can increase motivation, the effectiveness can vary significantly with the design of the system and the context in which it is used, indicating that customization and context are critical for realizing the full benefits of ITS in educational settings. By comparing these results with those of similar studies, it becomes clear that the integration of ITS and AR not only supports existing theories about motivational enhancement through technology in education but also provides a practical demonstration of these technologies' impact in real-world educational settings. This comparison not only strengthens the validity of our findings but also highlights the potential of ITS-AR systems to transform educational practices by making learning more personalized, engaging, and motivating for students.

Thirdly, the study revealed that the ITS-AR system had a statistically significant impact on enhancing students' self-efficacy in science education. According to the results, students who engaged with the ITS-AR intervention exhibited significantly higher levels of self-efficacy in science than their counterparts in the control group. This improvement suggests that the integration of AR and ITS technologies not only enriches the learning environment but also significantly bolsters students' belief in their ability to master science subjects. The enhancement of self-efficacy through the ITS-AR system can be attributed to several factors. Firstly, the immersive and interactive nature of AR technology allows students to visualize complex scientific processes and theories, which helps demystify subjects that might otherwise seem inaccessible. This clarity can increase students' confidence in their understanding of the subject matter. Secondly, the adaptive learning capabilities of ITS provide tailored educational experiences that meet the individual needs of each student, fostering a learning environment that is perceived as supportive and responsive to their personal academic challenges. The implications of these results are significant, given that self-efficacy is a critical determinant of student motivation and academic achievement in science education, as confirmed by Cai et al. (2021). Their study highlighted that enhanced self-efficacy leads to improved academic persistence and higher achievement in science courses. Similarly, Ciloglu and Ustun (2023) found that technology-enhanced learning environments significantly contribute to self-efficacy by providing students with immediate feedback and the opportunity to correct mistakes in real-time, which reinforces their sense of mastery over the content. Moreover, these findings align with the broader research literature, which consistently shows that higher self-efficacy is linked to better problem-solving skills, deeper engagement in learning activities, and greater persistence in overcoming academic challenges (Orakci, 2023). This correlation underscores the potential long-term implications of enhanced self-efficacy, which can influence not only immediate academic success but also future career trajectories in science-related fields. By comparing these results with those of similar studies, it becomes evident that the ITS-AR system's role in promoting self-efficacy is both impactful and aligned with current educational technology trends. These comparisons not only validate our findings but also highlight the transformative potential of integrating AR and ITS in educational settings to foster essential psychological constructs like self-efficacy, which are foundational to students' long-term academic and professional success.

The fourth finding of our study was that the ITS-AR system had a significant positive impact on students' engagement in science education. The results showed that students who participated in the ITS-AR intervention were notably more engaged and active in the learning process compared to their peers in the control group. This increase in engagement can be attributed primarily to the AR technology, which transformed traditional learning environments into interactive and exploratory spaces. By enabling students to visualize and manipulate scientific concepts through immersive simulations, AR helped demystify complex topics and made learning more tangible and intriguing. Additionally, the ITS component played a crucial role in sustaining this engagement by providing personalized and adaptive learning experiences tailored to the individual needs and preferences of each student. This personalization is critical, as it ensures that learning activities are aligned with students' own interests and learning styles, thereby maximizing engagement and reducing cognitive overload. The effectiveness of combining AR and ITS to boost student engagement is supported by similar findings in the literature. For instance, a study by Poonja et al. (2023) found that AR environments significantly increase students' curiosity and interaction with learning materials, which leads to higher levels of engagement. Similarly, researches by Lin et al. (2023) and Wang et al. (2023) demonstrated that ITSs that adapt to students' learning progress can keep students more involved by continuously providing challenges that are neither too easy nor too difficult, thus maintaining an optimal learning curve. This reflects the potential of ITS-AR systems to create a more dynamic and supportive educational experience that encourages students to become active participants in their own learning process. This comparative analysis underscores the unique contribution of our findings within the broader context of educational technology research.

Practically, the present study engages a variety of stakeholders, including educators, school administrators, parents, students, and the research community, each of whom could significantly benefit from the findings. The implications of this study are multifaceted, offering actionable insights that could influence science education broadly.

