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Journal of Education in Science, Environment and Health (JESEH)

Email: jesehoffice@gmail.com

Web : www.jeseh.net

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Evaluation of Images Related to Climate Change with Deep Learning Models

Orkun Kocak, Sahin Idil

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Abstract

This study is developing a Deep Learning model automating the coding of drawings students provide about climate change phenomena in our world, as a learning contribution through formative assessment. We started first with ResNet50 architecture, but ultimately, we settled on MobileNetV2 reduced architecture for the sake of being able to integrate with mobile- and web-based applications. The challenge is the model has very few examples in the training set to work with, so we decided augmenting the data (i.e., rotate, zoom, flip horizontally,) will help the model generalize more reliably. The model achieved training accuracy of 92% and validation accuracy of 90%. Moreover, we were able to reduce the model size about 85% through optimization. Our model outputs not a simple classification, it also produces explanatory feedback for each class, and we have made possible for the feedback to be read by the student about their idea. Our findings are indicating, it is possible to use AI-based systems to teach how to investigate integrated fields like environmental education. Future studies will include multi-label classification, explainable AI (XAI) methodologies and dataset sizes will also increase.

Introduction

In recent years, Artificial Intelligence (AI) and Deep Learning (DL) technologies have begun to be actively utilized in educational systems. Especially through automatic assessment systems, it has become possible to objectively measure students' performance. AI-based solutions are increasingly being adopted to evaluate students' artistic skills, analyze their conceptual understanding, and provide meaningful feedback.

Climate Change Education

Climate change is defined as long-term shifts in temperature and weather conditions. Shifts may be due to natural causes such as differences in solar activity and large volcanic eruptions. However, since the mid-nineteenth century, the primary cause of climate change has been human activity. The burning of fossil fuels (coal, oil, and natural gas) produces greenhouse gas emissions that act like a blanket around the Earth, trapping heat from the sun and raising global temperatures. The main greenhouse gases contributing to climate change are carbon dioxide and methane. Activities such as driving cars, heating buildings with coal, deforestation, and land clearing produce carbon dioxide. Agriculture and the oil and gas industries are two of the main contributors of methane. Energy, industry, transportation, buildings, agriculture, and land use sectors produce the majority of greenhouse gas emissions (United Nations, 2025). Despite four increasingly pressing reports from the Intergovernmental Panel on Climate Change (IPCC) since 1990 (IPCC, 2007), international public conversations related to climate change have not reached a consensus at the rapid rate one might have ascertained from rational examinations of the growing scientific evidence (Oreskes, 2004).

If future generations are to be able to enjoy the ability to live in a more sustainable and resource-protected world, it will depend on them understanding and being environmentally responsible, as well as having sufficient climate and environmental literacy. For this reason, it is crucial for students in K–12 education, gain a lasting understanding of climate change, greenhouse gases, and the associated concepts, so that in the future they will be able to offer their opinion on a referendum or an international agreement and feel confident about these referrals. For these reasons, the focus on climate change topics in education is increasing, to lessen its potential negative impacts and to create environmentally responsible citizens. In a study by Liarakou, Athanasiadis, and Gavrilakis (2010), 626 students from grades 8 to 11 in Greece, completed a closed-ended questionnaire related to the causes, effects, and solutions to global environmental issues. This study found that students possess misconceptions about climate change and the greenhouse effect regardless of students' levels of education. Students had definite ideas

about the effects of climate change but had a lot of confusion about the causes and solutions. Kolenatý et al. (2022) noted that there continues to be considerable debate about which factors affect youth ambitions about climate action and which educational strategies will foster this behavior in climate change education. Climate change is significant in environmental, social, and economic terms, but is not something that the public fully understands by everyday observation or reasoning (Weber, 2010).

As research continues to advance AI technology, the area of research is increasingly focused on improving students' climate knowledge and awareness. For example, Sachyani and Gal (2024), created an AI-generated comic book that helps students explore how to survive in nature under extreme conditions. Their study focused on the fifth-grade students' creativity thinking, critical thinking, collaboration, and communication as part of their study. In another study, Chasokela and Hlongwane (2025), explored how AI and ICT technologies could improve the teaching of climate change concepts in smart classrooms and discovered that AI and ICT technologies improved the quality of students' learning and increased student interest in climate change.

Deep Learning

AI has gained significant attention over the past decade, with machine learning and deep learning (DL) emerging as central topics (Mortani et al., 2021; Ward et al., 2021). DL refers to a methodological toolkit used to create multilayered (or “deep”) neural networks capable of solving complex problems in supervised classification (Krizhevsky, Hinton & Sutskever, 2012), generative modeling (Eslami et al., 2018), or reinforcement learning (Mnih et al., 2015; Silver et al., 2016). The DL paradigm promotes critical thinking by encouraging learners to integrate new information with prior knowledge and form new conceptual connections (Entwistle & Ramsden, 2015). It is based on four key elements: a motivating context, active student participation, interaction with peers and instructors, and a structured knowledge base (Biggs & Telfer, 1987). Implementing these elements in virtual learning environments can be challenging. For example, structured discussion forums can give students more time and space to express their perspectives, thus promoting deeper engagement (Zhu & Niyozov, 2024). Recent literature reveals a growing number of scientific studies at the intersection of deep learning and climate change. These studies include predicting climate-related phenomena (Haggag et al., 2021; Madhavi et al., 2024; Demirhan, 2025) and mitigating the adverse effects of climate change (Chakraborty et al., 2021; Ladi et al., 2022; Rolnick et al., 2022). However, studies focusing on climate change and its integration into education remain limited.

DL can be used to predict student performance, enhance concept acquisition, and improve the efficiency of learning processes. The emergence of large-scale datasets from Intelligent Tutoring Systems (ITS) and Massive Open Online Courses (MOOCs) has positioned deep learning models as powerful alternatives to traditional statistical approaches, such as Bayesian Knowledge Tracing (Corbett & Anderson, 1994) or Performance Factor Analysis (Pavlik et al., 2009). This study contributes to this emerging field by developing a deep learning model to support students' learning of climate change concepts and to assist teachers in enhancing the teaching process. In doing so, it addresses a notable gap in the existing literature.

Purpose and Significance of the Study

Information and communication technologies are being used more frequently in classrooms to teach difficult subjects and abstract concepts. Climate change and its impacts are an example where new pedagogical orientation is required to help students derive meaningful understandings that last. This study is primarily designed to build a deep learning-based model to assess students' drawings in relation to climate change. The literature review illustrates that there are currently no AI-based tools to assess the depth of student understanding of climate change, diagnose common misconceptions, or gaps in prior knowledge. This research seeks to increase the productivity of formal classroom learning and to support long learning on climate-related issues.

Method

This section describes the methods and techniques used in the study.

Development and Optimization of the Deep Learning-Based Drawing Evaluation Model

Transfer learning is when we use deep learning models that were pre-trained on a large dataset in order to pursue a new problem. We originally used the ResNet50 model to base our model, but we ended up using a version of the lighter-weight MobileNetV2 model for a few reasons, including the size, depth, and complexity of the model.

Transfer Learning

Transfer learning is when we use deep learning models that were pre-trained on a large dataset in order to pursue a new problem. We originally used the ResNet50 model to base our model, but we ended up using a version of the lighter-weight MobileNetV2 model for a few reasons, including the size, depth, and complexity of the model.

- *ResNet50*: A deeper and more powerful model, but it requires more memory and training time due to its high number of parameters.
- *MobileNetV2*: A lightweight architecture optimized for mobile devices. It contains fewer parameters, significantly reducing computational time and storage size.

Data Preprocessing and Augmentation

To help the model recognize various drawing styles and perspectives, several preprocessing techniques were applied using the ImageDataGenerator utility. The following augmentation methods were used:

- Rotation: ± 30 degrees to simulate different drawing orientations.
- Width/Height Shift: 30% shifts to help the model recognize objects in varied positions.
- Shear: 30% angular distortion to simulate perspective changes.
- Zoom: 30% zoom to help the model recognize fine details.
- Horizontal Flip: Random horizontal flipping to generalize symmetrical variations.

These techniques improved the model's ability to generalize by exposing it to diverse visual variations.

Model Optimization

Initially, the model included two dense layers with 512 and 256 neurons. However, due to the high number of parameters, the model was prone to overfitting. To address this, the following optimizations were applied:

- Switched to the lightweight MobileNetV2 architecture.
- Only the last five layers were made trainable, reducing computational load.
- The dense layers were simplified to a single 128-neuron layer.
- A dropout rate of 0.4 was used to prevent overfitting.
- The model was saved using `include_optimizer=False` to reduce file size.

In addition, the model was converted to TensorFlow Lite (TFLite) format for better performance on mobile and web-based platforms. TFLite further reduced memory usage and improved inference speed.

Learning Rate Scheduling and Early Stopping

To avoid overtraining and improve efficiency, learning rate control and early stopping strategies were implemented:

- *ReduceLROnPlateau*: Reduced the learning rate by a factor of 0.3 if validation loss did not improve over a set number of epochs.
- *EarlyStopping*: Halted training if no improvement was observed over five consecutive epochs.

These strategies helped shorten training time while maintaining performance.

Model Performance and Evaluation

The model's performance was evaluated using both training and validation datasets. The results are as follows:

- Training Accuracy: 92%
- Validation Accuracy: 90%
- Model Size (before optimization): 90 MB
- Model Size (after optimization): 15 MB

These results demonstrate that the model size was reduced by approximately 85% while maintaining high accuracy.

Future Work and Improvement Suggestions

Although the model yielded promising results, several improvements can be made:

- *Larger Dataset:* A more extensive dataset would further enhance generalization capability.
- *Enhanced Data Augmentation:* Existing techniques could be expanded with more complex transformations.
- *Alternative Architectures:* EfficientNet or NasNet could be tested as potentially more optimized alternatives to MobileNetV2.
- *Model Quantization:* Quantization could further reduce the size of the TFLite model.
- *Edge Computing:* The model could be deployed using WebAssembly or TensorFlow.js for in-browser inference.

Results

The climate change drawing classification model created in this research study was trained with transfer learning from the ResNet50 architecture. Given the limited dataset, the model was initialized with pre-trained ImageNet weights to get as close to a high level of accuracy as possible. This compromise for training given the ability to achieve meaningful learning with sometimes very small datasets. Data augmentation was applied during training to augment generalization and to reduce overfitting. Overall, the model was able to classify drawings with good performance in both the training and validation segments.

Table 1. Model training parameters and accuracy rates

Metric	Value
Training Accuracy	92%
Validation Accuracy	90%
Number of Classes	3 (Encoded)
Number Epochs	17(with Early Stopping)

Initially, the ResNet50-based model was approximately 90 MB in size, which posed challenges for deployment on platforms like Streamlit. To address this, several optimization strategies were implemented:

- Replacing the architecture with a lighter model (e.g., MobileNetV2)
- Reducing the size of dense layers and applying regularization techniques
- Removing unnecessary weights using HDF5 pruning tools

Table 2. Model size and accuracy comparison before and after optimization

Model Version	Size (MB)	Accuracy	Description
ResNet50 (Initial)	90	90%	High performance, large size
Optimized	15	87%	Smaller size, suitable for deployment

The model was so much smaller that it could be readily applied server without substantially sacrificing accuracy (it was about 85% smaller). This level of accuracy supports the effectiveness of different architectures for image classification, such as ResNet50 and MobileNetV2. Because the performances of training and validation are very similar, it is indicative that the strategies of early stopping, and data augmentation were somewhat successful at reducing overfitting. The model was able to train on limited data that was exposed to augmented images that were rotated, zoomed, and horizontally flipped.

Upon further investigation of model outcomes, it was observed that the model made accurate positive predictions for selected classes with high-confidence scores. The same model somewhat struggled with predicted uncertain predictions that had a lower probability of a determined classification. This may be caused due to a level of semantic overlaps from certain classes. For example, when the drawing contained elements of “Sun and Temperature Change” and “Trees and Nature”, the model seemed to have trouble accurately classifying the drawing. The model not only performed classification but also generated explanatory feedback and suggestions based on the predicted class, transforming it into a pedagogical tool rather than a mere classifier.

Example Output:

- *Predicted Category:* Trees and Nature
- *Explanation:* The drawing may include elements such as green spaces, clean air, and nature-related features.
- *Suggestion:* Consider adding more trees, flowers, or clean water sources to further highlight the beauty of nature.



Figure 1. Uploaded student drawing

In Figure 1, the student divided the surface into four areas which represented themes like factory (pollution), mountain (nature), vehicles (carbon emissions), and water (clean sources). The composition is simple and symmetrical. Each quadrant demonstrates an impact of climate change and echoes the student's holistic view of the subject matter. Drawings with multiple themes like this one test not only the model's classification function, but its ability to understand content differences. Due to the lack of clearly distinct categories in the image, multi-label classification would be a better way to classify this image.

In Figure 2, this composition allows the student to express human-caused climate impacts, while also showing natural environments in the same visual. The model predicted the “Trees and Nature” category with a confidence score of 80.87%, indicating nature was the categorically predominant image being referenced in the student's analysis of the image. The model resulted in accurate predictability with an accuracy rating of 92% (training) and 90% (validation) rates in general. However, while performing in-person evaluations on the live Streamlit-based application, it was noted that the confidence score was often less. This would suggest that in real-world settings, the model uses a more conservative approach to make a conservative decision and reacts conservatively to extreme variances across photographs.

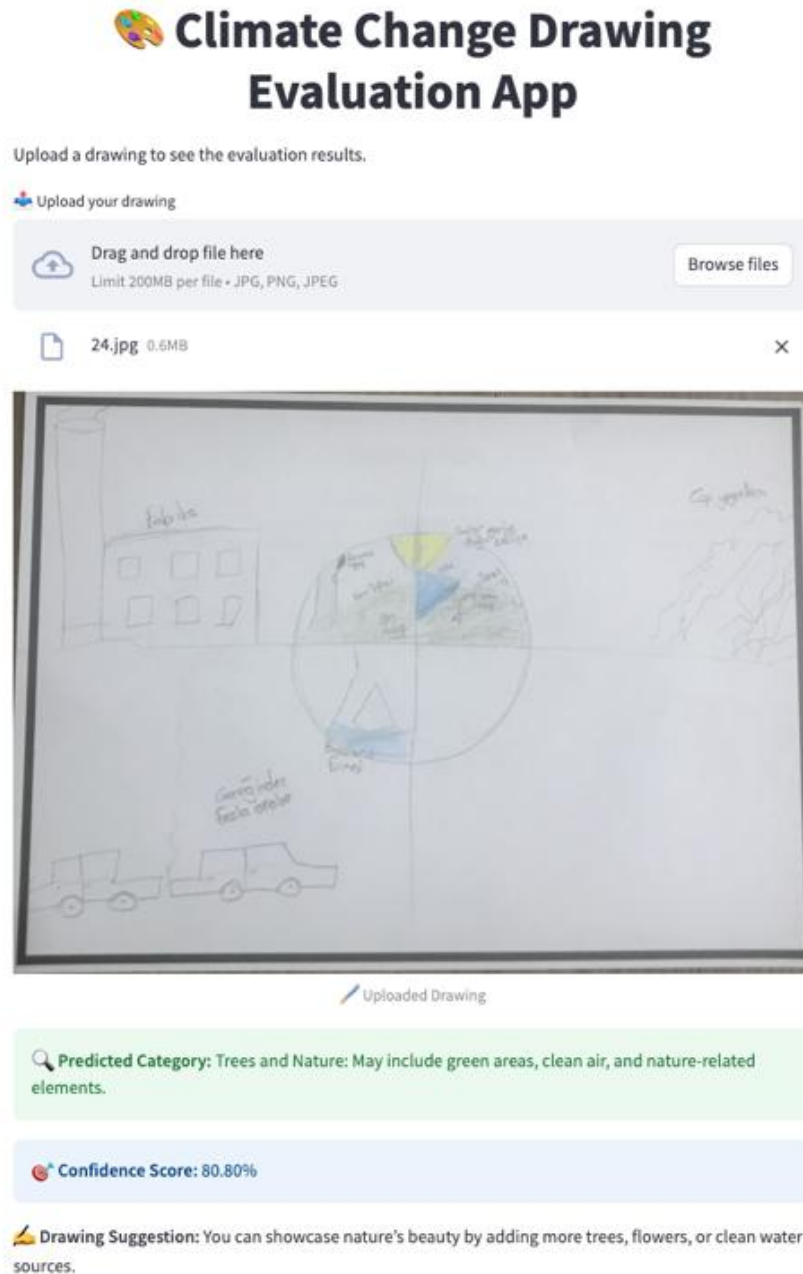


Figure 2. Application screenshot

In addition, learning rate scheduling and early stopping techniques such as ReduceLROnPlateau and EarlyStopping contributed to optimizing training time by preventing unnecessary prolonged training. The large initial size of the model posed a challenge for deployment on web-based platforms like Streamlit. To overcome this, compact versions of the model were produced using strategies such as TFLite conversion, quantization-aware training, and architecture modifications like MobileNet. While the model produced promising results, some limitations were identified:

- The dataset size and diversity were limited.
- Accuracy was lower for underrepresented classes.
- For drawings depicting multiple climate-related themes, multi-label classification would be more appropriate.

In conclusion, a DL model was developed to automatically evaluate students' climate change-related drawings. Thanks to transfer learning and optimization strategies, the model achieved high accuracy while maintaining a compact and efficient structure for practical deployment.

Discussion and Conclusion

In this study, a DL model was developed to automatically evaluate students' drawings related to climate change. Using transfer learning techniques and optimization strategies, the model's accuracy was improved while significantly reducing its size, thereby enhancing its usability. As shown in similar studies (Zhuang et al., 2020), such an approach facilitates meaningful learning even with small datasets. During training, data augmentation techniques were employed to enhance the model's generalization capability and reduce the risk of overfitting. The model achieved high classification performance in both training and validation phases. In the future, the model will be tested on mobile and web-based platforms to create an interactive, AI-assisted system that can provide instant feedback on student drawings.

The considerable reduction in model size has made it more practical for broader use. This aligns with existing literature demonstrating the effectiveness of architectures like ResNet50 and MobileNetV2 for image classification tasks (He et al., 2016; Sandler et al., 2018). Due to the limited dataset used in this study, data augmentation methods involving rotations, zooming, and horizontal flipping were applied to enhance the model's generalization. As supported in the literature (Shorten & Khoshgoftaar, 2019), such transformations positively contribute to the model's learning process.

A detailed analysis of the model outputs shows accurate predictions with high confidence scores for certain classes. However, in some cases, the model exhibited indecision and lower probability scores, which can be attributed to semantic overlaps between certain classes. For example, when a drawing simultaneously includes "Sun and Temperature Change" and "Trees and Nature" themes, the model struggles with accurate classification. The model not only classifies but also provides explanatory feedback and improvement suggestions tailored to the predicted category, transforming it into an educational tool rather than a mere classifier. This pedagogical functionality is supported by previous research (Shorten & Khoshgoftaar, 2019).

AI technologies are expected to play an increasingly significant role in evaluating learning and teaching processes in the future. DL models will be instrumental both in classroom settings and in remote education contexts. The ability to quickly analyze student outputs and provide feedback aligns well with the principles of formative assessment. In this regard, the feedback mechanism is designed based on formative assessment principles, supporting student engagement and the development of self-regulation skills (Nicol & Macfarlane-Dick, 2006). As demonstrated in this research, learning rate control and early stopping methods—such as *ReduceLROnPlateau* and *EarlyStopping* helped prevent unnecessarily prolonged training, thereby optimizing the overall training process. These techniques have been widely recommended in recent deep learning studies (Smith, 2018).

The initially large size of the model posed a limiting factor in the study. Several strategies can be employed to mitigate this issue, which is particularly important for maintaining a performance-cost balance in real-time applications (Jacob et al., 2018). Future efforts will focus on testing the model in mobile and web-based applications. The goal is to create an interactive AI-powered system capable of instantly evaluating student drawings and providing feedback in real-time.

Recommendations

Based on the findings and discussions presented in this research, the following recommendations are proposed:

- The dataset can be expanded with community-labeled drawings.
- Lightweight transformer models can be utilized for better image understanding.
- Attention mechanisms can be integrated to support explainable artificial intelligence (XAI).

Scientific Ethics Declaration

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

Conflict of Interest

* The authors declare that they have no conflicts of interest

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Author Information

Orkun Kocak

TED University

Ankara, Turkiye

Contact e-mail: orkun.kocak@tedu.edu.trORCID iD: <https://orcid.org/0000-0002-0586-6271>**Sahin Idil**

The Scientific and Technological Research Council of

Turkiye , Ankara, Turkiye

ORCID iD: <https://orcid.org/0000-0003-2366-913X>

Introducing Polar Animals with an AI-Based Educational Game: A Study for Middle School Students

Resul Butuner, Yusuf Uzun

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Image recognition

Abstract

The poles are recognized as the northernmost and southernmost points on Earth. These extremes are defined differently in terms of cartography, magnetism, geography, and the polar star. In Turkey, numerous activities have been carried out concerning the polar regions, such as the establishment of a scientific research camp and meteorological station in Antarctica, seabed mapping, and similar initiatives. These activities have continued to expand rapidly. In this context, it is anticipated that the targeted educational content will be more easily accessed through studies conducted not only by public and private research and development institutions but also within the field of education. This study aims to increase middle school students' awareness of 20 animal species living in the polar regions, as part of the "World of Living Things" unit and the "Let's Get to Know Living Things" section of the Science curriculum. The research was designed using a qualitative approach, specifically the phenomenological design, which aims to understand the essence of participants' lived experiences with a particular phenomenon. The participants consisted of 105 volunteer 5th-grade students from a public middle school in Ankara. Data were collected through open-ended, self-assessment forms and analyzed using qualitative methods. As part of the study, 20 animals living in the polar regions were identified, and an Artificial Intelligence-Based Educational Game (AIEG) was developed. The game was created using the image recognition feature on the Teachable Machine (URL1) platform and deployed as an online, web-based educational tool. After engaging with the game, students completed a self-assessment form. Additionally, qualitative data were obtained through question-answer interviews with students, and the findings were evaluated using content analysis. The results revealed that students initially had limited knowledge of animals living in the polar regions, but their awareness significantly improved after interacting with the educational game. Based on the findings, it is recommended that educational games be more widely integrated into school settings to support effective and lasting learning. Furthermore, this research is expected to serve as a model for future studies aimed at raising awareness about polar animals and contributing to the protection of species threatened by environmental challenges.

Introduction

The world is divided into various geographical regions, which have often attracted the attention of individuals, institutions, and countries for reasons such as exploration, research, security, and conservation (Çaputçu & Çaputçu, 2021). Moreover, the polar regions' unique ecosystems, extreme climatic conditions, social structures, and challenges posed by harsh living environments have become increasingly prominent in research. The Earth hosts two distinct poles: the North Pole and the South Pole.

The North Pole, situated at the Earth's northernmost axis, is characterized by extensive ice floes. It is located within the Arctic Ocean, which is one of the world's largest oceans and encompasses the entire Arctic region. The Arctic is bordered by eight countries: Denmark, the United States, Norway, Canada, Finland, Russia, Sweden, and Iceland (Tutan & Arpalier, 2020). The South Pole, located at the Earth's southernmost axis, encompasses a region dominated by landmasses and extensive ice sheets. This region is also referred to as the Antarctic continent, which is one of the seven continents (Çoşkun, 2018). The Antarctic continent is recognized for its highly complex ecosystem (Kırkinci et al., 2021). In terms of climatic characteristics, the eastern part of Antarctica is colder than the western part due to its higher altitude. It is the coldest continent on Earth and does not host any sovereign states. However, seven countries namely the United Kingdom, France, Argentina, Australia, Chile, New Zealand,

and Norway, have laid territorial claims over parts of Antarctica (Yüksel, 2021). Additionally, as of 2019, 53 countries, including 29 consultative and 24 non-consultative signatories of the Antarctic Treaty, among them Turkey, have been granted permission to conduct scientific research and activities on the continent (Şimşek, 2019). Polar research began globally in 1821. In Turkey, the first institutional initiative in the field of polar sciences was undertaken by Istanbul Technical University (ITU). As a result, the "Istanbul Technical University Polar Research Center Regulation" was published in the Official Gazette on January 17, 2015, and the ITU Polar Research Center was officially established (Istanbul Technical University, 2015).

The increased use of fossil fuels, such as coal, natural gas, and oil, has led to the release of greenhouse gases. These gases trap solar radiation, resulting in a rise in the Earth's temperature, a phenomenon known as global warming. Global warming is one of the most critical environmental challenges affecting the world. The polar regions are among the areas most impacted by this phenomenon. Glaciers at the poles are gradually melting due to rising temperatures, posing a significant threat to their existence. This process has led to the extinction of species that are exclusively adapted to polar habitats. Additionally, the melting glaciers contribute to rising sea levels as the released water flows into the oceans (Akin, 2013). The Arctic region is a significant focus of biodiversity research. Various species, including polar bears, reindeer, polar algae, penguins, seals, polar martens, musk oxen, owls, and Arctic foxes, have adapted to the region's unique environmental conditions, such as landforms and climatic factors (Gözcüoğlu, 2013). Furthermore, the species inhabiting each polar region vary depending on the specific ecological characteristics of that region.

In Türkiye, extensive research is being conducted on the polar regions. In line with Türkiye's commitments under the Antarctic Treaty, the country aims to organize scientific expeditions to the poles, enhance its research activities and presence in the region, raise awareness and provide education on climate change, integrate environmental regulations of the region into national legislation, establish an institutional framework for polar studies, create a management center involving all relevant national stakeholders, and establish and operate a scientific research station in Antarctica.

Extensive research on the polar regions has been conducted both globally and in Türkiye, and such studies continue to be carried out. Education is one of the key areas where these research efforts are focused. Various teaching strategies and methods have been employed to introduce students to the polar regions. Among these, educational games have proven to be one of the most effective approaches for enhancing learning in this field.

Piaget asserts that all cognitive actions are determined by the balance between adaptation and assimilation. In the context of play, however, intelligence is driven by the dominance of assimilation over adaptation. Individuals integrate objects and events into their existing mental structures. Vygotsky, on the other hand, defines play as a continuous social activity, involving more than just an individual child. He argues that even when a child plays alone, the game remains a social element, as its themes and components reflect the cultural aspects of the surrounding social structure. According to Vygotsky, rather than merely reflecting cognitive development, play actively influences and contributes to a child's cognitive growth (Çankaya & Karamete, 2008). Considering the needs of modern learners and the evolving perspective on play, both Piaget and Vygotsky emphasize the importance of incorporating games into education. Educational games, designed for learning purposes, enhance learners' perception, decision-making abilities, and practical thinking skills (Yiğit, 2007).

The content conveyed through educational games holds significant importance in terms of both impact and implementation. In the teaching process, games should be utilized as a means rather than an end. Accordingly, educators must exercise great care in designing and implementing educational games, ensuring that all stages are carried out meticulously. The games developed by educators should be simple and engaging, allowing all students in a class to comprehend and participate actively. Additionally, fostering a competitive environment within the game can help maintain student engagement. Educators should effectively manage the game during its implementation, guide students throughout the process, and organize the play area accordingly (Demirel, 2012). Furthermore, educational games should be designed to align with course objectives and learning outcomes, integrating multiple disciplines, accommodating varying numbers of students, and incorporating diverse teaching methods to enhance their applicability.

A review of the literature on educational games reveals that Kızılcıoğlu and Taş (2007) investigated the use of spheres in geography education at the primary and secondary levels to facilitate students' understanding of the North and South Poles. Their study incorporated various models to enhance learning. The researchers found that students were better able to comprehend the location of the poles and their neighboring regions with modeled spheres (Kızılcıoğlu & Taş, 2007).

In the study titled *Science Journey in Antarctica*, training sessions were conducted for Science and Art Center students, and interviews were held. The findings of the study indicated that students developed awareness about Antarctica and demonstrated increased sensitivity toward the region (Barış, 2020). Göktaş and Göktaş (2022), in their study titled *The Reflection of State Policy on Polar Research in National Education*, presented at the 6th National Polar Sciences Workshop, examined the current Secondary Education Physics and Mathematics curricula and found no learning outcomes related to the poles or polar research. They also observed that mathematics activities and textbooks lacked topics and exercises related to the polar regions. As a recommendation, they proposed incorporating subjects and sub-themes on polar research into 9th and 10th-grade physics textbooks. Additionally, within the scope of the mathematics curriculum, they suggested integrating problem-based scenarios related to the polar regions into both curricula and textbooks, utilizing data from scientific research on the poles for educational activities.

Küçük et al. (2020) conducted a study on the impact of awareness-raising activities related to polar research on students in primary, secondary, and high school education. They stated that the methods employed in the study varied according to age groups and that different levels of sensitivity were observed across each group. Gözcelioğlu (2013), in his study titled *Polar Creatures: Lives That Don't Freeze*, provided explanations about the harsh living conditions in the polar regions and the adaptations of various species to these extreme environments. Parlak and Vural (2020) reported that they implemented various social activities to share and disseminate the knowledge and experiences gathered about the polar regions with the public. As a result of these initiatives, students' sensitivity and awareness regarding the polar regions increased.

Yirmibeşoğlu et al. (2020), in their study titled *Polar Educators Training*, stated that a secondary school teacher received hands-on training in the polar region and subsequently transferred significant knowledge to their students upon completion of the training. In another study on educational computer games, it was stated that games are used in schools to teach course subjects in three different ways: simulating real-life scenarios in a computer environment, serving as a tool for presenting topics, and motivating students by acting as a source of encouragement for learning (Linderöth et al., 2002).

According to Siang and Rao (2003), computer games are educational materials that provide the shortest learning strategy among all computer programs. Additionally, educational games enable participants to learn directly through play and experience rather than relying on reading help files or following instructions. With advancements in technology, numerous educational games have been developed and implemented, and extensive research has been conducted on these games.

Kaya and Elgün (2015), in their study titled *"The Effect of Science Teaching Supported by Educational Games on the Academic Achievement of Primary School Students,"* examined the impact of educational games on the teaching of the *"Our Planet Earth"* unit in the 4th-grade Science and Technology course. The study was conducted with a total of 61 fourth-grade students attending a primary school in the Bağcılar district of Istanbul. A quasi-experimental design was employed, incorporating pre-test and post-test measurements. The findings of the study indicated that the effective implementation of educational games in the classroom significantly contributes to student achievement.

Canbay (2012) examined the impact of educational games on students' self-regulated learning strategies, motivational beliefs, and academic achievement in mathematics. The study was conducted with 52 seventh-grade students using a pre-test and post-test design. The findings indicated that educational games did not lead to significant differences in knowledge retention, academic achievement, self-regulated learning strategies, or motivational beliefs.

Doğan (2017), in his study titled *The Effect of Teaching the Earthquake Topic in Social Studies through Digital Games on Academic Achievement*, examined the impact of digital game-based learning on student performance. The study was conducted with a total of 108 fifth-grade students from the provinces of Sivas and Tokat. The findings revealed that the academic achievement scores of the experimental group, which was taught using a digital game, were higher than those of the control group, which received instruction through traditional methods.

In the study titled *The Effect of Educational Games on Students' Academic Achievement and Knowledge Retention in the Science and Technology Course*, an experimental design with a pretest-posttest control group was employed. The study sample consisted of 60 eighth-grade students enrolled in a public school, with 30 students in the experimental group and 30 in the control group. The experimental group was taught the *Cell Division and Heredity* unit using educational games, whereas the control group received instruction through traditional methods. A Science and Technology Academic Achievement Test was used as a data collection instrument. The

findings indicated that the use of educational games in teaching significantly enhanced students' academic achievement and contributed to long-term knowledge retention (Alici, 2016).

The study titled "The Effect of Educational Games on Social Studies Course Teaching" by Uygun et al. (2018) was conducted with 21 fifth-grade students from a public school. The findings indicated that students' interest, motivation, and enthusiasm for the Social Studies course increased, leading to greater engagement in the lessons. It was noted that traditional evaluation activities conducted at the end of the lesson did not sufficiently support long-term retention. However, when the evaluation was conducted using the educational game method, learning was found to be significantly more permanent.

As evidenced by the studies, educational games have been shown to enhance students' interest, attention, motivation, and enthusiasm across various fields of study. Furthermore, these games contribute to students' academic achievement, foster a positive attitude toward learning, and facilitate the comprehension of complex subjects. Additionally, the findings suggest that educational games play a crucial role in the development of essential skills and values, including responsibility, cooperation, respect, empathy, and self-expression.

Purpose of the Study

The purposes of this study were to explore the learning experiences and perceptions of fifth-grade students regarding a web-based educational game supported by artificial intelligence technology. The game was designed to teach endangered animals living in the polar regions and to raise environmental awareness about the threats to their habitats caused by global climate change. Conducted with 145 volunteer fifth-grade students from a public secondary school in Ankara, the study aims to investigate how such a game can contribute to students' subject-specific knowledge, language use, attention, and motivation within a digital learning environment.

Adopting a qualitative research approach based on a phenomenological design, the study seeks to provide an in-depth understanding of students' individual experiences and feedback regarding the game. The study also aims to identify the strengths and potential areas for improvement in the design and instructional content of the game. The findings of this research are intended to inform educators, curriculum developers, and game designers about the pedagogical potential of AI-supported educational games, particularly in the context of environmental education.

The study is structured into four main sections. The Methodology section explains the research design, participant characteristics, and data collection tools, along with an overview of the AI-supported game development process. The Results section presents the data obtained from students' self-assessment forms. The Discussion section interprets these findings in light of relevant literature, and the Suggestions section offers recommendations for future research and practical implementations.

Method

Research Design

This study is qualitative research based on phenomenological design. Phenomenology focuses on individuals lived experiences and aims to uncover the meanings they assign to a particular phenomenon. According to Creswell (2018, p. 77), the phenomenological design seeks to reveal the common meaning of the lived experiences of several individuals regarding a phenomenon or concept. The main goal in this design is to understand the essence of experiences of individuals who have deeply encountered a specific phenomenon. In this context, after identifying the research area, a review of the literature was conducted on topics such as the Polar Regions, animals inhabiting these regions, and Turkey's polar policies. Although access to relevant sources was limited, it was observed that research in this field has increased in recent years. Noting the absence of an educational game specifically developed for middle school students about animals in the Polar Regions, a need for such a study was identified. Data were collected in line with the principles of qualitative research.

Participants

The study was carried out during the 2022–2023 academic year in the multipurpose hall of a public middle school in Ankara, Türkiye. The participants consisted of 145 volunteer fifth-grade students (82 boys and 63 girls). Before the data collection process, written approval was obtained from the District Directorate of National Education,

and informed consent was received from the students' parents or guardians. All official permissions and documentation are available on file. Ethical standards were strictly followed throughout the research process, and confidentiality was ensured at all stages.

Data Collection Tool

Google Forms was used as an online data collection tool. 145 students were asked about their opinions about the application. However, 40 students either filled out the scale incorrectly or left it incomplete. As a result, the final sample consisted of 105 students who properly completed google form. Each question was designed to gather specific data. The questions were developed and refined following a literature review. In total, six questions were prepared using Google Forms, and data were collected accordingly.

Data Collection

Data on Arctic animals were collected using Google Images because it is a widely used method. Initially, a list of the most well-known polar animals was compiled through a literature review, resulting in the identification of 20 species. The "Download All Images" extension from Google was used to download images of these animals in bulk. Each animal's name was entered into Google Images, and the resulting images were downloaded as compressed files using the extension. These compressed files were then extracted, and irrelevant images were removed.

Additionally, the backgrounds of the images were removed to ensure accurate classification with artificial intelligence. As a result, a dataset comprising 4,592 images of 20 Arctic animal species was created. After constructing the dataset, the Teachable Machine platform (URL-2), which operates using artificial neural networks and is widely used for web-based image classification, was utilized. Classes for the 20 Arctic animals were created on this platform, and the model was trained by adjusting parameters such as epoch count, batch size, and learning rate.

Data Classification

The dataset includes 20 classes of Arctic animals categorized for classification using artificial intelligence technology. The distribution of images for each class is given in Table 1.

Table 1. The distribution of images for each class.

Image	Counts
Alaska Wolf	228
Albatross	213
Antarctic Orca	256
Owl	315
Sea Elephant	419
Sea Rhino	234
Seal	261
Ferret	312
Greenland Whale	364
Thick-Billed Bird	194
Polar Bear	229
Arctic Tern	143
Arctic Hare	171
Arctic Fox	121
Lemming	229
Minke Whale	234
Musk Ox	160
Walrus	197
Penguin	176
Reindeer	136

Data Analysis

This figure illustrates the general design of an artificial intelligence-based classification model. The model was developed using Teachable Machine, an AI-powered web platform where different classification categories were defined. The dataset was structured to include various animal species, with each class represented by a specific number of images. The training process was conducted using 50 training cycles, a batch size of 16, and a learning rate of 0.001.

As shown in the figure, the system was tested in preview mode to evaluate its accuracy. The model successfully classified an input image of an owl with 98% accuracy, demonstrating the effectiveness of the training process. The high classification accuracy indicates that the model was properly trained using optimized hyperparameters, enhancing its ability to recognize and categorize images correctly. This AI-based classification model can be applied in image processing and object recognition tasks, where the diversity and balance of training data play a crucial role in overall model performance. The general design of the system was shown in Figure 1.

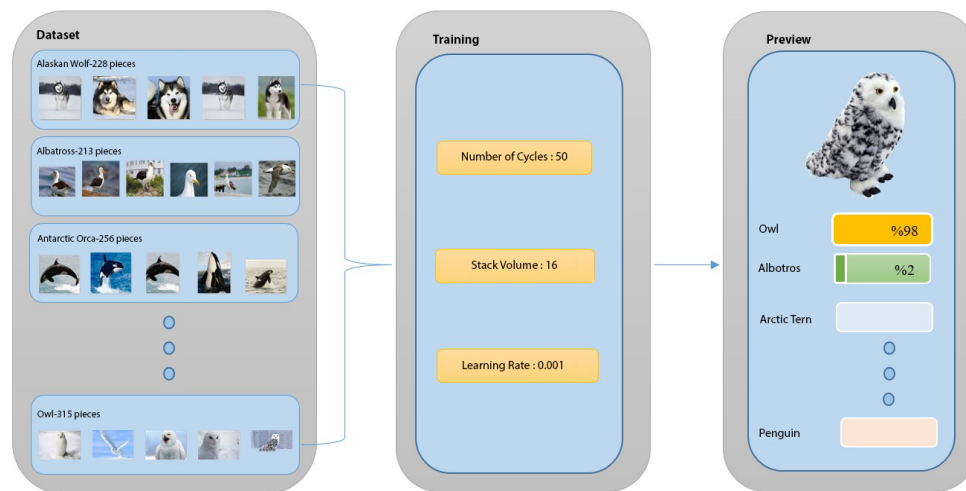


Figure 1. General design of the system

This figure illustrates both the development process of an artificial intelligence-based classification model and the ratio of training to test data. Initially, data collection was conducted, and the quality of the collected data was validated. Subsequently, 85% of the data (3,903 images) was used to train the AI model (Figure 2). To assess the model's performance, the remaining 15% (689 images) were reserved for testing. After training, the AI model processed input data to generate predictions, and its accuracy was evaluated using the test data. This process represents a systematic model development approach consisting of data collection, training, testing, and validation phases.

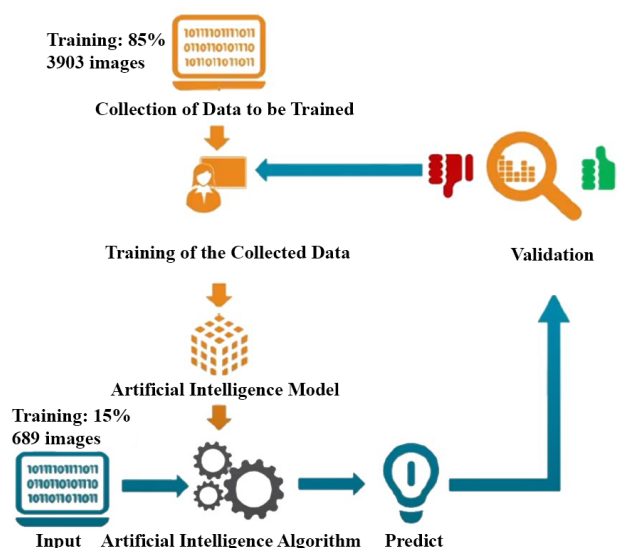


Figure 2. The ratio and modeling of training and test data in the system

Preparation for a Web-Based Educational Game

Figure 3 presents the block-based coding structure of AIBEG, an artificial intelligence-based online educational game designed to enhance students' knowledge of polar animals. The development of the game followed an instructional phase, where informational presentations on the Polar Regions and their wildlife were delivered to four different classes. Student feedback was collected and incorporated into the game design to ensure an engaging and effective learning experience.

The block diagram illustrates the game's logic and interaction flow. The system utilizes Teachable Machine, an AI-powered model, to recognize and classify images of polar animals. The program begins by activating the model and camera input. It then prompts students with a question about a specific polar animal and processes their responses by comparing them with the AI-generated prediction. If the prediction matches the expected answer, the game provides positive reinforcement through visual (costume change) and auditory (sound effects) feedback. If the response is incorrect, the system signals an incorrect answer using different visual and auditory cues. This AI-integrated educational tool enables students to engage in interactive learning, reinforcing their understanding of polar animals through gamification and real-time feedback. The integration of machine learning in educational settings enhances student participation and fosters a deeper understanding of the subject matter.

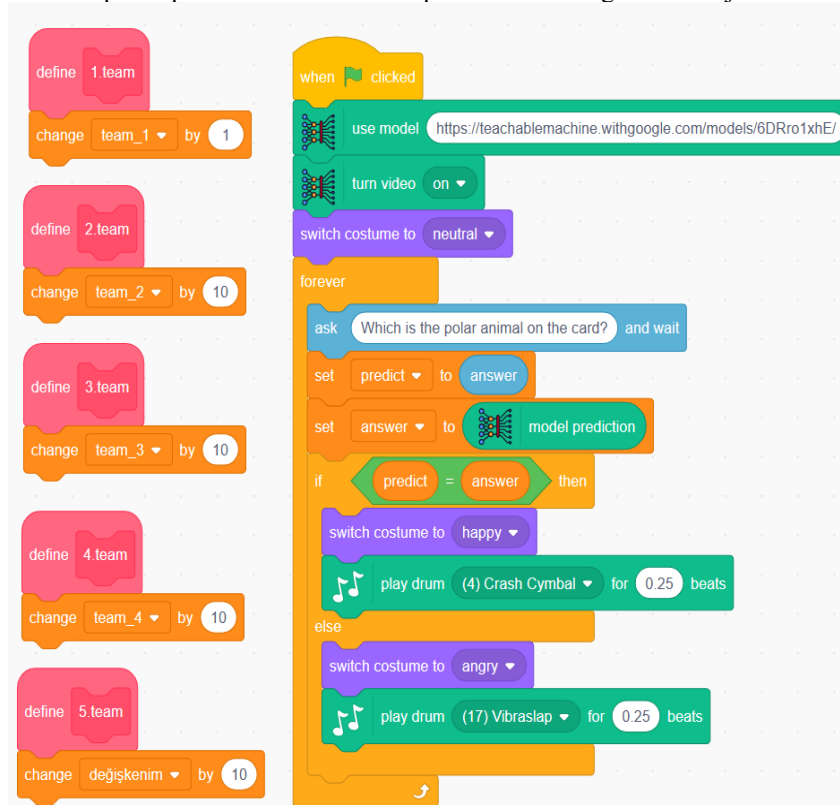


Figure 3. Block coding of an artificial intelligence-based online educational game

The block coding structure of AIBEG consists of 14 sequential tasks, which are as follows:

- **Step 1:** Initiates the program.
- **Step 2:** Enter the URL of the model created using the Teachable Machine platform, enabling the artificial intelligence model to function.
- **Step 3:** Activates the camera connected to the computer.
- **Step 4:** Sets the puppet to a neutral state.
- **Step 5:** Executes the code blocks in a continuous loop.
- **Step 6:** Prompts the student with the question: *"Which polar animal is on the card?"*
- **Step 7:** Creates a variable named *Prediction* and stores the student's response.
- **Step 8:** Transfers the predicted polar animal name from the artificial intelligence model to the response variable.
- **Step 9:** Compares the student's response with the prediction generated by the artificial intelligence model.

- **Step 10:** If the answer is correct, the puppet displays a happy expression.
- **Step 11:** Plays a *Crash Bell* sound effect.
- **Step 12:** If the answer is incorrect, the puppet displays an angry expression.
- **Step 13:** Plays a *Vibraslap* sound effect.
- **Step 14:** Awards 10 points to the team's score for each correct answer.

Implementation of the Educational Game

Figure 4 displays the card images of 20 distinct polar animal species utilized in the AIBEG (Artificial Intelligence-Based Educational Game) system. The dataset was curated to include key representative species inhabiting the Arctic and Antarctic regions, with each animal being assigned a unique identification number ranging from 1 to 20. To optimize image recognition accuracy, the backgrounds of the selected images were removed, ensuring a clear and standardized visual format for the game.

The AIBEG system was designed as an interactive and competitive educational tool to engage students in learning about polar animals through AI-based image recognition. The research activity was conducted in a classroom setting, where students were divided into six groups. Each group received ten polar animal cards, and a designated student was asked to identify and name the animal depicted on their card. The student then presented the card in front of a webcam, allowing the AIBEG system to process the image and determine whether the identification was correct. If the system's recognition matched the student's response, the group was awarded 10 points, fostering a gamified learning environment that encouraged participation and knowledge retention.

The maximum achievable score in AIBEG was 100 points, with the highest-scoring team declared the winner. Analysis of the results demonstrated that top-performing teams exhibited a higher accuracy rate in identifying the polar animals, suggesting that the AI-supported educational approach enhanced student engagement and learning outcomes.



Figure 4. Card images of arctic animals

The working screen of AIBEG was shown in Figure 5. After naming the polar animal depicted on the card, the student verifies their answer by holding the card up to the computer's webcam. AIBEG utilizes an artificial intelligence model running in the background to recognize the Arctic animal. If the answer is correct, 10 points are added to the team's leaderboard. If the answer is incorrect, no points are awarded.

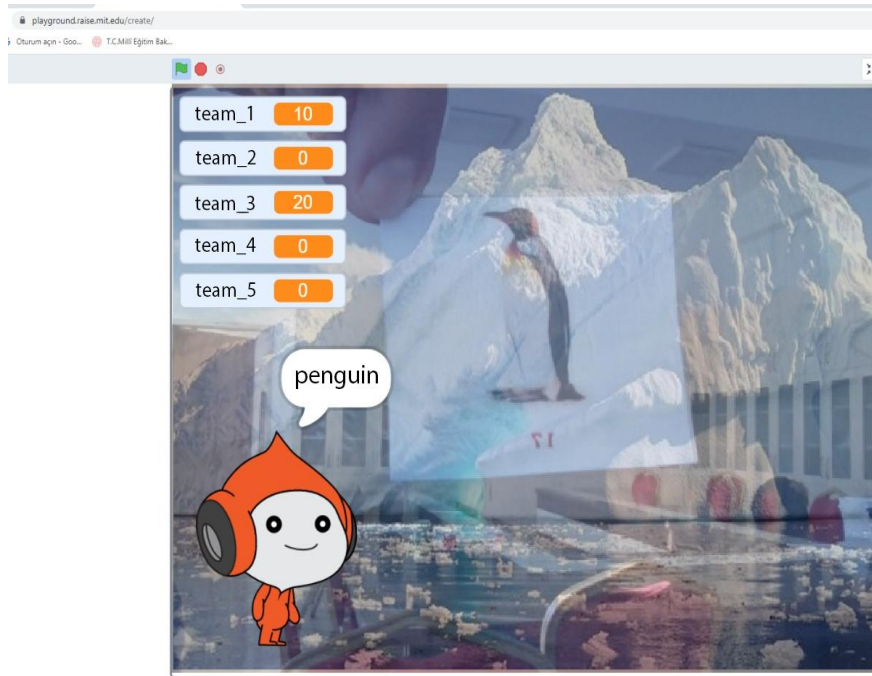


Figure 5. AIBEG working display

Findings

The responses to the Arctic Animals Educational Game Self-Assessment Form were provided below Figure 6.

Learning Arctic Animals with AI-Based Educational Games

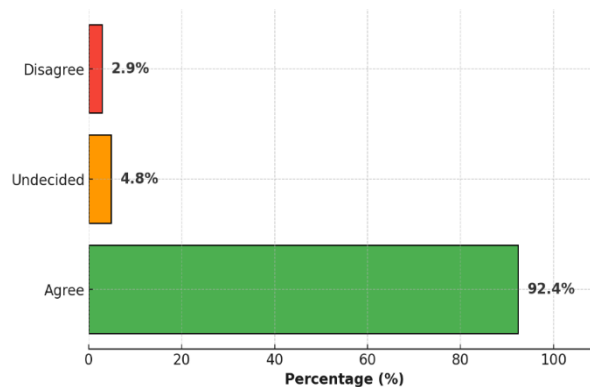


Figure 6. Percentage-based graphical representation of the responses to the third question.

This graph illustrates the responses to the statement: "I learned about new Arctic animals while playing the game." The survey results reveal the following:

- 92.4% (97 students) *agreed* with the statement. This overwhelming majority indicates that the game was highly effective in introducing new Arctic animals to the students. The high engagement level suggests that the game's educational content was well-received and contributed positively to their learning experience.
- 4.8% (5 students) were *undecided*. These students were uncertain about whether they had learned new Arctic animals or not, which might suggest varying levels of prior knowledge or different learning experiences within the game.
- 2.9% (3 students) *disagreed* with the statement, meaning a small fraction of students felt that they did

not learn any new Arctic animals during the game. This could be due to prior familiarity with the topic or a lack of engagement with the game's educational content.

Overall, the results strongly suggest that the game successfully achieved its educational goal of teaching students about Arctic animals. With over 92% of students confirming their learning experience, the game appears to be a highly effective and engaging tool for interactively introducing new information. Based on the results of the activity, it was found that students acquired new information about polar animals. Through content analysis, it was observed that their awareness particularly increased regarding the animals' habitats, feeding habits, and the environmental threats they face.