Educators stand as a primary beneficiary group of this study. Science teachers and curriculum developers could utilize the results to inform the development and implementation of ITS-AR systems in their classrooms. These findings provide a clear understanding of how such technologies can be used not only to enhance student learning outcomes but also to innovate teaching methodologies. For instance, educators could integrate ITS-AR systems to create more dynamic and engaging lessons that cater to diverse learning styles. Additionally, the study offers insights into effective resource allocation for technology and the development of policies that support the sustainable use of ITS-AR systems in educational settings. School Administrators also play a crucial role in the practical application of these findings. The study provides evidence that could help administrators make informed decisions about investing in and deploying ITS-AR systems. It underscores the importance of aligning technological resources with educational goals to maximize student engagement and learning outcomes. Furthermore, administrators could use these insights to strategize the integration of AI technologies into the curriculum, ensuring that teachers are supported and that systems are used effectively to enhance educational experiences across subjects. Parents and Students are direct beneficiaries, as the enhanced learning environments facilitated by ITS-AR systems can lead to improved educational outcomes. Parents in particular may find the results useful for understanding how technology influences learning and for making informed decisions about the technologies they advocate for in their children's schools. Similarly, students can benefit from engaging with ITS-AR systems that make learning more interactive and enjoyable, potentially boosting their motivation and interest in science. Finally, the Research Community benefits from the foundational analysis provided by this study. Researchers can build upon these findings to explore further the capabilities and limitations of ITS-AR systems in education. This study paves the way for future research into how these technologies can be adapted for use in different educational settings and across various academic disciplines. By examining the broader impacts of ITS-AR integration, researchers can also delve into longitudinal studies that assess the sustainability of technology-enhanced learning benefits. To truly capitalize on these findings, detailed guidelines and best practices for implementing ITS-AR systems should be developed. These should include technical specifications, pedagogical strategies, and evaluation metrics to help stakeholders at all levels—from classroom teachers to district administrators—implement these systems effectively. Additionally, continuous professional development should be offered to educators to ensure they are equipped with the skills and knowledge necessary to leverage ITS-AR technology in enhancing student learning experiences.

5.1 Limitation and future studies

Although this study has enhanced our understanding of the integration of AR into ITS to bolster science education, interpreting the results requires caution due to several noted limitations, which also suggest avenues for future research. One primary limitation was the use of a convenience sampling method involving 58 participants from a single school, which may not fully represent the broader population. This restricts our ability to make definitive assertions about the effectiveness of the ITS-AR system across diverse educational settings. Additionally, the reliance on volunteer participants might introduce a selection bias, as these individuals could inherently possess a higher motivation or interest in the subject matter compared to the general student population. Another significant limitation is the eight-week duration of the intervention, which, while providing initial insights into the benefits of the ITS-AR system, may not be sufficient to assess its long-term impacts fully. Short intervention periods like this often fail to capture the sustainability and evolution of educational benefits over time, which is critical for understanding the lasting effects of technological interventions in education. Moreover, the study did not account for individual variations in learning styles and preferences, which can significantly affect the effectiveness of educational technologies. The absence of such considerations may limit the applicability of the findings to all learners, potentially overlooking how different students might uniquely benefit from or struggle with the technology. Cost-effectiveness analysis of the ITS-AR system relative to traditional instructional methods was also lacking. This analysis is crucial for evaluating the feasibility of broader adoption in educational settings, as it helps stakeholders understand the economic impacts alongside educational benefits.

In future studies, it would be beneficial to expand the sample size and increase diversity to enhance the generalizability of the findings. Employing stratified random sampling could help mitigate risks of selection bias and yield a more representative sample of the student population. Extending the duration of interventions to several months or even an academic year is crucial for investigating the prolonged exposure effects of the ITS-AR system on educational outcomes, providing a clearer picture of its long-term impacts. Exploring the application of the ITS-AR system in other disciplines such as mathematics or language arts could provide valuable insights into its versatility and effectiveness across various educational contexts. Such cross-disciplinary studies would help delineate the specific features of the ITS-AR system that are most beneficial for different subject areas. To address the study's limitations related to individual differences, future research should explicitly include analyses of how learning styles and preferences impact the efficacy of the ITS-AR system. Designing studies that assess responses of students with different learning modalities—visual, auditory, reading/writing, and kinesthetic—to the technology-enhanced learning environment would be particularly insightful. Integrating diagnostic tools that identify individual learning styles at the outset allows researchers to tailor the ITS-AR interventions accordingly and examine how these tailored approaches affect learning outcomes. Furthermore, incorporating a mixed-methods research design that includes both quantitative and qualitative data would offer a more comprehensive view of the ITS-AR system's effectiveness and user experience. This approach would not only enrich our understanding of its educational implications but also allow for a nuanced exploration of how different learning styles and preferences affect engagement with and outcomes from the ITS-AR system. Developing more adaptive and inclusive educational technologies that cater to a diverse range of learner needs could significantly enhance both engagement and educational achievement.