From a scientific perspective, students demonstrated gains in knowledge related to ecosystems, adaptation mechanisms, and the impacts of global warming on polar regions. The visuals and explanatory content presented during the game contributed to the development of students' skills in identifying and classifying the physical characteristics of animals. Furthermore, students experienced the processes of collecting and classifying scientific data through an artificial intelligence-supported application. This experience also enhanced their understanding of the technological tools used in scientific research. To further analyze the impact of the educational game on the students' semi-structured interviews were conducted with two randomly selected students. The following questions were asked by the students in the interviews:

- What new information did you learn thanks to this game?
- How did the game contribute to the learning process in science class?
- Which parts did you like the most while playing the game and why?
- Do you have any suggestions for improving the game?

Some of the student responses obtained are as follows:

S1: "A fifth-grade male student stated that although he had previously heard of the Arctic fox, he was not aware of its specific behaviors. Through the game, he learned that Arctic foxes change color—appearing white in the winter and brown in the summer. He noted that although this information had been explained during science class, he had not remembered it as well. However, because he learned it through matching animals in the game, he found it easier to retain the information (personal communication, 2022)."

S2: "One fifth-grade female student reported that she previously believed penguins only lived in Antarctica, but through playing the game, she learned that there are various species of penguins and that some inhabit warmer regions. She expressed that answering questions and earning points during gameplay made the learning process enjoyable and stated, "I don't remember learning something in science class with so much fun before." She further suggested that the game could be improved by including more animal species and occasionally increasing the difficulty of the questions (personal communication, 2022)."

The data obtained from these interviews shows that the game helps students learn science topics in a fun and permanent way. It was also determined that it increased students' interest in educational games and encouraged their active participation in the learning process.

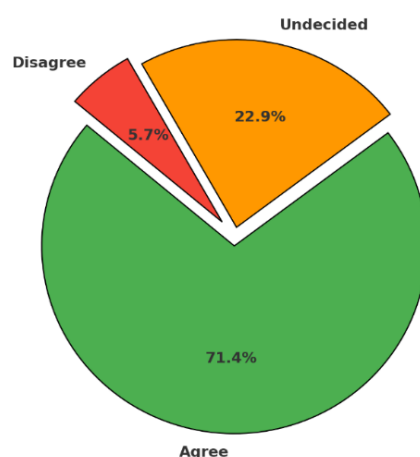


Figure 7. Percentage-based graphical representation of the responses to the fourth question.

Here is a more aesthetically pleasing pie chart with different colors and styles to enhance readability (Figure 7). Below is a detailed explanation of the results:

Detailed Explanation: The survey question asked students whether they were able to match polar animals while playing the game correctly. The results indicate the following:

- 71.4% (75 students) agreed that they were able to correctly match polar animals, suggesting that the game effectively helped them recognize and pair the animals.
- 22.9% (24 students) were undecided, meaning they were unsure of their ability to match the animals.
- 5.7% (6 students) disagreed, indicating that they did not find the game helpful in recognizing and matching polar animals.

These findings highlight that most students (nearly three-quarters) successfully engaged in learning through the game. The high percentage of agreement suggests that the game provided an interactive and effective way to improve students' knowledge of polar animals. However, a small percentage of students either struggled or were uncertain, which could indicate areas where the game might be improved to enhance learning outcomes further. Students stated that they gained knowledge on the following subjects after playing the game:

- Names and characteristics of animals living in polar regions: They had the opportunity to get to know animals they had never heard of before.
- Animal habitats and adaptations: They learned how they adapt to cold weather conditions.
- Biodiversity and environmental awareness: They gained awareness about how polar animals are under threat due to climate change.

Students noted the game supported science learning by:

- Visual and interactive learning: Since they learned by directly seeing and matching animals, their knowledge became more permanent.
- Experiential learning: It was more effective than traditional teaching methods thanks to the learning by doing and living method.
- Increased motivation: Thanks to gamification, students' interest increased, and they stated that they found the lesson more entertaining.

Challenges in Using AI-Based Educational Games

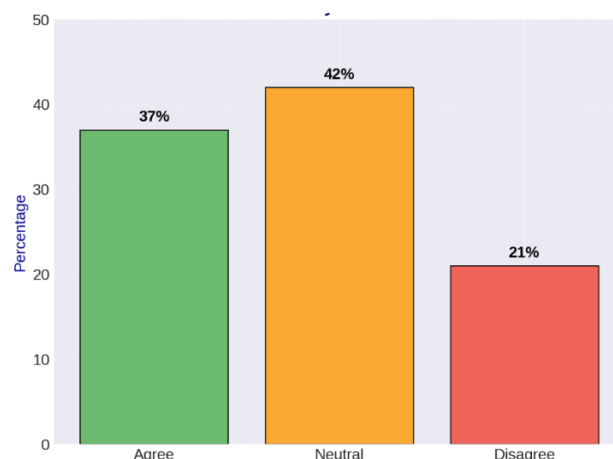


Figure 8. Graphical representation of the responses to the fifth question as a percentage.

The survey asked students whether they found it difficult to play the game. The responses were distributed as follows (Figure 8):

- 41.9% (44 students) disagreed, indicating that they did not experience significant difficulty while playing the game. This suggests that the majority of students were able to engage with the game easily.

- 37.1% (39 students) agreed, meaning they faced some level of difficulty during gameplay. This indicates that a considerable portion of the students encountered challenges while playing.
- 21% (22 students) were undecided, suggesting they were uncertain about whether the game was difficult or not.

In addition to the advantages that AI-supported educational games provide to students, it has been determined that some difficulties are also encountered during the learning process. In line with the feedback from students and the data analyzed, these difficulties are addressed within the framework of the following themes:

The game uses image processing technology to introduce arctic animals. However, some students may have experienced errors due to the AI model not recognizing certain animals correctly or the images being of low quality at times. In particular, the probability of students and the AI model making matching errors increased in species that are similar to each other, such as the arctic fox and the arctic hare.

S1: "I thought I guessed some animals wrong, but it turns out that the AI also sometimes gets them wrong. I got a little confused when I saw the arctic hare instead of the arctic fox."

Although this situation provides a learning opportunity for students to develop their visual discrimination skills. It has led to conceptual confusion, especially for students who have no previous knowledge of these animals. Students encountered some technical limitations during the game process. Among these, camera detection problems, dependency on internet connection, and moments when the AI worked with low accuracy stand out. In particular, incorrect camera angles or variable lighting conditions made it difficult for the AI to make correct identifications.

S2: "Sometimes it was difficult to recognize the animal while holding the camera. When the light was too bright, it was difficult to recognize some animals."

Such technical obstacles show that students need to develop technological literacy in AI-based learning processes.

Enjoy Using Educational Games Based on Artificial Intelligence

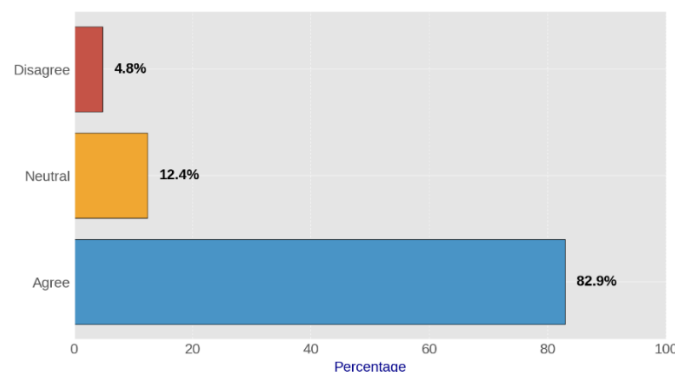


Figure 9. Graphical representation of the responses to the sixth question as a percentage.

The bar chart illustrates the responses to the statement "I had fun playing the game", which was the sixth question in the survey. The responses were collected from a total of 105 students, and their opinions were categorized into three groups: Agree, Neutral, and Disagree (Figure 9).

- 'Significant majority' and '87 out of 105' express the same idea. This indicates that the game was generally well-received and enjoyable for most participants.
- 13 students (12.4%) were neutral, meaning they were unsure or had mixed feelings about their enjoyment of the game.
- A small minority of 5 students (4.8%) disagreed, indicating that they did not find the game enjoyable.

The results suggest that the educational game was effective in engaging students, with a high percentage (over 80%) reporting a positive experience. However, a small portion of students either remained indifferent or did not

enjoy it, which could be due to personal preferences, gameplay mechanics, or other external factors. This feedback can be valuable for further improvements in game design to enhance engagement and ensure that even those who were neutral or disagreed have a more enjoyable experience in the future. Although the game contributes greatly to students in terms of science education, some students stated that they had difficulty in the process of learning information in depth. It was stated that topics such as:

The role of animals in the ecosystem, climate change, and adaptation of animals, and the food chain in the polar region should be included more in the game.

S3: "I got to know the animals, but the game did not explain why there were so few or why they disappeared. I wish these topics had been included more."

In line with this feedback, it was concluded that AI-supported games should include more detailed content suitable for the science curriculum instead of providing only superficial information. Since students were accustomed to traditional learning methods, they experienced some adaptation problems in the transition to the game-based learning model. Students who could not establish a direct connection between the points earned and learning success could not fully understand the educational value of the game.

S4: "It was nice to collect points, but I realized I had memorized some things. I wasn't sure if I had learned them."

This situation shows that gamification mechanisms should not only make knowledge fun but also support deep learning. In AI-supported games, detailed explanations should be added to better explain the differences between similar animal species. To minimize technical glitches, the accuracy of the game's AI model should be increased, and a user-friendly interface should be provided. The game should have a stronger integration with the science curriculum and should not be limited to just introducing animals. To increase students' adaptation to game-based learning, guiding information should be provided in advance.

Discussion

This study explored fifth-grade students' lived experiences and perceptions regarding an Artificial Intelligence-Based Educational Game (AIEG) designed to teach polar animals. Conducted within the framework of a qualitative research approach using the phenomenological design, the study aimed to understand the essence of students' experiences while engaging with the game and the meanings they attributed to those experiences.

Findings indicate that the majority of students reported positive emotions and thoughts after engaging in the educational game. Most participants expressed enjoyment, increased interest, and a sense of curiosity toward the topic, suggesting that the game succeeded in creating a meaningful and engaging learning environment. This aligns with prior studies indicating that educational games foster intrinsic motivation, encourage active participation, and make abstract concepts more tangible (Prensky, 2001; Tüzün et al., 2006).

Students commonly described the game as fun, informative, and visually appealing, noting that they were able to better recognize and remember the animals featured in the polar regions. These qualitative responses are in line with literature asserting that game-based learning supports deeper understanding and long-term retention of content (Gee, 2003; Papastergiou, 2009).

A significant theme emerging from students' responses was the clarity of instruction and language used in the game. While most students found the instructions understandable, a few mentioned challenges with some of the language or gameplay steps. These comments highlight the need to ensure age-appropriate linguistic design and potentially support comprehension with visual or auditory aids (Kafai & Burke, 2015). Such enhancements can make the experience more inclusive and accessible.

Another key theme was engagement and sustained attention. Many students emphasized that the game kept them focused and attentive throughout the experience. This is consistent with research suggesting that interactivity and visual stimulation in educational games help sustain learners' focus (Squire, 2003). However, a few students noted difficulty concentrating, which might reflect differing learning styles or external distractions, pointing to the value of designing flexible and adaptive learning tools (Fleming & Mills, 1992).

In terms of cognitive engagement, the students' ability to match animals with their characteristics revealed that many could apply what they had learned meaningfully. Some students, however, reported confusion or

uncertainty, suggesting that further enrichment of content—such as more descriptive information or contextual visuals—could strengthen learning outcomes (Shute & Ke, 2012).

Students' feedback on the difficulty level varied: while some found the game appropriately challenging and enjoyable, others reported it as too easy or too difficult. This variance suggests that future versions of the game might benefit from offering differentiated levels of difficulty or scaffolding options to better support individual learners (Tomlinson, 2014).

Overall, students' reflections emphasized that the educational game helped them engage with the topic emotionally and cognitively, suggesting that such tools have strong potential for enhancing awareness of lesser-known ecosystems like the polar regions. The enjoyable format and accessible interface appeared to support learning while maintaining student motivation (Hamari et al., 2016).

In conclusion, this phenomenological study reveals that digital educational games, —when thoughtfully designed— can enhance students' awareness, promote engagement, and foster meaningful learning experiences. Nevertheless, the study also highlights areas for improvement, such as instructional clarity, content richness, and adaptability to diverse learning preferences. Future research could explore how these games affect long-term understanding and whether similar methods could be used for other science topics, contributing to both curriculum development and ecological awareness.

Conclusion

This study, grounded in a qualitative research approach with a phenomenological design, aimed to explore the experiences and perceptions of 145 fifth-grade students (63 females and 82 males) who interacted with an Artificial Intelligence-Based Educational Game (AIEG) designed to teach about polar animals. All participants voluntarily took part in the study and completed the self-assessment form following their gameplay experience.

The findings demonstrate that the educational game effectively supported student learning and engagement. A majority of students reported acquiring new knowledge about Arctic animals, indicating that the game successfully achieved its instructional purpose. This aligns with the view that digital games can reinforce subject-specific content and support meaningful learning. Students' statements revealed that the game was not only educational but also enjoyable and engaging, fostering curiosity and sustained attention. Many participants noted that they were able to use Turkish correctly and effectively during the game, suggesting that the language and instructions were generally age-appropriate and accessible. However, a small subset of students expressed difficulty understanding certain instructions, pointing to a need for clearer and more simplified language, or the addition of supportive visuals and auditory cues to improve comprehension. While student opinions on the game's difficulty level varied, the majority found the gameplay elements realistic and the instructions understandable. These responses indicate that the game was mostly well-balanced in terms of challenge and usability. Nevertheless, the presence of varied feedback highlights the importance of integrating adaptive difficulty levels or scaffolding strategies to better meet individual learner needs.

In conclusion, this study illustrates that an educational game designed with pedagogical intent and user-centered design principles can enhance learners' understanding of scientific topics such as polar animals, while also promoting engagement and correct language use. Future iterations of such games would benefit from increased clarity of instructional content, enhanced detail in the informational materials, and greater adaptability to accommodate diverse learning preferences. These refinements would further strengthen the educational impact and accessibility of game-based learning environments.

Suggestions

In light of the findings from this phenomenological study exploring fifth-grade students' experiences with an artificial intelligence-based educational game focused on polar animals, several recommendations are presented to enhance the use and development of educational computer games in learning environments:

- **Integration into Curriculum:** The Ministry of National Education should consider systematically integrating educational computer games into classroom curricula as complementary learning tools. These games can reinforce subject-specific knowledge while increasing student motivation and engagement.

- **Teacher Training and Professional Development:** Comprehensive professional development programs should be developed to train teachers in the effective pedagogical use of educational games. Educators need guidance not only on technical usage but also on instructional integration and assessment strategies.
- **Support for Game Development and Research:** There is a noticeable scarcity of domestically developed educational computer games and corresponding academic research in this area. National efforts should support interdisciplinary collaborations between educators, game designers, and researchers to create culturally relevant and pedagogically sound games. Funding mechanisms and research grants can also be expanded to stimulate innovation in this field.
- **Raising Polar Awareness:** Polar-themed learning content, including digital games, should be expanded within the national education system to raise awareness of polar ecosystems, climate change, and biodiversity. Such content contributes to global environmental consciousness among young learners.
- **Experimental and Comparative Studies:** Future research should include experimental or mixed-method designs to further investigate the impact of educational computer games on student achievement, motivation, and knowledge retention. Replicating international studies within local contexts can provide valuable comparative insights.
- **Digital Learning Infrastructure:** To maximize engagement and access, the game can be implemented in a fully equipped computer laboratory with internet access and interconnected devices. Transforming all components of the game—including information cards—into fully digital formats would enable a seamless learning experience while promoting environmentally conscious practices.
- **Differentiation and Adaptability:** The developed game can be adapted for different educational levels (e.g., middle school, high school) and for use in various professional or public awareness contexts (e.g., museums, environmental education programs). Such scalability ensures the broad utility of the game across learning ecosystems.
- **Expanding Turkish-Language Resources:** Further academic studies focusing on the Polar Regions should be conducted in the Turkish language to expand the national bibliography and ensure accessibility for Turkish-speaking researchers, educators, and students.

By addressing these recommendations, educational stakeholders can better harness the potential of game-based learning environments to foster meaningful, engaging, and long-lasting learning experiences for diverse learner populations.

Scientific Ethics Declaration

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

Conflict of Interest

* The authors declare that they have no conflicts of interest

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URL-1: <https://teachablemachine.withgoogle.com/>

URL-2: <https://teachablemachine.withgoogle.com/train/image>

Author(s) Information

Resul Butuner

Ministry of National Education of Türkiye,
Ankara, Türkiye
Contact e-mail: rbutuner@gmail.com
ORCID iD: <https://orcid.org/0000-0002-9778-2349>

Yusuf Uzun

Necmettin Erbakan University,
Department of Computer Engineering,
Seydisehir Ahmet Cengiz Faculty of Engineering,
Konya, Türkiye
ORCID iD: <https://orcid.org/0000-0002-7061-8784>

The Impact of Generative AI Applications on Student Learning Outcomes in Science Education: A Systematic Review

Meryem Seda Gunsaldi, Elif Gamze Guner, Musa Uckan, Kaan Bati

Article Info	Abstract
Article History Published: 01 July 2025 Received: 02 April 2025 Accepted: 25 June 2025 Keywords GenAI, Artificial intelligence, Science education	This systematic literature review examines the impact of generative artificial intelligence (AI) applications on student learning outcomes in middle school science education. Twelve studies that met the inclusion and exclusion criteria were included in the study. The studies were accessed from the WOS, SCOPUS, ERIC, and TrDizin indexes and databases. The PRISMA protocol was used in the selection of studies. The analysis reveals that generative AI tools significantly contribute to academic achievement, conceptual understanding, scientific and digital literacy, personalized learning opportunities, and students' motivational and emotional outcomes. The systematic review further emphasizes the importance of integrating AI tools into science education in a pedagogically and ethically sound manner. Recommendations include increasing AI literacy among teachers, incorporating ethical awareness into instruction, and developing culturally sensitive and interdisciplinary educational practices. Generative AI stands out as a transformative technology for improving the quality, accessibility, and inclusivity of science education.

Introduction

Science education is one of the basic disciplines aiming to develop students' critical thinking, problem-solving, and analytical thinking skills. In recent years, with the increasing role of technology in education, it is observed that especially technologies such as generative artificial intelligence tools have started to transform learning processes. When the literature is examined, different approaches and studies in which productive artificial intelligence applications are employed to improve students' learning outcomes stand out (Arslan, 2020; Erkoç & Çolak, 2024; Zengin et al., 2023). Generative Artificial Intelligence (GAI) technologies are increasingly used in the field of education in general and science education in particular and offer the opportunity to apply innovative approaches in educational processes. AI technologies are considered to have significant and great potential in education, especially for increasing the accessibility of learning opportunities, scaling individually customized learning experiences, and optimizing methods and strategies for targeted learning outcomes (Zengin et al., 2023).

Arslan (2020), in his study in which various tools and examples of GAI and the use of artificial intelligence in education are tried to be given as a whole, states that any explanation or any information about artificial intelligence in education will be incomplete. New educational applications based on artificial intelligence will appear tomorrow as they do today with new techniques (Arslan, 2020). Artificial intelligence applications enable students to learn according to their abilities and learning speed is considered the most positive effect of these applications (Vieriu & Petrea, 2025).

In addition to the advantages of using artificial intelligence in education, it is also possible to come across studies that mention its disadvantages. In particular, when the justifications of teachers who do not find the use of artificial intelligence in lessons useful are examined, it is seen that the opinions expressed by them that it reduces creativity is not sufficient, and is unnecessary come to the fore. In addition, it is reported that many teachers today believe that technological applications can reduce students' manual dexterity and creativity (Zawacki-Richter et al., 2019). This belief weakens teachers' tendency to use productive artificial intelligence tools in their lessons (Erkoç & Çolak, 2024).

This study aims to systematically examine the impact of generative artificial intelligence applications on student learning outcomes in science education and to reveal the potential of these technologies in education. It is believed that the results of the study will provide concrete evidence to educators, researchers, and policymakers in the integration of GAI tools into science education.

Theoretical Framework

In the developing technological world, innovations in the field of technology are increasing day by day. This situation also closely concerns and affects education. Artificial intelligence is a very effective field that has been used quite actively recently. It is known that the concept of artificial intelligence was first mentioned in a proposal for the 'A Proposal for the Dartmouth Summer Research Project on Artificial Intelligence' in 1955 (McCarthy et al., 1955). This proposal is based on the premise that every way of learning for artificial intelligence or other features of intelligence can be defined so clearly that it can be realized by a machine (Eral, 2024). The integration and utilization of generative artificial intelligence (GAI) applications in science education show significant potential for enhancing students' learning outcomes. Recent research indicates that GAI tools can improve teaching practices, assessment strategies, and student engagement in science-related subjects (Holmes, Bialik, & Fadel, 2019; Zawacki-Richter et al., 2019). By enabling the personalization of learning experiences and fostering higher levels of student interaction, GAI applications contribute meaningfully to academic success (Luckin et al., 2016).

Intelligent tutoring systems and adaptive learning platforms offer tailored educational content that addresses individual learning needs, thereby creating more effective learning environments (Woolf, 2010). Furthermore, GAI technologies have the capacity to analyze student performance data, identify patterns in strengths and weaknesses, and design customized learning pathways that accommodate diverse learning styles (Chen et al., 2020). Intelligent tutoring systems provide real-time feedback that helps students gain a deeper understanding of concepts and instantly correct misconceptions (Good, 1987). In addition, generative artificial intelligence applications, including virtual reality simulations, provide more active learning experiences by increasing students' interest and motivation in science subjects. The use of interactive learning tools encourages active participation by making science education more dynamic and fun.

Studies in the literature demonstrate that the use of GAI based methods in science education offers significant advantages over more traditional teaching approaches (Zawacki-Richter et al., 2019; Chen et al., 2020). These advantages are largely rooted in pedagogical principles that emphasize student-centered learning, where learners are actively involved in constructing their own understanding. For example, Luckin et al. (2016) argue that GAI technologies enable personalized and interactive learning environments that empower students to take ownership of their learning processes. Similarly, Holmes and colleagues (2019) highlight that GAI tools promote inquiry-based and participatory learning models, which align with modern constructivist educational frameworks. The pedagogical possibilities offered by GAI are orientated towards achieving significant learning in students and encourage the visual component, which can take different forms such as simulations, VR, AR, or games. (García-Martínez et al., 2023). Research shows that different generative AI methods not only affect the quantity of students' learning but also lead to higher levels of motivation, which is indicated by a desire to be more engaged in their learning (Holmes et al., 2019; Chen et al., 2020). At the same time, most studies on generative AI have been shown to become more meaningful in STEM knowledge domains, which require higher levels of abstraction and greater complexity in order to accurately understand the information (Luckin et al., 2016; Zawacki-Richter et al., 2019). GAI not only helps students to focus while building things but also encourages their creative ability to shape their thinking (Barak & Zadok, 2009). Similarly, several studies have shown the effectiveness of AI tools in education (Fabregas et al., 2016). Moreover, many educational institutions around the world actively implement the STEM (Science, Technology, Engineering, and Mathematics) teaching methodology to equip students with 21st-century skills such as critical thinking, problem-solving, and technological literacy. Prominent examples include the Massachusetts Institute of Technology (MIT) in the United States, which integrates interdisciplinary STEM education with cutting-edge research; the Imperial College London in the United Kingdom, known for its emphasis on engineering and science innovation; and Tsinghua University in China, which offers comprehensive STEM programs with a strong focus on artificial intelligence and robotics. These institutions serve as global models in promoting inquiry-based learning, interdisciplinary collaboration, and the integration of advanced technologies into education (Bybee, 2013; Marginson et al., 2013). This methodology is characterized by using a set of new and up-to-date tools for teaching different school subjects. This allows the design and development of a computational model based on learning and teaching conditions controlled over any subject with high visual and multimedia content, facilitating the acquisition and understanding of contents through ongoing interaction with the computer (Vlachopoulos & Makri, 2017).

Different studies on the use of artificial intelligence show that the potential of generative AI on student performance is addressed through applications, simulations, VR, and AR. Regarding applications, the literature shows that their use in education is becoming increasingly common at all levels (Wirjawan et al., 2020). Given their high impact on students, generative AI needs to be effectively utilized in education. Applications vary according to the subject area and the educational level of the student. Some applications allow the user to interact

with the environment, use questions and answers, find some items, find directions, watch tutorial videos, create a portfolio, learn mathematics, play video games, and even give smart lessons (Holmes et al., 2019; Chen et al., 2020; Zawacki-Richter et al., 2019). For instance, applications such as Khan Academy and Socratic use AI to support mathematics learning and problem-solving; Minecraft: Education Edition promotes interactive exploration and game-based learning; and platforms like Duolingo and Quizlet incorporate smart lesson delivery and question-answer interaction to personalize language and content learning (Luckin et al., 2016). Similarly, studies are focusing on the use of some applications at any educational stage (Dunleavy et al., 2019). Moreover, apps tend to be used more frequently by teachers because they require higher levels of literacy and are more accessible (Gao et al., 2021). In addition, there are also studies in which different applications were used with people with autism or people with attention deficit hyperactivity disorder (García-Martínez et al., 2023). This means that this type of artificial intelligence is easier to apply in the design, adjustment, and development of teaching processes for students with special educational needs (García-Martínez et al., 2023). Moreover, in terms of simulations, generative AI offers a variety of scenarios in which students can explore, play games, or solve everyday problems by applying what they have learned to progress at different levels. Its easy accessibility, individualization potential, and low cost are said to be some of the benefits that encourage its widespread use in education (García-Martínez et al., 2023).

GAI allows us to understand complex concepts in subjects categorized as 'difficult' to strengthen and improve students' attitudes towards the subject and, in some cases, to create collaboration strategies among students (Holmes et al., 2019; Chen et al., 2020). Similarly, research using simulations as an AI, augmented reality, and virtual reality module is oriented towards providing students with more real learning situations and shows an effectiveness similar to that in real laboratories (Radianti et al., 2020; Makransky & Mayer, 2022). These experiences allow students to interact with the external environment in the classroom (García-Martínez et al., 2023). In addition, the use of virtual reality in education enables students to interpret signs, whether visual, auditory, or tactile and to construct their knowledge through their movements and interactions with their environment (García-Martínez et al., 2023). To put this technology into practice at school, teachers need to experiment with using generative artificial intelligence, learn how to use it, and then connect the content to the student's environment (Tondeur et al., 2017).

In higher education, university studies in medicine or nursing involve the use of VR to perform surgeries and treatments (Baxter & Hailey, 2019). In the field of science education, a wide range of technologies including Web 2.0 tools, robotics applications, simulations, virtual reality environments, virtual laboratories, digital game-based learning, and various GAI applications are extensively utilized to enrich the learning process (Zawacki-Richter et al., 2019; Holmes et al., 2019). These GAI-driven tools enable students to better grasp abstract concepts, understand content through hands-on experimentation and inquiry, engage in creative design processes, and participate actively in their own learning (Chen et al., 2020; Luckin et al., 2016). Such outcomes represent just a few of the numerous educational advantages that generative artificial intelligence brings to contemporary science education. Although there are many more benefits, the use of productive artificial intelligence in science education should be encouraged. Since artificial intelligence, which enters our lives with the developing technology, has many benefits, its use in education will be very beneficial for students and teachers. Therefore, artificial intelligence should be included in education. It is important to determine whether this technology, which is still new, is included in education, how it is used, how it is used by students, how teachers' competencies in this subject are determined, and whether it is integrated into lessons.

Purpose and Significance of the Study

GAI can perform cognitive processes of human intelligence such as language processing, problem-solving, reasoning, and learning with computer algorithms. Chatbots, which are part of productive artificial intelligence, can respond as if a natural human is being in front of them. Today, the most widely used chatbots are as follows (Basaran & Ozenc- Yesilbas, 2024), ChatGPT, Gemini, and Copilot. The common basic feature of these chatbots is to give informative answers. In addition to giving informative answers, it supports the personal development of individuals and helps the professional life of content producers by having features such as producing creative content, creating visual materials, writing different types of text, programming, and coding (Basaran & Ozenc-Yesilbas, 2024). GAI tools are also used in the field of education and are said to have the potential to be a powerful tool in the field of education (Baidoo-Anu & Owusu-Ansah, 2023; Ucar, 2023).

Chatbots have applications such as individualized education, automatic trial scorer, language translation, interactive learning, and adaptive learning to support learning (Baidoo-Anu & Owusu-Ansah, 2023; Gürlek et al., 2023). With the individualized education feature, educational plans can be tailored to students' needs, age,

and cognitive development, allowing for more personalized and effective learning experiences (Luckin et al., 2016; Chen et al., 2020; Vieriu & Petrea, 2025). The automatic essay scorer is a valuable tool that assists teachers in evaluating students' written work efficiently and consistently (Shermis & Burstein, 2013; Uyar & Buyukahiska, 2025). Additionally, chatbots equipped with information delivery functions provide an interactive learning environment by simulating the presence of a virtual instructor, which enhances learner engagement and accessibility (Winkler & Sollner, 2018). Education can also be continuously adapted based on students' progress and the results of formative assessment and evaluation processes, fostering a more responsive and student-centered learning model (Holmes, et al., 2019). These contributions of productive artificial intelligence in the learning and teaching process tend to increase learning outcomes (Dargut- Guler, 2024).

Studies on the effects of artificial intelligence applications on education in the literature say that individuals in the learning process perform deep learning, provide structuring information, and learners have enough knowledge to express themselves and thus increase learning outcomes (Afzaal et al., 2024; Akbulut et al., 2024; Chen et al., 2020). In studies on the use of productive artificial intelligence tools in science courses, the use of chatbot ChatGPT is encountered (Cooper, 2023; Ergun, 2023). Cooper (2023) and Ergun (2023) had a positive approach toward the use of ChatGPT in science education, as there were a wide variety of scenarios, activities, and examples in the science lesson plan with the 5E teaching model prepared by ChatGPT.

When the literature is analyzed, it is seen that the reflections of generative artificial intelligence in education are widely used. However, it is seen that the number of artificial intelligence application examples that can be used in different educational fields (such as science teaching) is low (Incemen & Ozturk, 2024). The fact that chatbots support learning by answering the questions of the learners, explaining, exemplifying, and shaping according to the level and needs of the learner has led to the need to examine the effect of productive artificial intelligence on students' learning outcomes in science education. This study aims to evaluate the effect of generative artificial intelligence on students' learning outcomes in science education through a meta-analysis study. The problem statement of the research was determined as 'What is the effect of productive artificial intelligence applications on students' learning outcomes in secondary school science education?'

Method

Systematic literature review (SLR) is defined as the process of comprehensively reviewing all published studies on a specific topic, determining which studies will be included in the research according to the specified criteria, and then synthesizing the findings of these studies and proposing a solution to an existing problem (Davis et al., 2014). This method also aims to make a detailed evaluation by accessing a wide range of scientific resources related to a specific research question or subject area and to shed light on future research by revealing the gaps in the literature (Kitchenham et al., 2009).

Systematic literature review is the process of examining the studies in the literature in a comprehensive, objective, and reproducible manner in line with predefined criteria to find an answer to a specific research question. This method not only selects relevant studies but also synthesizes the data from these studies to provide a structured and scientific answer to the research question (Booth et al., 2016). Systematic reviews include five basic steps: (1) firstly, the research question should be clearly defined, (2) databases and keywords suitable for the research should be identified, (3) after the database is identified, inclusion and exclusion criteria should be established, (4) the literature should be reviewed and analyzed according to the selected criteria, (5) finally, the findings should be reported in a structured manner (Gough et al., 2017).

Systematic literature review is widely used especially in health sciences, education, psychology, and social sciences. This is because systematic reviews enable knowledge-based decisions to be made in the field of research by presenting the existing body of knowledge in a transparent and unbiased manner (Liberati et al., 2009). A systematic literature review compiles and summarizes the existing scientific evidence in the literature through a comprehensive literature review. SLR allows researchers to examine previous research and serves as a basis for developing new research questions (Liberati et al., 2009). SLR can guide future research by pointing out existing research gaps and weaknesses on a particular topic (Dixon-Woods et al., 2006). By focusing on gaps in the literature, researchers can identify areas that require further research and contribute significantly.

Systematic literature reviews combine the results of various studies to produce results that can be widely applied. These results can be statistically combined using techniques such as meta-analysis (Borenstein et al., 2009). This makes it easier to determine whether the findings of many studies are consistent or contradictory. SLT makes it possible to examine many research techniques and strategies that can be used to determine which approaches can

have an impact on research findings and which techniques are more successful (Higgins & Green, 2011). One of the most reliable methods of obtaining accurate and reliable information is a systematic literature review. Decision-makers should base their choices on accurate data and information, especially in critical areas such as social sciences, health, and education. As a result, SLT facilitates decision-making (Pope et al., 2007). New and important research questions can be developed by identifying gaps in the existing body of knowledge. A systematic literature review not only reveals the existing body of knowledge but also paves the way for creative research (Torraco, 2005).

Screening Process

Web of Science (WoS) [Social Science Citation Index (SSCI), Emerging Science Citation Index (ESCI)], Elsevier [Scopus], ERIC, and TRDizin electronic databases and indexes were used in the systematic literature review to determine the effect of generative artificial intelligence applications on students' learning outcomes in science education. The keywords 'science', 'science education', 'generative artificial intelligence', 'GenAI', 'artificial intelligence', 'AI', 'secondary school', 'interest', 'motivation', 'attitude', "achievement" and 'learning outcome' were used in the searches made through databases. Different combinations of keywords were reached by using Boolean operators AND and OR. In the scans made with keywords, studies related to computer science education, science teachers, and prospective teachers were found. These studies were not included in the search by using the NOT Boolean operator.

Selection Process

The studies that were related to the effects of artificial intelligence applications on students' outcomes in science education were included in the selection process. Firstly, in this process, the studies whose full text could not be accessed from a university network were eliminated. Then, the publication languages of the studies other than Turkish and English were excluded from the study. In the systematic literature review, studies presented as articles and papers were included. Since the frequency of use of artificial intelligence tools in education has increased as of 2020, those published from 2020 to the present have been included. As a result of these eliminations, the titles of the remaining studies were examined first. Studies with computer science education in the title of the studies that did not include science education were excluded from the selection. While examining the abstracts of the remaining studies in detail, it was paid attention that the method of the studies was experimental and quasi-experimental. By going to the full text of the studies that did not provide information about the method used in the research in the abstract, studies that were not experimental and quasi-experimental in the method section were not included. In the studies examining the effect of artificial intelligence applications in science education, it is among the selection criteria that the research group should be secondary school students. The studies conducted with 5th, 6th, 7th, 8th, and 9th grade students were included. The inclusion and exclusion criteria are presented in Table 1.

Table 1. Inclusion and exclusion criteria

<i>Inclusion Criteria</i>	<i>Exclusion Criteria</i>
• Experimental and quasi-experimental research • Research written in Turkish and English • Article, conference paper • 3rd - 8th grade students • Research conducted in the last 5 years • Full text is accessible from a university network	• Qualitative, review and compilation studies • Research written in languages other than Turkish and English • Books, book chapters, letters • K -2 / high school / college students • Research older than 5 years • Full text is not accessible from a university network

In the selection process, 15 studies on the effect of artificial intelligence on students' learning outcomes in science education were reached by considering the criteria of publication language, publication date, being in the field of science education, method, and grade level of the participants. Each of these studies was read carefully and the results were noted. Findings from 15 studies were classified according to academic achievement, science literacy, nature of science, learning opportunity, multiculturalism, inclusiveness, interdisciplinarity, individual learning, participation, interest, motivation, self-efficacy, and opinion codes. PRISMA protocol was applied in the selection of the studies included in the study. PRISMA protocol is presented in Figure 1. After the implementation of the PRISMA protocol, 12 studies were included in the study. The included studies are presented in Table 2.

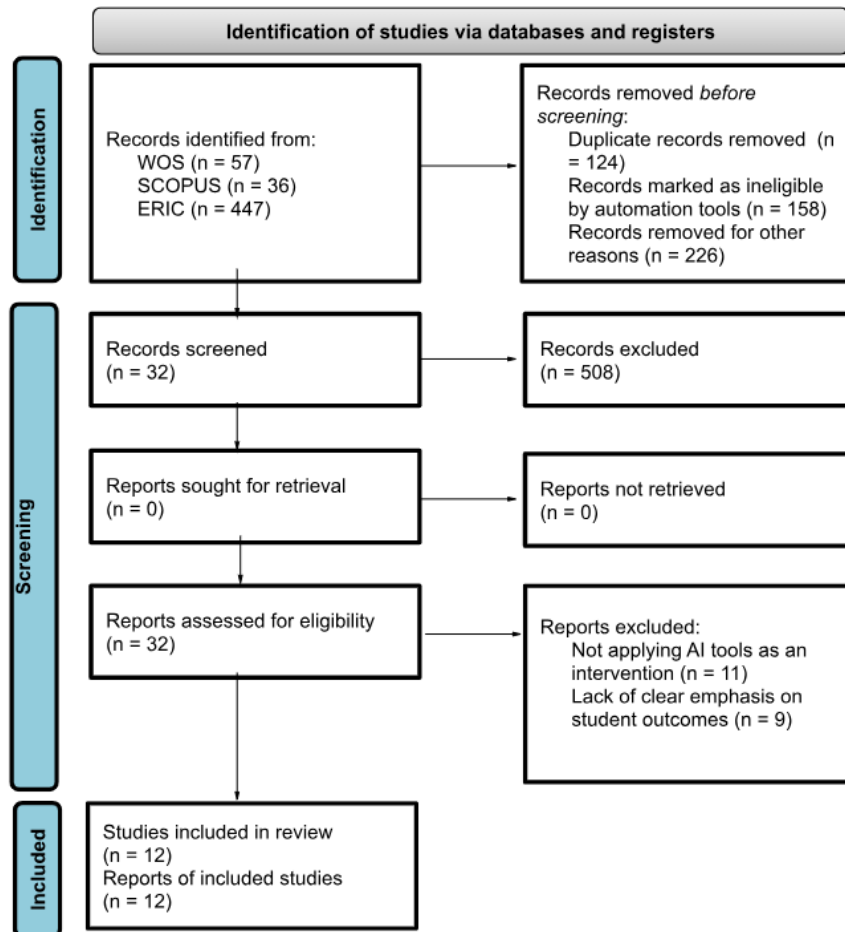


Figure 1. PRISMA flowchart of the study

Table 2. The research analyzed in this study

Study	Intervention	Method	Participants
Deveci -Topal et al. (2021)	Chatbot based learning	Pre-test post-test experimental design	quasi- N = 41, 5. Grade
Chang (2023)	Chatbot in scientific inquiry	Design-based research	N = 18, 6, 7 grades
Ding (2023)	VR-enhanced science learning	Pre-test post-test experimental design	quasi- N=66, 7, 8. grade
Kahila et al. (2023)	AI education	Pre-test post-test experimental design	quasi- N = 213, 4, 7 grades
Lee et al. (2023)	Learning through Rule-based AI Chatbot	Quasi-experimental design with pre-test post-test control group	N = 192, 6. Grade
Matavo et al. (2023) and Ates (2024)	Image STEAM workshop	Pre-test post-test experimental design	quasi- N = 116, 6 -8 grade
	AR with an Intelligent tutoring system	Pre-test post-test experimental design	quasi- N = 58, 8. Grade
Chen and Chang (2024)	AI-assisted game-based learning in science education	Pre-test post-test experimental design	quasi- N = 202, 7. grade
Chen and Liu (2024)	AI robot image recognition technology in science learning	Pre-test post-test experimental design	quasi- N = 81, 7. grade
Cheung et al. (2024)	ChatGPT-generated socio-scientific texts in science learning	Pre-test post-test experimental design	quasi- N= 117, 8, 9. grade
Simbolon et al. (2024)	AI-Driven sociocultural interactive model in science learning	Mixed - method	N = 200, middle school
Wei et al. (2025)	GPA-enhanced 5E model within AR environments	Quasi-experimental design with pre-test post-test control group	N = 60, 6. Grade

Findings

The findings of the studies included in this study were analyzed under the titles of academic achievement, literacy skills, opportunity to learn, and affective characteristics.

Academic Achievement

Studies in the literature on the effects of artificial intelligence applications on student outcomes in science education reveal that these technologies make positive contributions in various dimensions. The use of artificial intelligence-based tools can increase students' academic achievement (Wei et al., 2025), and especially in experimental groups where AI robot image recognition technology is used, higher success is observed in understanding cell applications compared to control groups (Chen et al., 2024). In addition, students who worked with AI-supported game examples such as Game GPT performed significantly better than students who only played traditional games (Chen et al., 2024). In students with low academic levels, AI-supported applications increase the level of interest in learning (Lee et al., 2023), and students begin to see themselves as more competent, more knowledgeable in scientific concepts, and more aware individuals in STEM fields (Ramana et al., 2023). In the studies on chatbot-supported science education, although there were significant differences between the pre-test and post-test achievements of students, it was also stated that this method did not show a significant superiority compared to traditional education methods (Deveci -Topal et al., 2021). These findings emphasize the potential of artificial intelligence applications to improve students' cognitive, affective, and academic outcomes.

Recent studies examining the impact of artificial intelligence (AI) applications on student outcomes in science education indicate that these technologies make significant contributions to learning processes. In a study conducted by Chen et al. (2024), it was found that students who participated only in traditional game-based activities reported higher levels of mental fatigue compared to those who used AI-supported applications such as GameGPT. This finding highlights the potential of AI-based systems to reduce cognitive load. Similarly, Wei et al. (2025) revealed that students' Grade Point Average (GPA), which reflects their overall academic performance, had a significant effect on cognitive load. These findings suggest that AI-supported science education applications can enhance the efficiency of the learning process and help students utilize their cognitive resources more effectively. Recent literature further demonstrates that AI technologies in science education have positive effects on conceptual development and levels of understanding. For example, in a study conducted by Chen (2024), AI-assisted instructional practices were reported to facilitate students' transitions from misconceptions to scientific concepts—particularly in the context of meiosis—more effectively than in the control group. Similarly, Ding (2023) emphasized that the visual and interactive features provided by virtual reality (VR) technology ease the comprehension of scientific concepts among multilingual students. Lee et al. (2023) also reported significant improvements in students' understanding of scientific concepts following the use of rule-based chatbot systems in science lessons. These findings illustrate that AI technologies function as powerful tools in supporting conceptual understanding and interactive learning within the context of science education.

Literacy Skills

Findings regarding the impact of AI tools on student outcomes in science education reveal that these technologies have the potential to enhance various dimensions of scientific literacy. In a study by Cheung et al. (2024), which examined students' engagement with AI-supported learning tasks (further details about the study design should be specified), it was found that students perceived content interpretation as the most accessible task, while epistemic evaluation—such as questioning and assessing scientific claims—was experienced as the most challenging. The same study reported that, following a reading-to-learn science intervention, students demonstrated more advanced and tentative views regarding the nature of science. However, only a small number of students were observed to critically evaluate claims related to climate change made by an AI tool like ChatGPT, questioning both the reliability and the non-epistemic nature of such tools. On the other hand, Simbolon et al. (2024) demonstrated that AI-supported, socio-culturally grounded Interactive Digital Modules (IDMs) significantly improved scientific literacy among middle school students in Papua. This study also emphasized that digital educational tools can contribute to the achievement of Sustainable Development Goals (SDGs) by supporting quality education, particularly in under-resourced regions. These findings suggest that AI applications can impact not only conceptual understanding but also higher-order skills such as critical thinking and scientific inquiry, thereby serving as powerful tools for fostering comprehensive scientific literacy.

Opportunity to Learn

AI-supported applications have been found to offer multifaceted contributions to science education for both students and teachers. Chang (2023) demonstrated that the AI-based conversational agent Inquiry Bot enhanced students' inquiry skills by enabling them to engage in more structured learning processes. Through reviewing their chat histories, students were able to reflect on their previous lines of reasoning, thereby reinforcing their learning. Simultaneously, teachers were able to analyze students' thought processes and monitor their learning progression via the chat transcripts, which allowed for targeted guidance within digital environments. Ding's (2023) study further revealed that multisensory content can make learning more accessible and effective. In particular, VR-supported activities enabled students to learn both scientific language and content simultaneously—an advantage that proved especially beneficial for students with low English proficiency in grasping scientific terminology. These findings highlight the potential of AI and VR technologies to create personalized and interactive learning environments that cater to diverse learner profiles.

The integration of AI applications into science education has also been shown to significantly support the development of students' cognitive and critical thinking skills. In a similar vein, Kahila et al. (2023) emphasized the critical role of co-design processes between researchers and teachers in developing innovative learning environments and applications for machine learning (ML). In the initial workshop, which was grounded in knowledge production and design-based pedagogy, students were encouraged to connect their interests and everyday experiences with classroom discourse and learning materials. This approach facilitated a deeper conceptual understanding of ML among students. Collectively, these findings suggest that AI-based applications not only enhance cognitive development but also foster technological awareness in science education settings.

The role of AI-supported applications in education is becoming increasingly diverse and profound. Simbolon et al. (2024) emphasized that adapting AI-powered Interactive Digital Modules (IDMs) to different regions facing similar educational challenges can contribute to reducing global educational inequalities by enabling more inclusive and culturally responsive learning experiences. This finding suggests that technological tools are not merely facilitators of information transmission but also hold the potential to provide learning environments that are attentive to cultural diversity. Accordingly, AI-supported learning environments can create transformative impacts not only at the pedagogical level but also at societal and cultural levels. Studies investigating the impact of AI-based applications on learning outcomes in science education underscore the importance of inclusivity and cultural diversity in shaping educational experiences.

Simbolon et al. (2024) highlighted that the implementation of AI-supported IDMs in diverse contexts can foster inclusive and culturally sensitive learning environments on a global scale, particularly in under-resourced regions. This approach points to the potential of digital technologies to equalize learning opportunities and close global educational gaps by offering tailored learning experiences that respond to local needs. Thanks to their capacity to adapt learning processes to individual needs, AI-powered IDMs not only enhance pedagogical effectiveness but also promote the universal accessibility of education by demonstrating sensitivity to cultural contexts. Additionally, studies exploring the effects of AI-based applications on learning outcomes in science education emphasize the significance of individualized learning. In a study conducted by Chang (2023), the AI-supported learning tool Inquirybot was shown to allow students to progress at their own pace and engage in personalized, inquiry-based learning processes. By encouraging students to deeply explore topics of personal interest and construct their learning paths, the system amplified the impact of inquiry-based learning. Thus, Inquirybot serves as a compelling example of how AI-supported learning environments can strengthen student-centered and self-regulated pedagogies in science education.

Affective Characteristics

Studies investigating the effects of AI-based applications on learning outcomes in science education have shown that these technologies play a significant role in enhancing students' interest and engagement in the subject. For instance, in a study conducted by Ateş (2024), the integration of Intelligent Tutoring Systems supported by Augmented Reality (ITS-AR) into eighth-grade science classes led to a notable increase in student participation levels. This finding indicates that AI-supported instructional tools not only offer opportunities for personalized learning but also contribute to students becoming more actively and motivationally involved in the learning process. Research findings further suggest that AI-based technologies hold considerable potential to increase student interest, participation, and motivation in science education. Virtual reality-based learning environments have been shown to foster active classroom engagement (Ding, 2023), and even students with relatively lower academic performance have demonstrated greater interest in science classes when supported by AI-driven

instructional applications (Lee et al., 2023). These findings suggest that integrating AI applications into science education can serve as a powerful means of creating more inclusive and interactive learning environments, thereby enhancing the overall quality of learning outcomes.

Findings in the literature on the impact of artificial intelligence (AI) applications on learning outcomes in science education reveal that these technologies significantly enhance student motivation and engagement. In a study conducted by Yu Chen (2024), a notable increase in motivation was observed among students in the experimental group participating in AI-supported science learning. Similarly, Ding (2023) reported that students using AI technologies in both individual and group activities demonstrated greater willingness and interactivity. In addition, the Intelligent Tutoring System–Augmented Reality (ITS-AR) developed by Ates (2024) was found to be effective in enhancing students' motivation toward science education. These findings suggest that AI-based applications positively support student participation and learning processes in science education.

Research on the effects of AI-supported applications on learning outcomes in science education also indicates that these technologies contribute to increases in students' perceived competence and self-efficacy levels. In a study by Ching-Huei Chen et al. (2024), students in the GameGPT group reported higher levels of perceived competence compared to those who only participated in traditional game-based activities. Likewise, the ITS-AR system developed by Ateş (2024) was found to have a positive effect on students' self-efficacy perceptions. These findings highlight the important role that AI-based learning environments play in strengthening students' confidence and beliefs in their academic capabilities. The impact of AI applications in science education extends beyond academic achievement to include transformative changes in students' professional perceptions. In a study by Ramana et al. (2023), it was found that students who participated in AI-supported workshops developed more active perceptions of artists and revised their views of coders and engineers. The same study also revealed that students tended to feel a stronger identification with scientists after participating in these workshops. Furthermore, Wei et al. (2025) reported that students developed positive perceptions of Extended Reality (XR)-based applications. These findings suggest that AI-based educational applications positively influence students' professional identity development and their attitudes toward technology.

Discussion

In this study, the multidimensional effects of generative artificial intelligence (GAI) applications on students' learning outcomes in science education were examined, and significant findings consistent with the existing literature were obtained. The results demonstrate that GAI technologies contribute not only to academic achievement but also to conceptual understanding, science and technology literacy, personalized learning, affective engagement, and professional identity development. Firstly, the findings related to academic achievement align with studies such as those by Zengin et al. (2023) and Chen et al. (2024). AI-supported instructional environments were reported to facilitate students' conceptual understanding and to yield higher levels of achievement, particularly in complex biological processes (e.g., cell division), compared to traditional methods. Similarly, the potential of immediate feedback during instruction to enhance student performance, as emphasized by Good (1987), has become more accessible through AI-based intelligent tutoring systems. In terms of science literacy and critical thinking skills, the studies conducted by Cheung et al. (2024) revealed that students not only gained access to scientific information but also improved their abilities to question and interpret that information. These findings support the “self-regulated and critical learning environments” approach advocated by García-Martínez et al. (2023), indicating that GAI provides cognitively rich learning contexts. With regard to diversified learning opportunities, applications such as Inquiry Bot were reported by Chang (2023) and Kahila et al. (2023) to enable students to construct their learning paths, thereby supporting personalized learning experiences. These tools accommodate different learning styles and individual needs, enabling pedagogical differentiation and, in turn, promoting inclusivity in education.