6 Conclusion

This study provides evidence that the integration of AR in ITS can have a positive impact on middle school students' science learning outcomes, motivation, engagement, and self-efficacy. The results suggest that using the ITS-AR system can help students visualize complex scientific concepts and experiments, receive personalized feedback and support, and follow an adaptive learning path tailored to their individual needs and progress. One of the major contributions of this study is the use of artificial intelligence algorithms to develop an ITS-AR system that can provide personalized and adaptive learning experiences for students. The system was designed to continuously monitor and analyze students' performance and provide appropriate support and feedback to enhance their learning outcomes. The results suggest that this approach can be effective in improving science education outcomes for middle school students. To sum up, this study demonstrates the potential of the ITS-AR system to enhance science learning outcomes and student engagement, motivation, and self-efficacy. This study provides an initial framework for the integration of AR and ITS, which could have implications for the development of effective learning tools and strategies in the future. This study underscores the need for continued research in this area and the potential for new technology to improve the quality of education and the learning experiences of students.

Appendix

Sample Achievement Test: The Periodic Table

Part 1: Comprehension of Scientific Concepts

Instructions: Read the following questions carefully and select the best answer.

1. What is the Periodic Table?

A A list of the elements arranged in alphabetical order
B A chart that organizes the elements by their properties and atomic structure
C A graph that shows the reactivity of the elements
D A table of chemical reactions between elements

What is the atomic number of an element?

A. The number of neutrons in the nucleus of the atom
B. The number of electrons in the outermost energy level
C. The number of protons in the nucleus of the atom
D. The mass of the atom in atomic mass units

2. Which of the following elements is a halogen?

A Sodium
B Chlorine
C Calcium
D Nitrogen

3. Which group of elements is known as the noble gases?

A Group 1
B Group 2
C Group 17
D Group 18

4. What is the difference between a period and a group in the Periodic Table?

A A period is a row of elements, and a group is a column of elements.
B A period is a column of elements, and a group is a row of elements.
C A period is a group of nonmetals, and a group is a group of metals.
D D. A period is a group of metals, and a group is a group of nonmetals.

Part 2: Accuracy of Scientific Explanations

1. Does the periodic table organize elements based on their atomic number? (Yes/No).
Which of the following is NOT a group in the periodic table?

a) Alkali metals
b) Halogens
c) Noble gases
d) Transition metals

2. Match the following element to its correct group in the periodic table:

a) Iron

b) Chlorine
c) Xenon
d) Calcium
e) Alkali metals
f) Halogens
g) Noble gases
h) Transition metals

3. Explain how the periodic table is organized and the significance of the trends observed in the table.
4. Do elements in the same group of the periodic table have similar chemical properties? (Yes/No).
5. Which element is located in Group 17 and Period 2 of the periodic table?

a) Lithium
b) Fluorine
c) Oxygen
d) Sodium

6. Match the following element symbol to its name:

a) Na
b) Cl
c) Fe
d) He
e) Iron
f) Helium
g) Sodium
h) Chlorine

7. What was the significance of Dmitri Mendeleev's contributions to the development of the periodic table?

Part 3: Clarity and Coherence of Written Responses

1. Explain how the periodic table organizes elements and the significance of the trends observed in the table.
2. Describe one of the groups in the periodic table and the properties of the elements in that group.
3. Match each of the following elements to its correct group in the periodic table and explain how the location of the element in the table relates to its properties:

   a) Iron
   b) Chlorine
   c) Xenon

d) Calcium

4. Discuss the significance of Dmitri Mendeleev's contributions to the development of the periodic table and how his work influenced the modern understanding of chemical elements.
5. Choose one group in the periodic table and describe the similarities and differences among the elements in that group.

Part 4: Use of Scientific Terminology

Instructions: Fill in the blanks with the appropriate scientific terminology.

1. The ________ number of an element is equal to the number of protons in the nucleus of an atom.
2. The ________ of an element refers to its ability to react with other elements.
3. The elements in Group 1 of the Periodic Table are known as the ________.
4. The horizontal rows in the Periodic Table are known as ________.

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Declarations

Ethics approval and consent to participate This study was approved by Kırşehir Ahi Evran University, and all participants provided written informed consent to participate in the research.

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