In terms of affective outcomes, the development of positive attitudes and increased motivation levels among students toward AI-supported applications is supported by studies such as Ateş (2024), Lee et al. (2023), and Barak & Zadok (2009). These findings highlight the significant role that AI-based technologies can play in sustaining student interest—particularly in STEM fields—and in supporting the development of scientific identity. The observed increase in students' self-efficacy, in particular, suggests that these technologies may also enhance students' academic self-esteem (Chen et al., 2024). However, as the literature also indicates (Erkoç & Çolak, 2024), teachers' attitudes toward AI technologies and their lack of pedagogical integration skills may pose barriers to the effective use of AI in educational settings. Moreover, the pedagogical design and ethical implementation of such applications are among the key factors determining whether teachers are able to successfully integrate technology into classroom environments (Tondeur et al., 2017). In conclusion, the findings of this study

demonstrate that GAI applications contribute meaningfully to science education processes on structural, pedagogical, and cognitive levels. These results are consistent with current literature and underscore the importance of integrating such technologies into educational environments in an effective, inclusive, and ethically sound manner.

Conclusion

This systematic literature review presents important findings by examining the effects of generative artificial intelligence (GAI) applications on the learning outcomes of middle school students in science education from a multidimensional perspective. In line with the existing literature, the study shows that GAI technologies have a positive impact not only on academic achievement, but also on conceptual learning, scientific and digital literacy, opportunities for personalized learning, affective engagement, and professional attitudes. The main conclusions drawn from the research can be summarized as follows:

- Academic achievement increases significantly in AI-based learning environments.
- Conceptual understanding and scientific thinking skills are strengthened.
- Science and technology literacy develop with AI.
- Learning opportunities increase and become more individualized.
- Affective development and self-efficacy are supported.

As a result, GAI applications are considered powerful tools that strengthen both the cognitive and affective aspects of science education and respond to the digital educational needs of the age.

Recommendations

The following recommendations can be developed in line with these findings:

- Teachers' AI literacy should be increased and professional development should be supported.
- Ethical awareness should be integrated into educational content.
- Interdisciplinary and culturally sensitive designs should be prioritized.
- Future research should examine the impact of AI in the long term and various contexts.

Scientific Ethics Declaration

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

Conflict of Interest

* The authors declare that they have no conflicts of interest

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Author Information

Meryem Seda Gunsaldi

Hacettepe University, Graduate School of Educational Sciences, Beytepe Campus, Ankara, Türkiye.
Contact e-mail: seda.gunsaldi@gmail.com
ORCID iD: <https://orcid.org/0009-0006-8659-8104>

Elif Gamze Guner

Hacettepe University, Graduate School of Educational Sciences, Beytepe Campus, Ankara, Türkiye.
ORCID iD: <https://orcid.org/0009-0007-5367-5828>

Musa Uckan

Hacettepe University, Graduate School of Educational Sciences, Beytepe Campus, Ankara, Türkiye.
ORCID iD: <https://orcid.org/0009-0007-4388-1492>

Kaan Bati

Hacettepe University, Faculty of Education, Beytepe Campus, Ankara, Türkiye.
ORCID iD: <https://orcid.org/0000-0002-6169-7871>

APPENDICES

Appendix- A: References of Studies Included in Systematic Literature Review

References of Studies Included in Systematic Literature Review

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Technological Tools Used in Misconceptions Studies in Physics Education: A Systematic Review

Atilla Ayaz Unsal, Cemil Aydogdu

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Abstract

Today, knowledge and technology are produced rapidly. In this case, the aim of educators is to develop appropriate environments instead of presenting information directly to students and to develop students' ability to access and use information by blending it with other information. This situation reveals the importance of concept education in education with technological tools. In this study, it is aimed to understand what and how technological tools have been used to identify or eliminate misconceptions in physics education in the last 10 years. For this reason, 83 studies, including 22 theses and 63 articles, were analyzed in this field between 2010 and 2020. The studies were examined according to the themes of publication year, publication type, purpose, method/pattern, sample, data collection tools, technological tool method/technique used, data analysis method, and the subject studied. As a result of the examinations; it was seen that the studies in this field increased as the year 2020 approached, that they were aimed at eliminating rather than detecting, that the majority of the studies consisted of articles, that they focused on the abstract concepts of physics, which are difficult, that animations and simulations were mostly used, and that quantitative research methods were preferred.

Introduction

In today's world where knowledge is produced rapidly, the goal of educators is to improve students' ability to access information and use it by blending it with other information by preparing appropriate environments to enable students to access information with their own efforts instead of directly giving it to them. For this reason, students should be actively involved in the teaching process. The most specific example where this is observed is in science courses, which include subjects such as earth science, physics, astronomy, chemistry, and biology. Science can be expressed as the effort to examine the events that occur in nature and to make inferences about the events that have not yet been observed with the data obtained or, in short, as people's efforts to understand nature (Fisher, 1985; Gurdal et al., 2001, Erden & Akman, 2011).

All individuals create their own concepts and knowledge through their own lives. In addition, knowledge is constantly increasing with technological and scientific developments, and as a result, the meanings attributed to concepts change and develop over time (Kiray et al., 2015). This situation ensures that conceptual learning still has a very important place in science education and increases the importance of research in this field day by day (Joung, 2009). In order to determine the conceptual knowledge of individuals, researchers have developed various diagnostic and detection tools. Research has revealed that there are various factors affecting students' conceptual knowledge (Clement et al., 1989; Kiray et al., 2015).

Chemistry and physics in science is a subject that many students have difficulty with because it contains abstract concepts. When the researches in the field of science education are examined, it is seen that the topics of concept, misconceptions and conceptual changes gain weight. When we look at the reasons for students' failure in science courses, it can be said that it is due to the fact that the subjects contain complex and abstract concepts. Because the subjects and abstract concepts require more thinking and comprehension activities. (Ayas & Costu, 2001).

Problem Status

In order to ensure that students first make sense of the concepts, as well as the permanence of the concepts, if there is a contradiction between the new concepts learned and the concepts they had before, these situations should be eliminated and meaningful relationships should be established between the previous and new concepts (Unsal, 2019).

When recent researches conducted in science education examined, it is seen that it is aimed to realize meaningful learning in students and to determine learning difficulties in students. For this reason, it is of great importance to identify and eliminate misconceptions in all educational disciplines in order to realize meaningful learning (Committee on Undergraduate Science Education, 1997).

In addition, considering that especially primary school students have difficulty in learning abstract concepts, educational technology tools and especially computers play a very important role in concretizing these concepts in a way that is appropriate to the level of the student and presenting them almost vividly, learning them in depth and observing the events repeatedly. Research on the application of various dimensions of educational technology in teaching shows that educational technology applications have a positive effect on student achievement in many ways. In this regard, it has been determined that various teaching materials (game, analogy, case study, experiment, model) (Aktamis et al., 2002), model-based teaching (Sahin et al., 2001), computer-aided materials (Kibos, 2002) increase students' achievement. Since technology has become an integral part of our lives today, it has become one of the necessities of education. The importance of technology for education has once again emerged in cases such as pandemics, earthquakes, floods, terrorist attacks that affect the whole world, such as Covid 19 (Kayacan & Ulker, 2020).

When such advantages of educational technologies are considered, it is obvious that their use in the detection and elimination of misconceptions will make great contributions to education. For this reason, this study aims to understand the technological tools that have been used in the literature in the field of physics education in the last 10 years to eliminate misconceptions and how they have been used. In this context, answers to the following questions are sought:

- Which technological tools were used to eliminate misconceptions in the field of physics education in literature between 2010 and 2020?
- What is the distribution of the intended use of these technological tools?
- How was the use of technological tools distributed according to physics subjects?

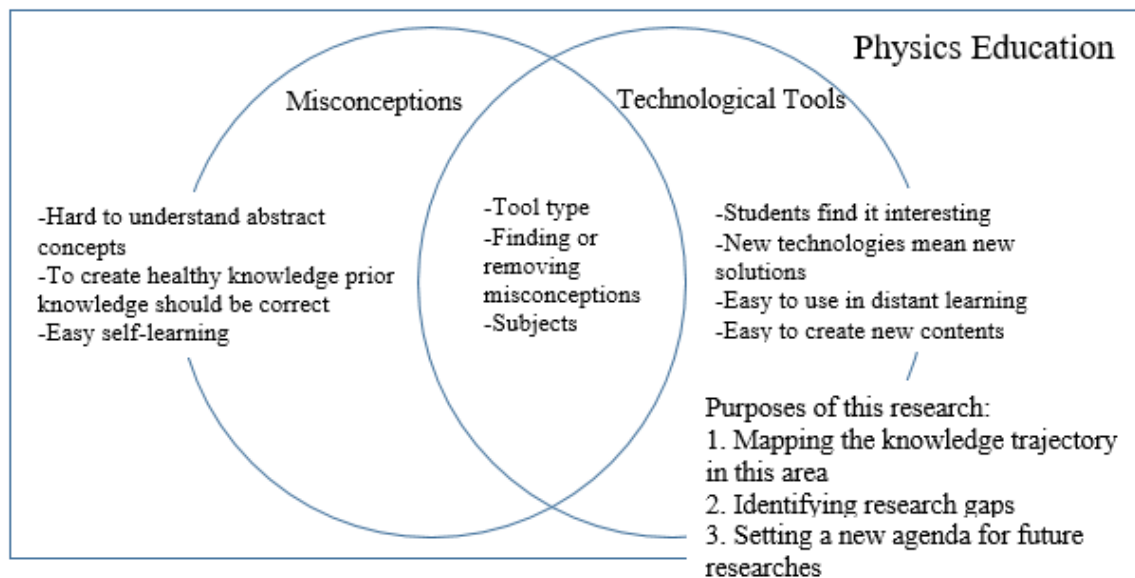


Figure 1. Purpose of the study

Method

Research Design

In this study, a systematic review will be conducted from qualitative research methods. A systematic review is a comprehensive review of all studies published in that field, using various inclusion and exclusion criteria and evaluating the quality of the studies, determining which studies will be included in the review, and synthesizing the findings of the studies included in the review in order to create an answer to a clinical question or a solution to a problem (Burns & Grove, 2007; Centre for Reviews and Dissemination [CRD], 2008; Higgins & Green, 2011; cited in Karacam, 2013).

Systematic reviews can examine quantitative and qualitative evidence, or they can examine two or more types of evidence in a so-called "mixed method systematic review" (Hemingway & Brereton, 2009). Systematic reviews contain more scientific information and are important because they produce stronger evidence. The reasons why systematic reviews contain more scientific information and are accepted can be listed as follows (Moule & Goodman, 2009; Hemingway & Brereton, 2009);

- They are more objective, with fewer biases and errors,
- A literature review is much more comprehensive and reproducible as it is done with a specific methodology,
- The methods used for the literature review are clearly stated in the study,
- The criteria used to select the studies are clearly stated,
- The quality of the studies included in the review is assessed,
- When combining data from studies, even the smallest evidence/effects are included in the review,
- Researchers can repeat the systematic review and confirm their results.
- The number and duties of the researchers who will work in the systematic review research project are determined.

Data Collection

A systematic search was carried out in 10 databases in order to reach the studies in which technological tools used in misconception studies in the field of physics education in the literature. These databases are Google Scholar, ERIC, Ulakbim, Proquest, Scopus (elsevier), Wiley, Web of Science, JSTOR, YOK Thesis Center. Articles and theses published in refereed journals were included in the studies. Due to the recent introduction of technological tools, the search was limited to English and Turkish studies published between 2010 and 2020 to obtain studies on misconceptions in physics education.

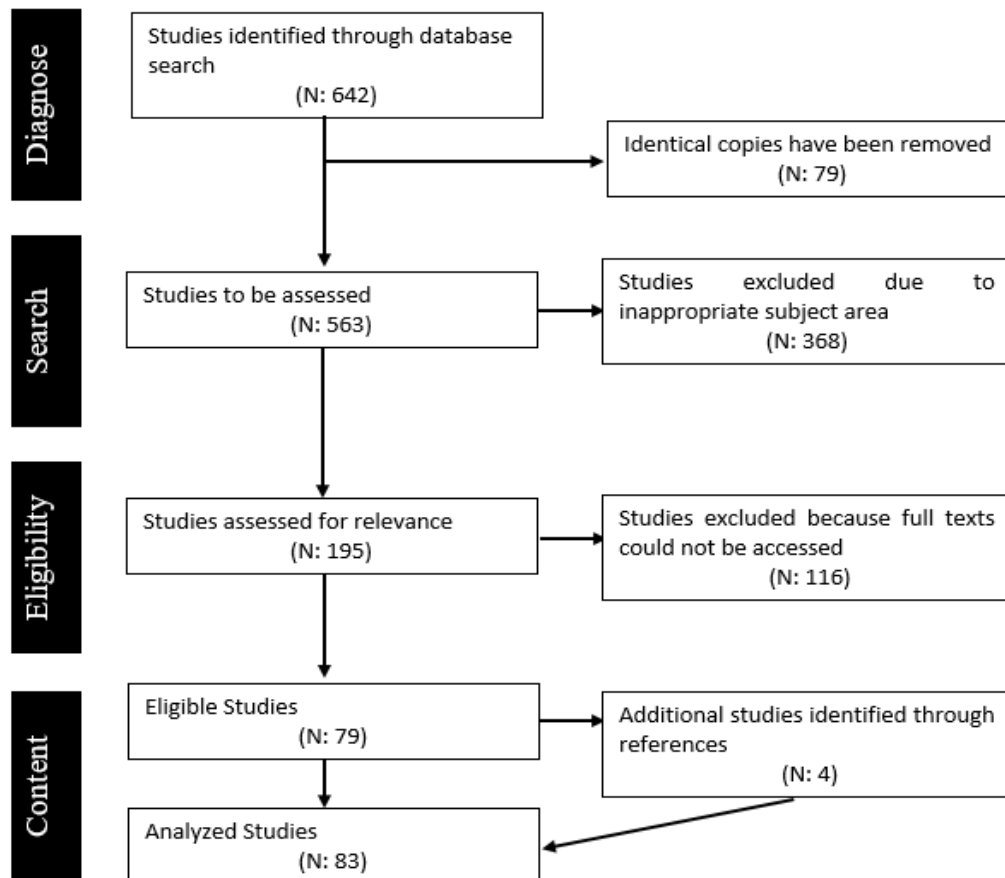


Figure 2. Path diagram (PRISMA model)

The research was conducted by two people. All stages were carried out by these researchers. A multi-stage process was followed in which each study was read and the information retrieved was identified. The literature review followed an iterative process. The reference list of each article found was used as the source of new references. The words physics education, physics education, misconceptions, technological tools, technology, science education were used in the literature review. The total records accessed and the process of eliminating the records are shown below. To create a systematic review research PRISMA diagram is used. PRISMA stands for Preferred Reporting Items for Systematic Reviews and Meta-Analyses. It is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses. The flow diagram in figure 2 depicts the flow of information through the different phases of a systematic review. It maps out the number of records identified, included and excluded, and the reasons for exclusions (Karacam, 2013).

Validity Reliability

In order to ensure the validity and reliability of the study, two field experts were consulted about the content and themes throughout the process. The experts were asked to code 10 different studies included in the study and the percentage of agreement between the expert's codes and the codes prepared by the author of this study was checked. Sandelowski (1998) states that reliability in studies can also be ensured in this way. Based on this, in order to ensure the reliability of the study, an expert who has both a good command of the qualitative field and conducts science education studies was selected and a part of the data representing the whole data was sent and an opinion was obtained. This percentage of agreement was calculated with the reliability formula suggested by Miles and Huberman (1994) and was calculated as 96%. This result shows that coder reliability is at a sufficient level. In order to ensure the validity of the study, the researcher took care to explain each step of the systematic review process in detail.

The literature review process continued from November 2020 to December 2020. The transfer of the studies reached in the review to the relevant parameters was carried out in January 2021. Therefore, studies published after January 2021 were excluded. Expert opinion was sought in January on the suitability of the relevant studies for the context of the current study, and the findings section of the study was started to be written in January 2021. The studies reached as a result of the review were recorded as full text. Each of these studies was coded in Excel under a certain parameter. These parameters were determined as publication year, publication type, purpose, method/pattern, sample, technological tool used, subject area examined, conclusion and recommendation. These parameters have been used many times in the related literature (Bag & Calik, 2017, 2018; Gul & Sozbilir, 2015; Yildirim et al., 2016).

Data Analysis

Content analysis was used for the analysis. The main purpose of content analysis is to reach concepts and relationships that will help explain the collected data. Data summarized and interpreted through descriptive analysis are subjected to in-depth processing through content analysis and new concepts are discovered. The basic process in content analysis is to bring together similar data within the framework of certain concepts and themes and to organize and interpret them in a way that the reader can understand (Yildirim & Simsek, 2013; Moula & Gooman, 2009). Content analysis is a scientific method that draws attention to objectivity between subjects and allows elements such as validity, reliability, reproducibility, generalizability and testing of hypotheses (Patton, 2014). Frequency tables were created according to the determined criteria. The themes that form a relationship between the data were determined. The studies obtained were analyzed in depth in terms of the classification of technological tools used in diagnosing and eliminating misconceptions.

Results and Discussion

The studies examined within the scope of this study were coded according to the parameters determined and themes were reached. The findings of the themes are explained respectively. Firstly, the publication year and type of the studies are presented in Table 1. According to the coding result in Table 1, while there was no research on concept education using technological tools in science education in 2010, there were 4 in 2011, 5 in 2014, 2016 and 2017, 7 in 2015, 6 in 2012, 8 in 2013, 13 in 2018, 14 in 2019 and 16 in 2020. In addition, 28 studies conducted to determine misconceptions using technological tools and 55 studies conducted to eliminate misconceptions using technological tools were reached. While 22 of these researches are master's and doctoral theses, 61 of them are articles.

Table 1. Codes and frequencies related to year, type and purpose of publication

Detection of misconceptions using technological tools			Elimination of misconceptions using technological tools		
Year of Publication	Research Type	f	Year of Publication	Research Type	f
2010	Article	0	2010	Article	0
	Thesis	0		Thesis	0
2011	Article	2	2011	Article	2
	Thesis	0		Thesis	0
2012	Article	1	2012	Article	4
	Thesis	0		Thesis	1
2013	Article	2	2013	Article	2
	Thesis	1		Thesis	3
2014	Article	0	2014	Article	2
	Thesis	1		Thesis	2
2015	Article	1	2015	Article	3
	Thesis	1		Thesis	2
2016	Article	0	2016	Article	4
	Thesis	1		Thesis	0
2017	Article	2	2017	Article	2
	Thesis	0		Thesis	1
2018	Article	3	2018	Article	7
	Thesis	1		Thesis	2
2019	Article	4	2019	Article	6
	Thesis	1		Thesis	3
2020	Article	6	2020	Article	8
	Thesis	1		Thesis	1
Total		28	Total		55

The purpose of the studies examined in this study and the codes and frequency distributions created for the subject themes obtained from the studies examined are presented in Table 2.

Table 2. Codes and frequencies related to subject and study purpose

Study Objective	Detection of misconceptions using technological tools	Elimination of misconceptions using technological tools
Codes	f	f
Dynamic	4	7
Optics	1	5
Electricity and Magnetism	4	4
Pressure and Buoyancy	2	4
Fluid Mechanics	2	6
Heat, Temperature and Expansion	6	7
Work, power, energy	1	5
Wave Mechanics	1	2
Matter and Properties	2	3
Motion and Force	3	5
Electrostatic	2	5
Modern Physics	0	2
Total	28	55

According to Table 2, 12 thematic subject areas were identified. It is seen that a total of 11 of the studies conducted to determine misconceptions by using technological tools and to eliminate misconceptions by using technological tools are in dynamics, 6 in optics, 8 in electricity and magnetism, 6 in pressure and buoyancy, 8 in fluid mechanics, 13 in heat and temperature, 6 in energy, 3 in wave mechanics, 5 in matter and its properties, 8 in motion and force, 7 in electrostatics and 2 in modern physics.

The codes and frequencies related to the purpose of the study and the technological tools and equipment used in the related studies are presented in Table 3.

Table 3. Codes and frequencies related to the tools used and the purpose of the study

Study objective	Detection of misconceptions using technological tools	Elimination of misconceptions using technological tools
Codes	f	f
Games / Mobile games	0	2
Web 2.0 learning technologies (e.g. social media, Social Networking systems, Wiki or Blogs)	3	5
Mobile learning (e.g. tablets, iPads, computers, interactive tools/technologies or mobile device)	7	3
Virtual world / virtual reality	0	3
Digital instructions or educational visual aids	0	4
Management systems (e.g. classroom management systems, learning management systems or self-organized learning systems)	6	0
Animations and simulations (e.g. educational animation or computer animation)	0	12
Discussion / Online discussion platforms (e.g. online interaction platform, online collaboration network or collaborative simulation)	4	2
Online learning course delivery, e-learning	0	1
Blended learning (e.g. using technology with face-to-face learning)	3	6
Technology-enhanced feedback system, online feedback system or audio feedback system	5	1
Student response system	0	1
Programming	0	3
Augmented reality (AR) technology	0	2
Robotics	0	9
Online book, e-book or digital storytelling	0	1
Total	28	55

According to the coding in Table 3, 16 technological tools used in the analyzed studies were identified. In the studies conducted to determine misconceptions by using technological tools and to eliminate misconceptions by using technological tools, computer games or mobile games were used in 2 studies, web 2.0 tools in 2, computer games or mobile games in 8, web 2.0 tools in 10, mobile learning in 10, virtual reality in 3, various digital visuals and instructions in 4, special management systems in 6, animations and simulations in 12, discussion on online platforms in 6, e-learning in 1, blended learning as distance and face-to-face in 9, feedback systems in 6, institution-specific student response system in 1, programming in 3, augmented reality in 2, robotic coding in 9, e-book in 1. In the studies conducted to determine misconceptions using technological tools, it was determined that tools such as games, virtual reality, digital visuals, simulations, e-learning, student response system, programming, augmented reality, robotics and e-books were not used. In the field of eliminating misconceptions by using technological tools, it was seen that only management systems were not used.

The codes and frequencies related to the method and design, sampling, and data analysis methods preferred in the related studies are presented in Table 4. When the methods and designs of the studies are analyzed in Table 4, it is seen that quantitative methods were mostly used. In these studies, quasi-experimental designs with pretest-posttest control groups were generally preferred ($f = 29$). This design was followed by survey studies ($f = 22$). It is seen that the rate of preference for qualitative research designs is low ($f = 6$). However, it was stated that both quantitative and qualitative research methods were used together in 2 of the studies. The method and design of 4 studies were not specified.

Table 4. Codes and frequencies of the studies regarding method/pattern, sample level, data analysis method

Themes	Categories	Codes(f)	f	
Method/Pattern	Quantitative	Experimental	Weak experimental design (2), quasi-experimental design (29), full experimental design (16)	51
		Survey		22
	Qualitative	Case study		5
		Pattern not specified	not	1
		Mixed Pattern	Quantitative-experimental	2
	Unspecified		4	
	Total		83	
	Sample	Secondary School Students		27
		High school students		18
		Teacher candidate		35
Unspecified			3	
Total			83	
Data Analysis Method	Quantitative		Descriptive analysis	18
			Content analysis	10
			Descriptive statistical analysis	14
			t-test	16
			ANOVA	13
			ANCOVA	12
			MANCOVA	3
			Mann Whitney U test	10
			Tukey Test	7
			Kruskal Wallis test	1
			Wilcoxon signed-rank test	4
		Unspecified		3
		Total		101*

*The high frequency values are due to the fact that more than one data analysis method was selected in the same study.

When the samples of the studies in Table 4 are examined, it is seen that the majority of them ($f = 35$) were conducted with prospective teachers at the university level. This was followed by secondary school students in 27 studies and high school students in 18 studies. In 3 studies, no information was given about the sample. It is seen that the number of quantitative data analysis methods is also high ($f = 83$) due to the high use of quantitative methods in the studies. In most of the studies, changes before and after the application were examined in experimental studies. Therefore, this situation led to the excessive use of t-test, ANOVA, ANCOVA ($f = 41$). Although the data analysis method was not explained in 3 of the studies, it was seen that advanced statistical analyzes were not performed. Regarding qualitative analysis methods, it was observed that descriptive analysis ($f = 18$) was preferred more than content analysis ($f = 10$).

Conclusion

As a result of this study, the number of studies, study types, study topics, technological tools and study methods were determined under the misconceptions group according to years.

When evaluated in terms of study type and study year, it was seen that the studies in which technological tools were used both in the detection and elimination of misconceptions increased after 2018. The reason for this is that the technological tools used in education develop and increase in variety as time progresses (Corwther & Price, 2014). Thus, the tool for the need can be found easily and can be used in the desired way by making it appropriate. In addition, technological tools were used more in the elimination of misconceptions ($f=55$) rather than the detection of misconceptions ($f=28$). Since the elimination of misconceptions is usually a process (Ulgen, 2001), the convenience of using technological tools during the process may cause such a tendency (Kaya, 2010).

When the distribution of the subjects in the studies is examined, it is seen that the studies detecting misconceptions are concentrated around the subjects of Dynamics ($f=4$), Heat and Temperature ($f=6$), Electricity and Magnetism ($f=4$). Misconception detection studies were centered around the topics of Dynamics ($f=7$), Fluid Mechanics ($f=6$), Heat and Temperature ($f=7$). The fact that the subjects are difficult and contain many abstract concepts makes researchers think that students' misconceptions are much higher in these subjects. In particular, the commonality of Dynamics, Heat and Temperature subjects in the studies on the identification and elimination of misconceptions indicates that students may have the most difficulties in these subjects in their curriculum (Cirkinoglu, 2004; Sabancilar, 2006; Gurbuz, 2008).

In terms of the tools and equipment used, it is noteworthy that Mobile Learning ($f=7$), Management Systems ($f=6$) and Technology Enriched Feedback ($f=5$) Systems were used to identify misconceptions. Since the detection of misconceptions is carried out by using measurement tools, it is noticeable that technological systems that can develop measurement tools are used in these studies. In addition, it was observed that certain technological tools were periodically focused on for misconception detection. However, due to the increase in the studies after 2018, it was determined that the frequency of use of new technological tools was higher than the old technologies. Accordingly, Blended Learning ($f=6$), Animations and Simulations ($f=12$) and Robotics ($f=9$) tools were frequently preferred. The high frequency of these tools instead of newer technological tools such as Augmented and Virtual Reality may be due to the fact that these tools are not yet widely used (Kavanagh et al, 2017). Especially the use of Robotics tools may be due to the widespread use of STEM education between 2014-2019 (Freemen et al. 2019; Mpofu, 2020; Wells, 2019; Tyler, 2020; Li et al., 2020; Yildirim & Gelmez-Burakgazi, 2020; Jamali, 2023).

When the studies are examined in terms of method, sampling and analysis methods, it is seen that quantitative methods are adopted. In general, Experimental ($f=55$) and Survey ($f=22$) designs were preferred. When the studies were examined in detail, it was seen that misconception detection studies preferred the Survey design, while experimental studies were preferred in misconception elimination studies. This result is compatible with the nature of the studies (Senemoglu, 2005). In terms of sample, it was determined that pre-service teachers ($f=35$) and secondary school students ($f=27$) were preferred the most. When the results obtained from the misconception subject areas and the researcher groups are considered together, the reason for the preference of these samples comes to the forefront as an easily accessible sample (Wessel, 1998; Tekkaya et al., 2000; Kose, 2004; Arslan et al., 2012). Teachers conducting misconception studies in secondary school preferred to conduct research with their own students, and academicians conducting misconception studies at the university preferred to conduct research with their own students. In terms of data analysis, it was determined that there was a homogeneous distribution of quantitative and qualitative methods and designs. Since misconceptions can be identified in a variety of ways, analysis methods appropriate to the nature of the study were adopted (Unsal, 2019). It was observed that parametric and non-parametric tests were used in quantitative analysis methods. The reason for the use of non-parametric tests is mostly due to the fact that experimental studies ($f=55$) were preferred as a method and small groups were studied (Onen, 2005).

Recommendations

According to these results, it is recommended to carry out identification and elimination studies especially on Modern Physics as a subject area with very few studies. It is recommended to use online learning, e-book or digital storytelling, augmented and virtual reality as the tools used. The small number of these studies shows that meaningful contributions can be made to the field. Newer technological tools can also be preferred. While conducting these studies, methods appropriate to the nature of the study should be selected. Because when the methods of the studies were examined, a homogeneous distribution was observed. In addition, it is recommended to conduct a meta-analysis study in which the reasons for the choice of the subject area and technological tools will be examined in a deeper way.

Scientific Ethics Declaration

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

* This research did not require IRB approval because this paper is a systematic review study and content analysis is use as data analysis on articles and thesis's. Also this study was prepared in accordance with scientific ethics rules. At any time, in the event that a situation contrary to this statement regarding the study is detected, we accept and declare that we agree for all ethic and legal consequences that may arise.

Conflict of Interest

* The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Author Information

Atilla Ayaz Unsal

Hacettepe University,
Faculty of Education, Department of Science Education,
Beytepe, Ankara, Türkiye
Contact e-mail: atillaunsal@hacettepe.edu.tr
ORCID iD: <https://orcid.org/0000-0003-3305-8025>

Cemil Aydogdu

Hacettepe University,
Faculty of Education, Department of Science Education,
Beytepe, Ankara, Türkiye
ORCID iD: <https://orcid.org/0000-0003-1623-965X>

Virtual Reality Technology in Science Education: Exploring Trends and Future Perspectives

Aysun Tekindur, Serpil Kara

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Abstract

The importance of virtual reality in science education is constantly increasing. For this reason, this study aims to identify current trends in science education through virtual reality (VR) themes using a bibliometric analysis of the Web of Science (WoS) database. Data analysis was conducted with VOSviewer software. Findings reveal that VR studies are primarily categorized under “Education Educational Research” and “Education Scientific Disciplines.” VR technology first appeared in science education research in 2002, with publications steadily increasing over time. The most prolific and influential researchers were Lamb, Richard, and Etopio, Elisabeth, while the United States, Australia, and Türkiye had the highest academic impact. The most frequently used keywords were “virtual reality,” “science education,” “augmented reality,” and “higher education,” while recurring abstract terms included “technology,” “knowledge,” and “research.” These results underscore the rising importance of VR technologies in science education and map the evolving research landscape, offering valuable insights for future studies and educational practices.

Introduction

Digitalization, together with rapid developments in information and communication technologies, leads to radical transformations in many areas of life. In particular, basic social areas such as communication, economy, and education have experienced significant changes under the influence of digital technologies. The replacement of traditional work and life practices with digital processes has profoundly transformed the ways in which individuals access information and interact with it. Digitalization not only changes economic and social structures but also redefines individuals' lifestyles and learning habits. Thanks to the opportunities offered by technologies, individuals and organizations can share information much faster and more efficiently and time and space limitations are largely eliminated (Castells, 2010). While Castells (2010) defines digitalization as the basic building block of the information society, Negroponte (1995) describes it as the transition from the physical world to the virtual world, and underlines that this transition has profound effects on individuals and social structures.

Education has become one of the sectors most affected by digitalization. The education technology market, which is growing every year, clearly reveals the extent of this transformation. It has been reported that by 2023, the size of the global edtech sector will exceed 250 billion dollars (HolonIQ, 2023). This trend is also supported by the fact that the number of users of online education platforms is increasing by 20% annually. In Türkiye, data from the Ministry of National Education (MoNE) for 2022 shows that the EBA platform was used by more than 20 million people. Data such as these confirm that digitalization has led to radical changes in the field of education, while also revealing its contributions to educational processes. Digital education technologies transform learning and teaching approaches into a more effective, flexible, and interactive structure. Traditional classroom practices are being replaced by online platforms, simulation-based teaching techniques, and individualized learning methods (Doğan et al., 2024). This transformation enables students to access information more quickly, while teachers can monitor student performance more efficiently (Means et al., 2009). Moreover, digitalization provides teachers with the opportunity to implement a more student-centered and interactive teaching methodology. Additionally, students can advance at their own pace using digital resources, surpassing traditional classroom boundaries (Ozdemir et al., 2017). Another significant benefit of digitalization is its ability to foster the development of collaborative learning environments. According to Siemens (2005), digital technologies empower individuals to engage in in-depth and meaningful learning experiences by providing easier access to diverse sources of information. This shift transforms learning from a solitary activity into a collaborative community experience.

One of the most notable innovations in digital education is the adoption of VR technologies. VR enables users to experience realistic scenarios by immersing themselves in computer-supported three-dimensional environments (Dalgarno & Lee, 2010). This technology has enhanced educational experience by offering an interactive and dynamic learning process. VR applications, particularly those that simplify the understanding of abstract concepts, open new horizons in education. They allow students to engage in experiences that would be challenging or impossible to achieve in a physical environment (Merchant et al., 2014). The ability of VR to support immersive learning experiences can be used to demonstrate this argument. In history classrooms, for example, students can use VR to tour ancient cities; in chemistry classes, they can safely conduct dangerous experiments; and in astronomy classes, they can conduct in-depth analyses of the solar system (Aktamış & Arıcı, 2013; Dikyol & Isbilen, 2020; Kahveci & Sondas, 2023).

Science education, being a field that deals intensively with complex and abstract concepts, has significant potential to create a strong synergy with VR technologies. In the field of chemistry, the utilisation of three-dimensional visualisations of molecular structures or the employment of virtual environments to simulate chemical reactions has been demonstrated to facilitate students' comprehension of abstract concepts (Avcı & Taşdemir, 2019). In the context of physics courses, these technologies facilitate the experiential learning of fundamental principles, such as Newton's laws of motion, within a virtual laboratory environment (Karakaş & Ozerbas, 2020). In the field of biology, the potential for VR to facilitate detailed examination of complex biological systems, such as cellular structures and human anatomy, has been demonstrated (Azmanoglu & Topal, 2024). This technological advancement has the capacity to enhance students' understanding of these subjects. In the domain of astronomy education, the utilisation of VR applications facilitates spatial exploration of the solar system and galaxies through the medium of virtual planet simulations (Cankaya & Girgin, 2018). It is submitted that such virtual experiences make a unique contribution to science education by allowing students to experience scenarios that are not possible in the real world. These technologies have been shown to facilitate the comprehension and experience of abstract scientific concepts among students (Aktamış & Arıcı, 2013; Merchant et al., 2014). For instance, the visualisation of chemical reactions at the molecular level or the in-depth study of cell structures are some of the unique learning opportunities that can be offered in VR environments. Furthermore, VR applications offer a particularly valuable solution for schools with limited laboratory facilities. As posited by Rutten et al. (2012), experiments that may pose a threat to the health and safety of subjects, or that require a significant financial investment in real laboratory conditions, can be conducted safely and cost-effectively in a virtual environment. Consequently, student motivation is enhanced and the development of scientific process skills is accelerated. A further significant rationale for the accelerated propagation of these technologies within the domain of science education is that they facilitate a more dynamic and interactive engagement with scientific concepts among students. Interactive and visual learning environments have been shown to facilitate the retention of scientific knowledge by promoting meaningful and in-depth learning. Research has indicated that such applications contribute to students' enhanced comprehension of scientific processes and refinement of their cognitive abilities (Jensen & Konradsen, 2018).

VR in the Context of Türkiye

In recent years, there has been a notable surge in scholarly interest in the utilization of VR technologies within the domain of science education. A plethora of studies have indicated that the utilization of VR in the domain of science education has the potential to facilitate students' conceptual understanding, enhance their scientific process skills, and augment their motivation for learning, thereby contributing to an improvement in their academic achievement (Aktı Aslan, 2019; Bilen & Zor, 2024; Küçükşavcı, 2017; Makransky & Lilleholt, 2018; Merchant et al., 2014). In scientific disciplines such as chemistry, biology and physics, VR has been shown to be an effective tool in making abstract concepts more understandable (Aktamış & Arıcı, 2013; Boz, 2019; Yagcı & Şentürk, 2023). Significant research has been conducted on the use of VR in science education in the Turkish context. For instance, in the study conducted by Aktamış and Arıcı (2013), it was emphasized that VR applications are not only an effective method in increasing students' academic achievement in astronomy courses, but also in ensuring the retention of learned information. A study undertaken by Cankaya (2019) concluded that the integration of augmented reality applications, incorporating virtual elements, into secondary school science courses was associated with enhanced student achievement and motivation. Demir (2019) conducted a study to ascertain the attitudes of pre-service teachers towards VR technologies, revealing that VR technology can be considered an effective method to increase the interest and motivation levels of pre-service teachers towards their courses. The study also expressed the importance of integrating these technologies into teacher education programmes. The findings of this study demonstrate that VR can serve as an effective educational tool in the domain of science, contributing to both the instruction and the learning processes. Furthermore, it has been demonstrated that VR applications have a beneficial impact on science education processes in general (Jensen & Konradsen, 2018).

When literature is examined, there are also studies that systematically compile and review the use of VR technology in education. A bibliometric analysis of 307 postgraduate theses conducted in Türkiye between 1996 and 2020 was the basis of a recent study which found that VR and augmented reality topics have become increasingly prominent in postgraduate thesis studies in Türkiye in recent years (Gsnan, 2022). In their methodological analysis of studies on the applications of virtual and augmented reality technologies in the field of education in Türkiye Kapucu and Yıldırım (2019) sought to address this paucity of research. The research findings revealed that these studies largely focus on the discipline of computer education and have shown especially a significant increase in recent years. The investigation revealed a predominance of qualitative research approaches, with student groups being examined and techniques such as scales and t-tests being extensively utilised in the analysis processes. The findings of these studies generally took the form of descriptive results and frequently included various suggestions for future research. It is also stated that there is a more intense interest in studies on the integration of augmented reality into education. Turgut and Denizalp's (2021) study constitutes a comprehensive examination of the trends in research on VR technologies in the field of education in Türkiye. The findings revealed that studies on the use of VR have shown a significant increase, especially in recent years, and that ready-made content is generally preferred. A review of the extant literature reveals a preponderance of quantitative methodologies, with a judicious selection of samples for the purpose of study and the utilization of questionnaires and interview forms as the primary data collection instruments. Furthermore, it was observed that predominantly predictive statistical techniques were utilised in data analysis processes.

Systematic review methods, including meta-analysis, bibliometric analysis, and content analysis, are imperative tools for the analysis of research trends within a specific field, the meticulous examination of data, and the interpretation of results within a broader context. These methods play a crucial role in measuring and evaluating the efficiency of research techniques used in disciplines such as education and science (Borenstein et al., 2009; Krippendorff, 2018; Moed, 2005). A review of the extant literature reveals a paucity of studies that systematically examine VR in the field of education. This phenomenon is particularly pronounced in the context of science education, where the subject is addressed, resulting in a notable escalation in the perceived limitations within the relevant domain.

Purpose of the Study

The aim of this study is to determine the research trends by examining the scientific studies on VR in science education, based on the Web of Science (WoS) database. To this end, answers to the following sub-questions will be sought:

1. Which categories do studies on VR fall into?
2. How do research trends change over the years?
3. What is the distribution of prominent researchers and their publication profiles?
4. What are the most cited researchers and their citation distribution?
5. What is the structure of the analysis of bibliographic matches of the studies?
6. What are the trends of the countries that stand out according to the number of citations?
7. What are the trends of the most commonly used keywords in studies?
8. What is the structure of the conceptual network formed by the most commonly used words in article abstracts?

In line with these questions, scientific productivity, interaction networks and conceptual trends in the field will be analyzed in detail.

Importance of the Study

In recent years, there has been a noticeable increase in the number of academic studies on VR applications in science education. This increase is closely related to the growing recognition of the innovative and effective possibilities offered by VR technology in education. Especially in science education, VR applications, which facilitate the understanding of abstract concepts, enrich educational processes by providing students with active learning opportunities. This is frequently emphasized in the literature (Aktamis & Arıcı, 2013; Makransky & Lilleholt, 2018; Merchant et al., 2014). However, there is a significant gap in literature regarding a comprehensive review of academic studies on this subject. Considering the rapid advances in technology and transformations in educational approaches, there is an ongoing need to systematically evaluate more recent academic studies. In this context, the bibliometric analysis method stands out as a powerful tool for revealing trends in VR applications in science education, identifying existing research gaps, and analyzing scientific studies produced in this field (Moed, 2005; Yılmaz, 2021).

Studies show that significant improvements are achieved in student achievement, motivation and conceptual understanding levels in VR supported science education (Aktamıs & Arıcı, 2013; Aktı Aslan, 2019; Bilen & Zor, 2024; Kucuk- Avcı, 2017; Makransky & Lilleholt, 2018; Merchant et al.) However, the limited number of systematic reviews of these studies creates an important gap in literature. This deficiency makes it difficult to reveal the effects of rapidly developing technological innovations and changing educational approaches on science education. For example, Makransky and Lilleholt (2018) state that technological advances constantly offer new opportunities in education and that these innovations should be analyzed in depth in literature. Similarly, in Türkiye, it can be said that this situation limits scientific awareness in the field. In this context, the need for more up-to-date and systematic bibliometric analysis studies is evident (Irwanto et al., 2022). This study aims to reveal, by examining the existing literature in detail, how VR technologies are applied in science teaching and research trends in this field in line with current data. By addressing dynamic research trends and emerging themes, this bibliometric analysis aims to provide a comprehensive roadmap for researchers and educators. In addition, the main goal of the study is to evaluate the developments in the local context and to reveal new research opportunities in this field, with a special emphasis on VR-oriented studies in science education in Türkiye.

Method

In this research, the method of bibliometric analysis, which is defined as an attempt to manage big information through conceptualization that shows the trends and structural composition of scientific research in a field (Passas, 2024), was used, analyzed, and evaluated with VOSviewer visualization software. VOSviewer is defined as software that can create bibliometric maps by establishing network connections between items such as scientific publications, researchers, and keywords; analyze the relationships between them; and present these maps with network, layer, and density visualizations (Van Eck & Waltman, 2023; Zhang et al., 2023). By using this software, the aim is to obtain detailed profiles of research on VR technology until 2025 and thus guide future research trends in the related field.

Obtaining and Analyzing Data

The Web of Science (WoS) database, which includes three major citation indexing databases SCI, SSCI, and A&HCI, is a widely used source of scientific evidence in different disciplines (Jia & Mustafa, 2023; Sarkar et al., 2022). It also holds an important place as the first bibliographic database (Pranckute, 2021). For this reason, the WoS database was preferred in the study to create the dataset within the scope of the research. Web of Science was accessed on 06.02.2025 from the university database, to which the researcher was affiliated, and the framework was created using the contents as criteria within this context.

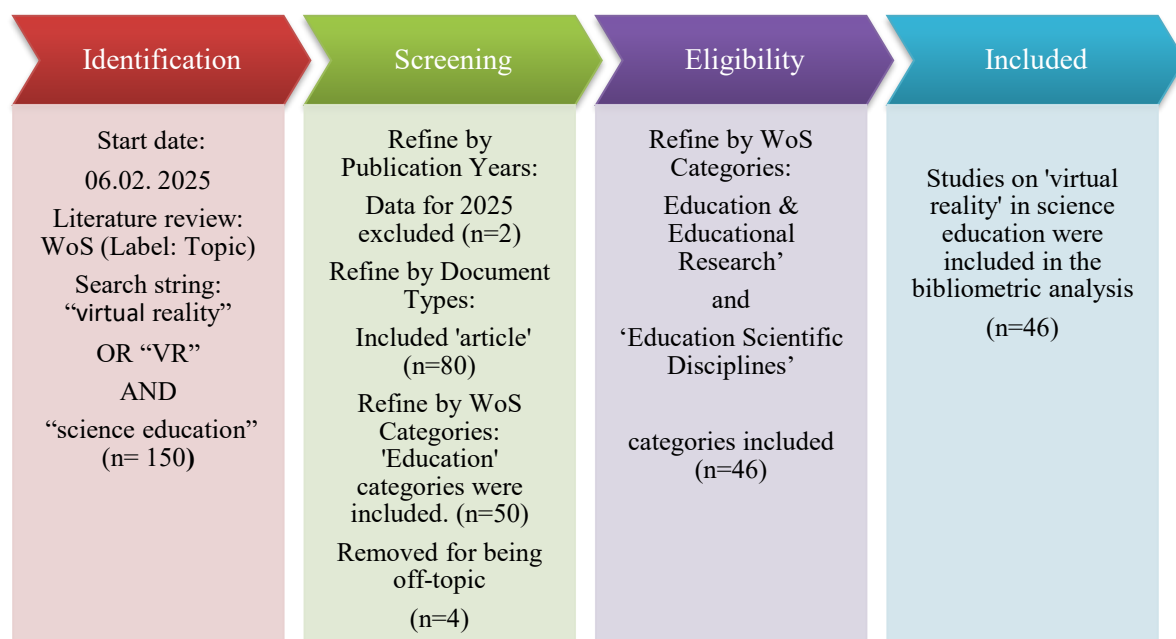


Figure 1. Flowchart followed in the creation of the dataset

In the WoS database, 150 studies were reached with the keywords “virtual reality” or “VR” and “science education” under the title of “topic”. Considering that the data flow for 2025 continues, the aim was to examine the studies until December 2024, and to determine the trend dynamics. In this context, 148 studies were identified. In the next stage, only the studies in the article type were included (n=80). The categories of ‘Education & Educational Research’ and ‘Education Scientific Disciplines’ in the WoS database were selected (n=50). The articles that were out of the subject were removed (n=4). As a result, a total of 46 articles were identified and analyzed. The process followed in obtaining the dataset of the study is presented in Figure 1, which includes the PRISMA flow diagram (Moher et al., 2009).

Results

Breakdown of the Top Ten WoS Categories of VR Technology Applications

Although the categories 'Education & Educational Research' and 'Education Scientific Disciplines' were included in the scope of the research, it was considered to examine the categories that include VR technology from a holistic perspective. In this context, when the WoS database is examined, VR applications are found to be included in 41 categories in total. The distribution of the first ten categories is given in Figure 2. When the results obtained are analyzed, VR applications are mostly categorized under the category of 'Education Educational Research' (f=45).

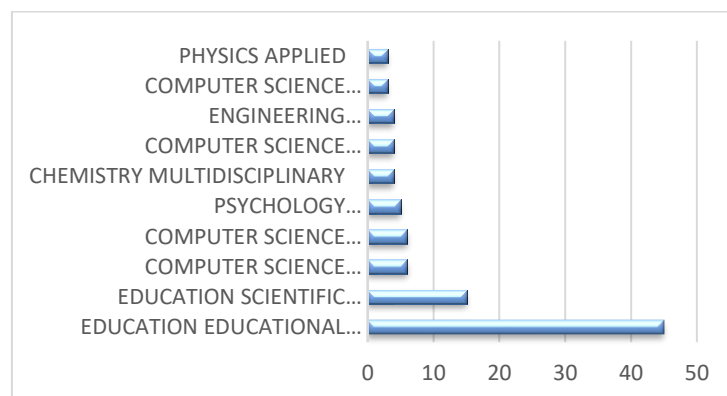


Figure 2. Breakdown of the top ten WoS categories of VR technology applications

Changes in Research Trends by Year

According to the results provided by the WoS database, the changes in VR technology applications in science education over the years appear in Figure 3. When the data in Figure 3 are analyzed, it is seen that VR technology in science education has been included in the studies since 2002. According to the results obtained, the trend shows that studies on VR technology increased with each passing year.

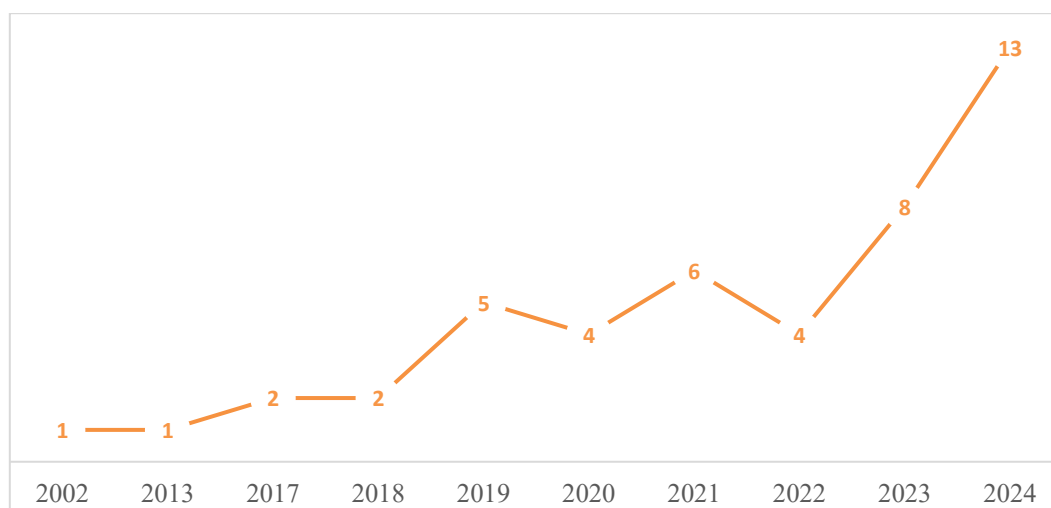


Figure 3. Changes in VR technology applications over the years

Featured Researchers and Publication Profiles

According to the WoS database results, the total number of researchers working on VR technology in the field of science education was determined to be 145. The top ten researchers and their publication profiles are given in Figure 4. The researcher who conducted the most academic studies on VR technology in science education was Lamb, Richard ($f=4$), followed by Etopio, Elisabeth ($f=3$).

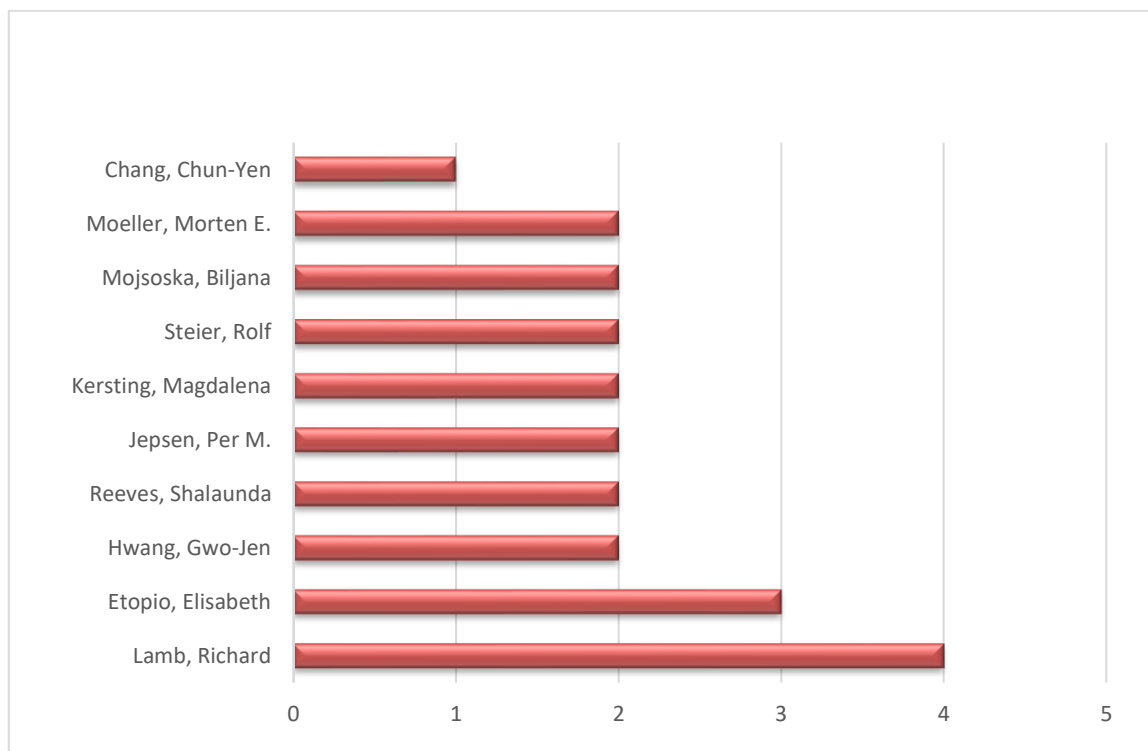


Figure 4. Featured researchers and publication profiles

Most Cited Researchers and Citation Distribution

In order to identify the most cited authors and the network interaction between them, at least two publications and at least two citation criteria were used. The findings obtained as a result of the VOSviewer analysis are presented in Table 1 and Figure 5.

Table 1. Most cited researchers and citation distribution

Author	NoD	NoC
Lamb, Richard	4	127
Etopio, Elisabeth	3	100
Jepsen, Per Meyer	2	26
Mojsoska, Biljana	2	26
Pande, Prajakt	2	26
Crippen, Kent J.	2	26
Reeves, Shalaunda M.	2	26
Kersting, Magdalena	2	25
Steier, Rolf	2	25
Hwang, Gwo-Jen	2	8

Note. NoD: Number of Documents, NoC: Number of Citations

The results of the analysis show that the most cited authors are Lamb, Richard and Etopio, Elisabeth. It is seen that these most cited authors are included in the citation network with Jepsen, Per Meyer, Mojsoska, Biljana and Pande, Prajakt.

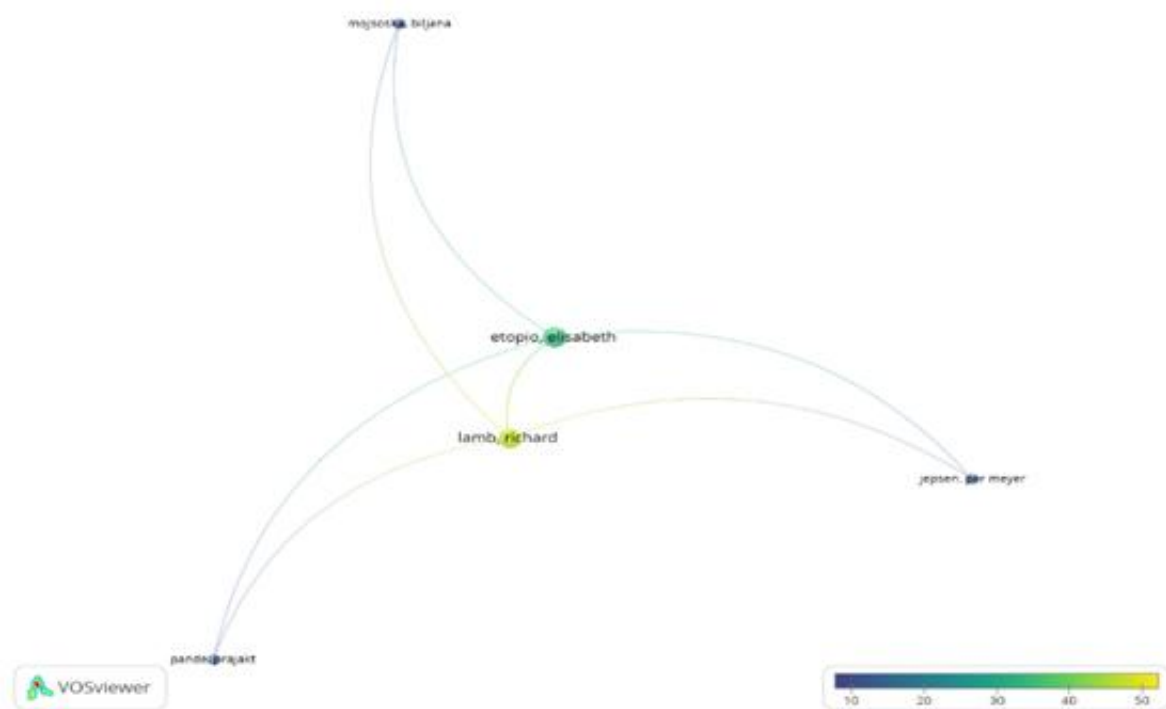


Figure 5. Most cited researchers and citation distribution

Analysis of Bibliographic Matches of Studies

An analysis was conducted to determine the bibliographic matches of the studies on VR in science education. The results of the analysis, made with the criterion of publishing at least 1 work and receiving 5 citations to determine the map of citations to a common work cited by two independent sources are given in Figure 6.

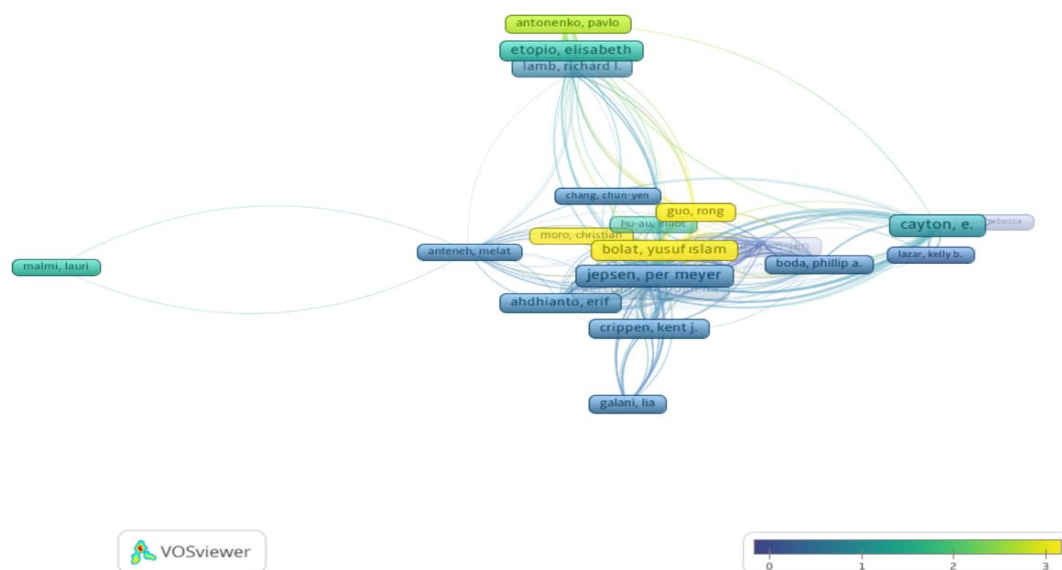


Figure 6. Bibliographic matching of studies on VR in science education

The authors with the highest number of bibliographic matches are Etopio, Elisabeth (100 citations and 685 total link strength), and Lamb, Richard (92 citations and 395 total link strength). On the other hand, other noteworthy names in the bibliographic match map are Jepsen, per Meyer (26 citations, 735 total link strength) and Bolat, Yusuf Islam (77 citations and 566 total link strength).

Prominent Countries by Citation Count

In order to identify the prominent countries according to the number of citations, fifteen countries and a total of 54 publications were identified based on analysis using the criterion that a country has received at least one citation. The profile of the first ten countries that stand out from these results is presented in Table 2 and Figure 7.

Table 2. Prominent countries by citation count

Country	NoD	NoC	TLS
USA	22	284	7
Australia	3	110	6
Türkiye	5	109	0
Peoples rChina	3	86	4
Taiwan	7	48	3
South Korea	2	39	2
Finland	1	34	0
Denmark	3	32	4
Norway	2	25	3
Chile	1	22	5

Note. NoD: Number of Documents, NoC: Number of Citations, TLS: Total Link Strenght

The most cited countries are the United States (USA), Australia, and Türkiye, respectively. Although Türkiye ranks third among the most cited countries, it is not reflected in the VOSviewer analysis result in Table 2 because of lack of total link strength.

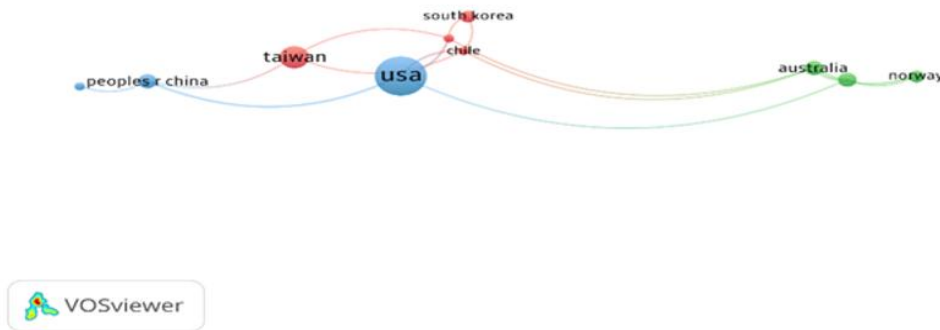


Figure 7. Prominent countries by citation count

Trends of the Most Commonly Used Keywords in Research

The results of the analysis conducted to identify the most used and recently prominent keywords within the scope of VR technology in the field of science education are presented in detail in Table 3 and Figure 8.

Table 3. Trends of the most commonly used keywords

Keyword	<i>f</i>
Virtual reality	31
Science education	19
Augmented realty	5
Higher education	4
Extended realty	3
Engagement	2
Astronomy education	2
Immersive learning	2
Teacher preparation	2
Gender	2

Note. *f*: Frequency

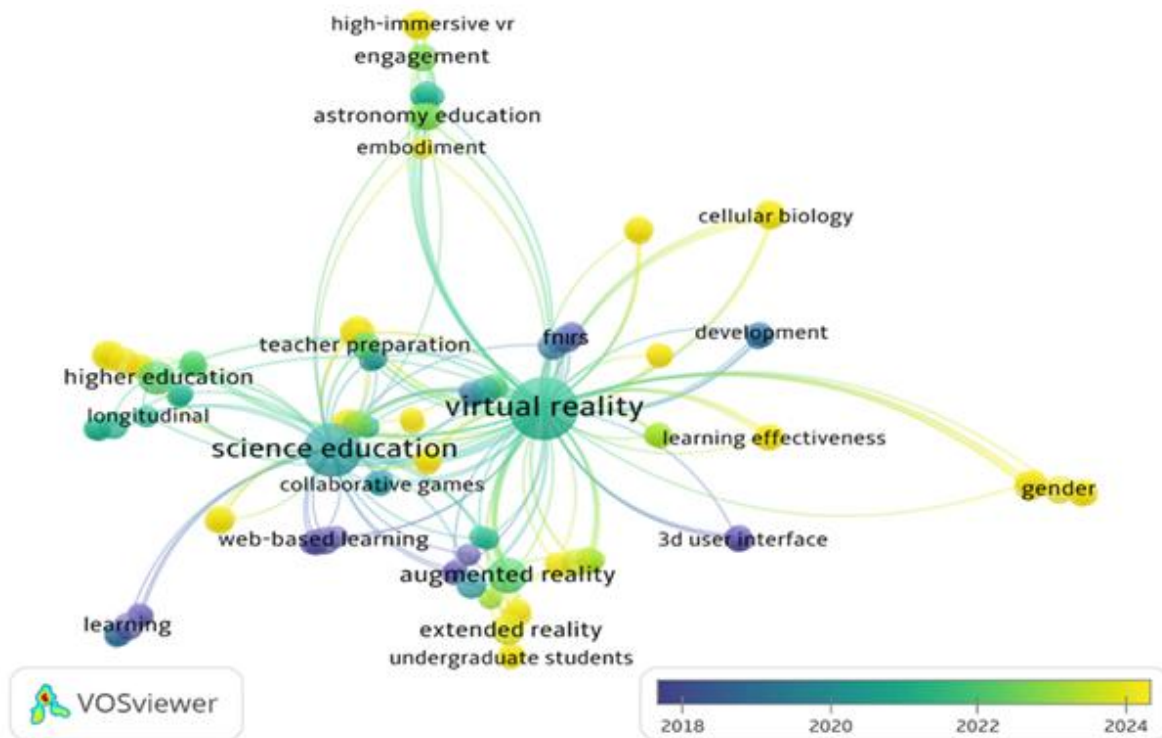


Figure 8. Trends of the most used keywords

According to Table 3, the most frequently used keywords are 'virtual reality', 'science education', 'augmented reality', and 'higher education'. In recent years, the concepts of 'extended reality', 'undergraduate students', 'gamified VR', 'cellular biology', 'education technology', 'high-immersive VR', 'self-study', 'constructivism', 'gender', 'virtual laboratory', 'experiential learning', were also found to be the subject of studies with virtual reality.

Conceptual Network Structure of the Most Commonly Used Words in Article Abstracts

'Abstract field' was selected and analyzed by determining the frequency of repetition of terms that were repeated at least five times. 1464 terms were identified, and 42 terms were found to meet the criteria. The results of the analysis are presented in Table 4 and Figure 9.

Table 4. Conceptual network structure of the most commonly used words in abstracts

Words in Abstracts	<i>f</i>
Technology	22
Knowledge	17
Research	17
Application	13
Difference	12
Analysis	12
Science	10
Data	9
Participant	9
Impact	9
Way	9
System	8
Ability	8
Framework	7
Role	7
Attention	6
VR environment	6

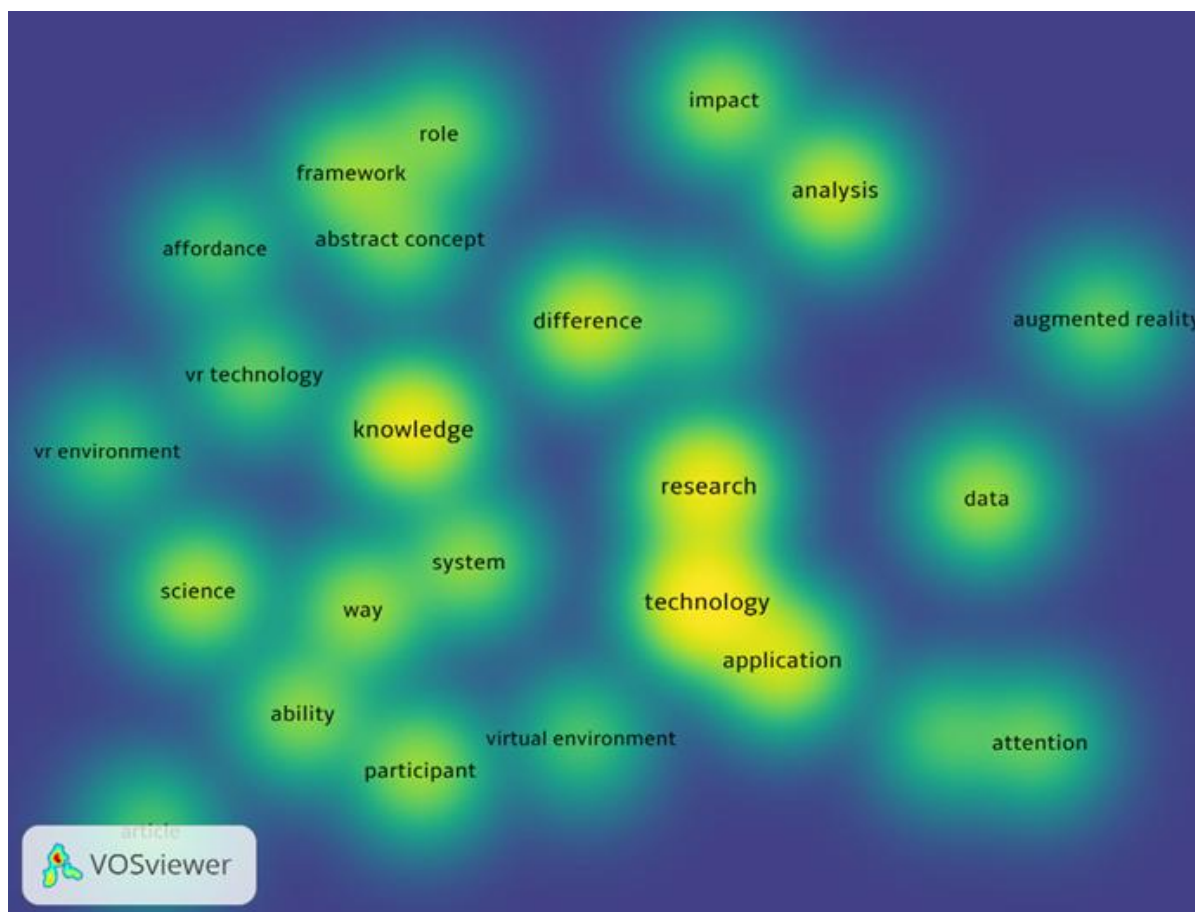


Figure 9. Conceptual network structure of the most commonly used words in abstracts

According to the results of the analysis, the most frequently used words in abstracts are 'technology', 'knowledge' and 'research'. In the VOSviewer analysis, the 'overlay visualization' method shows that the terms 'application', 'framework', 'ability', and 'impact' stand out among the words that frequently appear in research abstracts in recent years.

Conclusion and Discussion

By reviewing scientific literature on VR in science education using the Web of Science (WoS) database, this study seeks to detect research trends in the field. The data demonstrated that VR applications were dispersed across 41 distinct categories. "Education Scientific Disciplines" and "Education Educational Research" are notable names among these categories. According to this study, VR technology is becoming more and more popular in the field of education and is crucial to educational research (Dede, 2009; Merchant et al., 2014). Applications that utilize VR are mostly focused on educational and educational research, according to a number of bibliometric evaluations. For instance, a bibliometric study of graduate theses in Türkiye on augmented reality and VR revealed that these subjects have grown in popularity recently and are primarily focused on teaching (Guncan, 2022). Additionally, a different bibliometric analysis of the idea of the Metaverse in education revealed that the majority of the research on this subject is focused on education and related fields (Karakus & Seckin, 2024).

According to the study's results, VR technology has been the subject of scientific education research since 2002, and the amount of research in this area continues to increase over time. Since the early 2000s, VR technology has been more popular and available in educational settings thanks to improvements in computer hardware and a decline in the cost of VR systems (Kahveci & Sondas, 2023). Applications like augmented reality have made it possible to concretize abstract notions in science education through interactive learning environments, which are a result of the growing significance of the constructivist learning method (Aktamis & Arıcı, 2013; Cavas et al., 2004; Dede, 2009). Meanwhile, academics are focusing more closely on STEM education and using VR technology in the classroom because of the growing interest in this area (Merchant et al., 2014). Furthermore, research on VR-based education has significantly increased because of funding in the US, Europe, and Asia

(Radianti et al., 2020). By giving students, the chance to experience intricate processes in a risk-free setting, VR applications enhance experiential learning and support science education in this regard (Aktamıs & Arıcı, 2013; Makransky & Lilleholt, 2018).

Based on the study's findings, there were 145 researchers who studied VR technology in scientific education in total. The scholars with the greatest number of studies, citations, and bibliographic matches were found to be Richard Lamb and Elisabeth Etopio. This demonstrates their proficiency in the area and the significance of the work they have done in exposing the possibilities of VR technology in science instruction. It demonstrates that both researchers have a significant academic impact on their disciplines and that other academics regularly cite their work. In their joint research, Lamb and Etopio thoroughly investigated the usefulness of VR applications in science education as well as their impact on students' acquisition of scientific ideas and scientific writing techniques (Lamb et al., 2019). They underlined that pre-service science teachers can effectively apply their theoretical knowledge through VR (Lamb & Etopio, 2020).

Lamb and Etopio are in the same citation network as Jepsen, Per Meyer, Mojsoska Biljana, and Pande Prajakt, according to another significant finding. Yusuf Islam, Per Meyer and Bolat, and Jepsen are further noteworthy names in the bibliographic matching map, following Lamb and Etopio. An essential method for observing the concentration and interplay of knowledge in an area is the mapping of academic networks (Gonzales-Aguliar et al., 2023). This suggests that these authors work together academically, either directly or indirectly, or that they study related topics. Furthermore, the names that are garnering interest in the citation network may be used as a possible point of reference to direct further research. Researchers can better observe current trends in literature and formulate their own research questions within this framework by looking at the works of these authors. In addition to helping detect research gaps and scientific production, these citation network analyses are a valuable tool for determining which themes are prevalent in the academic area and which scholars concentrate on these subjects (Moed, 2005).

The analysis's findings indicate that, based on the quantity of citations, the United States, Australia, and Türkiye stand out. Large-scale research initiatives and significant resources in VR technologies have made the US a leader in this field. Prior study indicates that the United States is a global leader in VR applications and technology-oriented educational research (Mikropoulos & Natsiz, 2011; Slater & Wilbur, 1997). By using VR in the classroom, Australian institutions are also contributing significantly to the creation of visual and interactive learning experiences (Johnson et al., 2015). This is arguably one of the primary causes of the nation's rising citation count. Citations have increased considerably in Türkiye in recent years, primarily as a result of the incorporation of technology into science instruction. Innovative technologies like VR and their application in education are attracting more and more attention from academics in Türkiye (Muz & Yuce, 2023). Nevertheless, Türkiye's low link strength in the VOSviewer study suggests that there are few all over the world collaborations and that studies mostly have a local or regional impact, even with the high number of citations. This implies that in order to make a greater global contribution to the scholarly literature on VR and scientific education, Türkiye needs to expand its partnerships.

VR and augmented reality technologies have found many applications in the field of science education, and there is an increasing interest in their use, particularly at the higher education level (Mikropoulos & Natsis, 2011). The study's findings indicate that the studies on the use of VR technology in science education are focused around the themes of "virtual reality" and "science education." Other prominent keywords in the literature involve "augmented reality" and "higher education". Alongside these themes, phrases like "gamified VR," "extended reality," and "high-immersive VR" have started to appear in recent years, referring to emerging technologies that further broaden the use of VR in education. This result demonstrates interest in research on gamified and interactive technology applications. Research on "gamified VR" applications in particular highlights how these technologies affect students' academic performance, motivation, and engagement. Research in this area indicates that gamification techniques based on VR can significantly alter the way that lessons are taught (Bouchrika et al., 2019; Lampropoulos & Kinshuk, 2024). The applications of VR technologies to provide concrete form to abstract and complicated subjects like "cellular biology" is another significant scientific area. This highlights how VR technology can help students learn by bringing complicated scientific ideas to life (Dede, 2009). Students can also gain theoretical information through real-world applications in virtual environments thanks to ideas like "virtual laboratory" and "experiential learning". Especially in experimental and practice-based fields such as science, interactive learning tools are known to help students better comprehend the subject matter (Bogusevski et al., 2020). Other remarkable methods in VR-based education are "self-study" and "constructivism." According to constructivist learning techniques, this research demonstrates that VR technology may support individual learning processes (Aktamıs & Arıcı, 2013; Sarioglu, 2019). Specifically, ideas like "high-immersive VR" and "extended reality" (XR) enable students to learn more deeply by simulating real-world interactions. Research in this context

reveals that these technologies have a significant impact on both individual and group learning processes in education (Cheng & Tsai, 2020; Dalgarno & Lee, 2010). Simultaneously, the association of the concept of "gender", a social phenomenon, with the utilisation of VR applications in educational contexts can be regarded as a methodology for the examination of the impact of gender disparities on VR-based applications and educational learning processes (Basaran, 2010; Cakır et al., 2022; Tuzun et al., 2016). In this context, this association can provide a novel research domain for the comprehension and analysis of gender inequalities in the application of educational technologies. In accordance with the findings obtained, it was determined that the keywords frequently encountered in the abstracts of the studies on VR technology in science education were "technology", "knowledge" and "research". This situation suggests that there is an increasing interest in integrating VR technologies into teaching processes in the field of science education. Research into understanding the impact of these technologies on knowledge acquisition and learning processes is gaining momentum (Mikropoulos & Natsis, 2011). Furthermore, the "overlay visualization" method employed in the VOSviewer analysis reveals a notable increase in the utilization of terms such as "application", "framework", "ability" and "impact" in abstracts over recent years. "Overlay visualization" is a visualization method that facilitates the tracking of conceptual changes and developments in a particular research area by means of analysing the usage trends of certain terms over time (Van Eck & Waltman, 2010). This finding can be considered an indicator of a growing academic interest in the potential of VR applications in education, with a particular focus on implementation processes, methodological configurations, and strategies, and impact analysis (Bailenson, 2018; Lampropoulos & Kinshuk, 2024; Ozeren et al., 2021). The term "impact" has seen a surge in interest, particularly in research examining the impact of VR applications on student achievement and learning processes (Aktamıs & Arıcı, 2013; Ceylan & Kalaycı, 2024; Dikmen & Bahadır, 2021). When synthesised, these findings indicate an ongoing intensive research effort to enhance the efficacy of VR applications in science education and to facilitate their integration into educational processes.

Recommendations

In consideration of the constraints imposed by the current study, the following recommendations for subsequent research are proposed, drawing upon the findings obtained. The present study is constrained in its scope to the utilisation of VR technology in the domain of science education, as evidenced by the utilisation of scientific publications that have been indexed in the WoS database. While WoS incorporates prominent citation indexing databases such as SCI, SSCI, and A&HCI, it would be advantageous to investigate studies from additional major databases, including ERIC, Google Scholar, and SCOPUS. Furthermore, the evaluation of research conducted in Türkiye would contribute to a more comprehensive understanding of the country's potential in this field.

In order to enhance the effective use of VR technology in the sphere of science education, it is recommended that future research encourage interdisciplinary collaborations and conduct in-depth examinations of the long-term effects of VR applications. Concurrently, the formulation of strategies aimed at enhancing accessibility and inclusivity is poised to assume a pivotal role in addressing the multifaceted learning requirements of diverse groups. Concrete, data-driven studies exploring the integration of VR technology into the differentiated instruction approach embraced by current curricula could provide valuable insights. The execution of such research would facilitate the identification of methodologies for the utilisation of VR in the pedagogy of scientific subjects, the enhancement of educational processes, classroom interactions, and the promotion of students' active participation in a more efficacious manner. Furthermore, studies focusing on advanced applications, such as the "gamification of VR" and "extended reality," could create important opportunities for the enhancement of interactive and immersive learning experiences.

In this context, the establishment of professional development programmes for educators would be essential to enable the effective use of VR technology. These programs should offer both theoretical and practical content, equipping teachers to integrate VR's interactive, experiential learning opportunities into their curricula. Furthermore, the establishment of VR laboratories within educational institutions, the enhancement of accessibility, and the implementation of sustainable support mechanisms for technological infrastructure would substantially augment students' experiential learning processes.

From a policymaking perspective, the augmentation of financial resources to facilitate the development of VR-based content, in conjunction with the promotion of international collaborative initiatives, has the potential to enhance the global impact of research outcomes, particularly in nations such as Türkiye, which demonstrate considerable promise in the domain of VR research. Given Türkiye's strong position in the international academic literature, strategic support for VR-based educational projects could provide a competitive advantage on a global scale. The development of teaching materials tailored to the local context, aligned with cultural and pedagogical

needs, has the potential to expand the reach of VR technology to a broader student population and to promote greater educational inclusivity.

In conclusion, the effective integration of VR technology within the domain of science education is contingent upon the establishment of a robust and concerted collaborative network encompassing educators, policymakers, and researchers. The recommendations presented herein offer a comprehensive and strategic roadmap for stakeholders, guiding the more effective implementation of VR technologies in science education practices.

Scientific Ethics Declaration

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

Conflict of Interest

* The authors declare that they have no conflicts of interest.

Funding Declaration

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Author Information

Aysun Tekindur

Ministry of National Education, Türkiye
Konya, Türkiye
ORCID iD: <https://orcid.org/0000-0002-8260-788X>

Serpil Kara

Necmettin Erbakan University
A. K. Education Faculty, Department of Science
Education, Konya, Türkiye
Contact e-mail: serpilkara@erbakan.edu.tr
ORCID iD: <https://orcid.org/0000-0002-0482-7617>

The Effectiveness of Science Course Prepared According to Systematic Planning Model with ICT Integration: A Mixed Method Research

Mustafa Ok, Fusun Gulderen Alacapinar

Article Info	Abstract
Article History Published: 01 July 2025 Received: 10 March 2025 Accepted: 27 June 2025 Keywords Information and communication technologies, Systematic planning model, Augmented reality, Science education	This study examined the impact of the 'Systematic Planning Model', an ICT integration model, on student achievement and perceptions in a 4th-grade primary school science course. The research aimed to determine whether there were significant differences in the achievement and retention scores between an experimental group, where a curriculum based on this model was implemented, and a control group, where it was not. Additionally, students' views on the model were explored. Using an explanatory mixed-method design, the study involved 45 students from a private school in Konya during the 2022–2023 academic year. Data were collected through an achievement test (reliability: 0.896) focused on the unit “Lighting and Sound Technologies from Past to Present” and semi-structured interviews. The findings revealed statistically significant improvements in the achievement and retention scores of the experimental group, while no significant changes were found in the control group's scores. Qualitative results showed that students responded positively to the model, particularly appreciating the use of technology and interactive activities. They described the lessons as enjoyable and educational. Furthermore, many students suggested that similar technology-supported activities be implemented in other subjects, underlining the effectiveness of engaging, tech-integrated learning environments.

Introduction

Technology has become an integral part of education today because it supports learning and teaching processes and enables faster and more permanent acquisition of knowledge. The intertwining of individuals are intertwined with technology in every field, especially, has contributed to the permanent place of technology in the teaching process (Cesur- Ozkara et al., 2018). Rapid developments in technology have led to radical changes in the field of education and transformed traditional learning methods. Technology integration in education is used as an important strategy to support modern learning approaches and prepare students for the needs of the future (Alan & Kirbag- Zengin, 2023; Koyuncuoglu, 2021). This integration aims to provide students with the skills required by the modern age by incorporating technological tools and resources into the learning process (Aslyuksek et al., 2023). Thus, traditional classrooms can turn into more interactive and enriched learning environments. Learning can be made more meaningful and interesting with tools such as digital platforms, applications, simulations, virtual reality, and artificial intelligence.

Technology integration generally refers to the incorporation of information and communication technologies (ICT) into educational processes. In this context, emphasis is placed on the technological tools used to enhance students' learning experiences. important for the instructor to use technology effectively and to integrate technology into the curriculum in a holistic manner (Mazman & Kocak -Usluel, 2011). In these definitions, it is emphasized that the use of ICT will lead to permanent and sustainable changes that will enable the achievement of teaching goals (Belland, 2009; Hew & Brush, 2007; Lim, 2007; Vanderlinde & Van Braak, 2010; Wang & Woo, 2007). Today, science education, especially at the primary school level, aims to raise individuals who have the skills required by the age, adopt lifelong learning, use higher-order thinking and scientific process skills, have ethical and moral values, are entrepreneurial, and have achieved career awareness in science (MoNE, 2024). This goal necessitates the use of contemporary and innovative approaches in science teaching (Senturk, 2017).

Science is one of the most comprehensive disciplines that tries to explain everything that exists, arouses curiosity, and makes life easier with the solutions it offers (Obalı, 2009). Science education is a field that aims to understand and explore fundamental aspects of nature and the environment. This teaching aims to provide students with scientific thinking skills and enable them to use these skills in their daily lives. Science teaching, which includes disciplines such as biology, physics, chemistry, and astronomy, teaches scientific methods such as experimenting,

observing, hypothesizing, and analyzing results (Tan & Temiz, 2003).

Science teaching can be enriched with interactive methods such as experiments, simulations, group work, project-based learning, and field studies. Thanks to technological developments, digital tools and artificial intelligence applications can also be integrated into teaching. In this process, students acquire basic skills such as critical thinking, problem solving, communication and collaboration, as well as scientific knowledge (Bakırcı & Kutlu, 2018). In this way, they are supported to grow up as individuals who not only consume knowledge but also produce it. The main purpose of science teaching is to enable students to better understand their environment and the events taking place in the universe (Güven- Yıldırım & Koklukaya, 2016). By stimulating their sense of curiosity, students are encouraged to develop an interest in science-related subjects. In this way, students gain a scientific perspective, understand the world more deeply, and develop the ability to use scientific methods.

The Science Curriculum for 2018-2024 includes skills such as communication in mother tongue and foreign languages, science and technology, mathematical and digital competencies, citizenship, learning to learn, taking initiative, entrepreneurship, and cultural awareness as basic perspectives (MoNE, 2018). The specific objectives of the program include raising individuals with knowledge about science and engineering applications, gaining scientific process skills, creating awareness of sustainable development, developing entrepreneurship and career awareness, adopting national and cultural values, and gaining scientific ethical principles. In line with these goals, the curriculum should be integrated with technology (MoNE, 2018).

For successful technology integration, it is important for teachers to develop the skills to use technology effectively and critically evaluate content (Atis- Akyol & Askar, 2022). Integration is not just about the use of tools; it involves a strategic process that includes understanding student needs, lesson design, and assessment (Kaya & Yılayaz, 2013; McKnight et al., 2016). This process can increase students' motivation, deepen their learning and prepare them for the digital future. By using technology integration effectively, educators can ensure that students not only acquire knowledge but also develop learning as a lifelong skill.

Technology integration in education can be implemented through various models according to different learning needs and goals (Ince-Muslu & Erduran, 2020). These models guide teachers in the use of technology. *The TPACK Model (Technological Pedagogical Content Knowledge)* emphasizes the interaction between technology, pedagogical methods, and content knowledge (Koehler & Mishra, 2009). *The SAMR Model* is a framework for assessing the degree of integration of technology into educational processes and consists of four steps: Substitution, Augmentation, Modification, Redefinition, (Puentedura, 2023). *The Flipped Classroom Model* aims to spend more time on classroom practices by reversing traditional learning processes (Bishop & Verleger, 2013). *The 5W 1H Unified Integration Model* is structured with five main elements and one key component to support technology integration in the teaching process (Kuskaya-Mumcu et al., 2008).

The Systematic Planning Model developed by Wang and Woo (2007), which can realize ICT integration at three levels according to the content addressed. These are the curriculum (macro), the subject (meso), and the lesson (micro) level. At the *macro level*, the curriculum is integrated into ICT; at the *meso level*, ICT is used to support students' subject learning. At the *micro level*, ICT is used to better explain the subject in one or more lessons (Mazman & Kocak- Usluel, 2011).

At the macro level, the entire broad curriculum in a particular field, such as science, mathematics, physics, chemistry, biology, etc., is integrated (ICT). This usually means the widespread use of technology across courses in a discipline or a broad area of learning. This integration aims to strengthen interdisciplinary links by providing students with a broad perspective.

At the meso level, integrations are carried out for a specific learning area or topic within the curriculum. There is a focus on the use of ICT in lessons in a specific subject or learning area. This aims to provide students with an in-depth subject-based understanding and effective use of technology related to that subject.

At the micro level, integration is specific to a course and usually involves the use of ICT in teaching a particular subject or concept. For example, in a science course, interactive simulations, virtual experiments or other ICT tools can be used on a specific topic. Micro-level integration aims to provide students with a more in-depth experience of the topic.

The Systematic Planning Model is a preferred model in literature because the integration of technology into the environment takes place in stages, and each step of the evaluation processes is expressed in detail (Sevimli, 2020). The process in this model follows a logical flow; there is an interaction between all components. The development

of each component depends on the completion of the preceding component. The model includes planning, implementation, and evaluation stages of the integration process and emphasizes that these stages are interconnected and form a continuous cycle. This process aims at careful planning implementation and continuous evaluation of the technology for its successful use in the educational environment.

The Systematic Planning model addresses the integration of technology and learning environments in seven stages:

1- Problem Statement: The process starts with defining the basic and current problem that needs to be addressed. It serves as the first step of integration. This realistic approach should also be feasible.

2- Learning Objectives: The objectives to be achieved at the end of the process of integrating information and communication technologies into the learning environment should be consistent with the objectives in the curriculum of the relevant course.

3- Necessary Technologies: The technological materials needed to eliminate the problem situation mentioned in the first stage and for the goals expected to be achieved after the implementation of the method constitute this stage. The necessary material can be software, hardware, or any technological tool. One of the most important points is that such technological hardware or software should be compatible with the model in question and serve the learning objectives in terms of accessibility and applicability.

4- Rationale for Using Technology: Technology should be used to achieve learning objectives. For this reason, after determining the technology to be used during the design of the model, it is important to clearly identify the benefits that the technological materials will provide, the direction and extent to which they will support education, and most importantly, why they should be used.

5- Implementation Strategies: Teachers should integrate the preferred technology into subject teaching in an effective and meaningful way. At this point, an appropriate strategy should be determined regarding the methods and techniques of using technology in the classroom; the harmony and continuity between successive subjects should be ensured. Accordingly, while preparing lesson plans, technology-integrated plans should be designed to develop students' high-level thinking skills (critical thinking, creative thinking, reflective thinking, etc.).

6- Student Evaluation: At the end of the process, student assessment is carried out to determine how much learning has been realized, as a result of the implemented plan. The assessment takes into account how the students completed the learning activities or tasks; how they worked collaboratively with technology integration to reach the final product; written assignments; tasks completed through the online platform; and e-portfolios, which are used as assessment criteria (Theodosiadou & Konstantinidis, 2015).

7- Reflection: After the completion of integration, teachers need to reflect on their learning experiences in the teaching process. This reflection should focus on the appropriateness of the technology to the curriculum and its strengths and weaknesses. At this stage, teachers need to develop suggestions for other teachers to integrate technology into their fields, and students need to create learning outcomes that are appropriate for the curriculum (Wang & Woo, 2007).

The Systematic Planning Model was preferred because it focuses on the use of technology in line with goals and needs and on the process of evaluating learning outcomes (Izmirlı, 2012; Wang & Woo, 2007). The model aims to ensure the effective use of technological tools, especially in science teaching, and guides teachers by addressing technology integration in the classroom context. Despite the emphasis on the use of ICT in current curricula, concrete examples of activities and lesson plans for technology integration in science teaching are limited (Bal, 2015; Kuskaya-Mumcu et al., 2008; Kuskaya-Mumcu, 2011).

Science teaching is a fundamental field of education that aims to improve students' ability to understand and discover the world (Ceylan, 2014). With technological advancements, there have been significant changes in teaching methods in this field, and a transition from traditional approaches to technology-supported, interactive, and visually rich learning environments has been achieved. This transition increases students' interest and contributes to a better understanding of the subjects. Modern instructional technologies include computers, tablets, interactive whiteboards, virtual and augmented reality tools. These technologies facilitate learning with audiovisual content. In particular, computer-based simulations allow students to reinforce their theoretical knowledge through experience. In courses such as chemistry and physics, these simulations are used to concretize abstract concepts. Virtual reality (VR) and augmented reality (AR) technologies offer students the potential to experience different environments outside the real world (Ozdemir, 2017).

Virtual reality (VR) technologies enable students to go beyond the physical world and better understand abstract, scientific concepts (Arıcı, 2013). VR technology offers students a visually and aurally rich learning experience thanks to its ability to create a virtual world (Yılmaz, 2023). This technology provides students with the opportunity to visually observe abstract science concepts (Saricam, 2019), having an interactive learning experience, moving around in a virtual world, examining objects and conducting experiments, transforming

theoretical knowledge into practice, and exploring science topics in depth (Tepe et al., 2016). It supports students in increasing their motivation and developing scientific thinking skills (Cankaya & Girgin, 2018).

Augmented reality (AR) technology stands out as a powerful tool for transforming abstract scientific concepts into concrete and interactive learning experiences in science teaching (Altınpulluk, 2015; Law & Heintz, 2021). AR enriches the real world with virtual content, making students' learning processes more visual, auditory and interactive. Thanks to this technology, students can closely examine structures such as plant cells, see molecular models in three dimensions and conduct experiments in a virtual environment (Kına & Bicek, 2023; Taskın et al., 2023). Especially in units such as 'Solar System' or 'Let's Know Our Planet,' virtual excursions with AR technologies contribute to students' understanding of astronomy and geography subjects more effectively (Palmas & Klinker, 2020). In order to use this technology effectively in teaching, it is important that teachers have the necessary technical knowledge, technological infrastructure be provided, and equal access opportunities be provided to students (Chien, 2019; Lee, 2012; Sarioglu, 2021).

Research on the effective integration of information technologies (ICT) in education provides important findings on teacher and student dimensions. *Kocak-Usluel et al. (2007)* reported that teachers preferred word processing and internet applications the most in ICT use, while they used desktop publishing and graphics programs the least. *Kuşkaya Mumcu (2011)* found that ICT education given to pre-service teachers significantly improved their technological pedagogical content knowledge. *Gunes (2015)* found that there were significant differences in the attitudes of administrators and teachers towards ICT. In studies on augmented reality (AR) applications, *Izgi-Onbaslı (2018)* found that these applications positively affected primary school students' motivation to learn science and their attitudes towards AR. Similarly, *Dikkartın-Ovez and Sezginsoy-Seker (2022)* found that AR-supported materials had significant effects on student achievement, attitude, and motivation. *Kaleci (2018)* stated that the in-service training program developed on the basis of the SAMR model positively affected teachers' beliefs and attitudes towards ICT. *Bayezit (2019)* developed an effective design process in mathematics teaching by combining ADDIE and Systematic Planning Models, and showed that teachers supported this process. *Gocen Kabaran (2020)* reported that an in-service training program aimed at increasing teachers' digital material development skills received positive feedback. *Simsek and Direkci (2021)* stated that Turkish teachers adopt technology in education and give importance to technology integration in teacher training processes. *Dundar and Unaldı (2023)* emphasized that an in-service training based on the TPACK model had positive effects on teaching processes and student achievement.

Chambers (2011) aimed to determine the effectiveness of ICT in a primary school. As a result of the research, he found that the use of ICT enhanced teaching efficiency and success and provided students with more effective learning opportunities. *Tak (2013)* aimed to determine the level of ICT usage of lecturers working in a higher education institution and their opinions on the subject. The research revealed that lecturers believe that the effectiveness of teaching will increase thanks to ICT integration. *Merillo and Domingo (2019)* aimed to examine teachers' views on the effectiveness of ICT integration in foreign language teaching. As a result of the research, they found that teachers believe the use of ICT will have very positive effects on language teaching. *Simonova and Kolesnichenko (2022)* aimed to determine the impact of the use of AR in higher education on foreign language teaching. As a result of the research, they found that AR applications were effective in increasing language learning levels and improving the quality of foreign language teaching.

Purpose of Research

In this study, although effective use of ICT in the science curriculum is necessary, there are limited examples of concrete applications, activities, and lesson plans on how to integrate technology into science teaching (Bal, 2015; Kuskaya-Mumcu et al., 2008; Kuskaya-Mumcu, 2011; Wang & Woo, 2007). In this context, the aim was to develop a sample instructional design on how ICT integration can be realized for science teaching and to evaluate the effectiveness of this design. The research provides a framework to guide teachers on how ICT can be used effectively in science teaching through the Systematic Planning Model. This is one of the ICT integration models and aims to integrate technology into disciplines in a regular and planned manner.

In the study, "Is there a significant difference between the achievement and retention scores of the students in the experimental group where the curriculum prepared based on the 'Systematic Planning Model', one of the ICT integration models, was applied in the 4th grade science course and the control group where it was not applied? What are the student views on the subject?" the study sought to answer. In this context, the hypotheses related to the experimental dimension of the research are presented below:

1. There is a significant difference between the achievement scores of the experimental group, in which the curriculum prepared based on the Systematic Planning Model was applied.
2. There is a significant difference between the achievement scores of the control group, in which the curriculum prepared based on the Systematic Planning Model was not applied (the current curriculum was applied).
3. There is a significant difference between the achievement scores of the experimental group in which a curriculum prepared based on the Systematic Planning Model was applied, and the control group in which it was not applied.
4. There is a significant difference between the retention scores of the experimental group in which the curriculum prepared based on the Systematic Planning Model was applied and the control group in which it was not applied.

The sub-problem related to the qualitative dimension of the research is presented below:

* What are the students' opinions about the practices in the curriculum prepared based on the 'Systematic Planning Model,' one of the ICT integration models, in the 4th grade science course in primary school?

Method

Research Design

In this study, mixed methods were used. The explanatory design, one of the mixed methods designs, was employed. First, quantitative data were collected; then qualitative data were collected to interpret, deepen, and enrich these data (Creswell & Plano Clark, 2007). Karasar (2014) defines mixed methods as a method that uses both types of data in the research process and contributes to making the results more meaningful. The mixed methods enable the research problem to be addressed from a broader perspective by using quantitative and qualitative data together. This approach increases the depth of the research through the mutual support of quantitative and qualitative findings (Creswell, 2017; Johnson et al., 2007; Sonmez & Alacapinar, 2019).

According to Karasar (2014), experimental research involves making comparisons. This comparison can be in the form of changes within a method or a comparison of two different methods. In this study, two methods applied in two different groups were compared. The pretest-posttest control group experimental design, a quantitative research design, was used. In this design, groups are naturally determined as experimental and control groups. In the model, groups are taken, as they are, in the institutions, in their existing structure. No assignment is made by selection or chance. A pretest is administered to both groups at the same time. Afterwards, the experimental procedure is used in the experimental group, but not in the control group. The test is given to both groups at the same time as a posttest. The pretest-posttest score differences of both groups were found and the results were compared (Sonmez & Alacapinar, 2019). In experimental studies, the population and sample are not determined, but the study groups are. It is important that these groups are balanced in terms of undesirable variables, not their size (Sonmez & Alacapinar, 2019).

In the qualitative dimension of the study, the case study model was preferred. A Case study enables the examination of various aspects of a particular phenomenon or situation from a holistic perspective (Yıldırım & Simsek, 2013). Qualitative data were obtained through a semi-structured interview form, and the descriptive analysis method was used to analyze the data. This method enables the data to be systematically defined, interpreted and organized in a certain order (Sonmez & Alacapinar, 2019). Thus, the findings of the study were supported by the combined use of quantitative and qualitative methods, and the study's validity was thereby increased.

Study Group

The study group of this research consisted of 45 students studying at the fourth-grade level of a private primary school in the Selcuklu district, in the Konya province. There are two main reasons for choosing fourth grade students in the study. Firstly, the current fourth grade science curriculum is thought to be the most suitable for technology integration practices compared to other grade levels. The second main reason is that fourth grade students are more suited to the age maturity required for technology integration, which necessitates the use of technological hardware and software, compared to other grade levels.

All 4th grade students studying in three branches of a private primary school were included in the study. The students in these three classes were treated as three naturally formed separate groups, and no random assignment was made to the groups. Then, from these two equivalent groups, class 4-A was designated as the experimental group and class 4-C as the control group. The distribution of the students in the experimental and control groups by grade and gender is given in Table 1 below.

Table 1. Distribution of students in experimental and control groups

Groups	Male		Female		Total	
	n	%	n	%	n	%
Experimental (4-A)	15	65,22	8	34,78	23	100
Control (4-C)	11	50	11	50	22	100
TOTAL	26	57,78	19	42,22	45	100

Table 1 shows that a total of 45 students from the experimental and control groups participated in the study. While 57.78% (n=26) of the students participating in the study were male, 42.22% (n=19) were female. However, 65.22% (n=15) of the 23 students in the experimental group were male and 34.78% (n=8) were female. In the control group, there were a total of 22 students, 50% (n=11) of whom were male and 50% (n=11) of whom were female.

The analyses made with the pre-test scores of the experimental and control group students in order to reveal their equivalence in terms of academic achievement levels in the unit of 'Lighting and Sound Technologies from Past to Present' in the science course are shown in Table 2.

Table 2. T-test results of students' pretest score averages according to groups

Groups	n	$\bar{x}$	SS	sd	t	p
Experimental	23	23,95	8,18	43	-1,595	0.118*
Control	22	27,27	5,42			

*p>0.05

When Table 2 is examined, it is seen that the mean pretest score of the experimental group was 23.95 and the mean pretest score of the control group was 27.27; there was no significant difference between the pretest scores of the groups [$t(43) = -1.595$, $p=0.118$, $p>0.05$]. The groups are equivalent in terms of pretest mean scores.

Data Collection Tools and Techniques

For the achievement and retention test to be applied to the experimental and control groups, the researcher prepared a test consisting of 50 multiple-choice questions targeting the achievements in the "Lighting and Sound Technologies from Past to Present" unit in the science course for 4th-grade primary school students in the 2022-2023 academic year. The questions of the test were prepared according to Bloom's taxonomy and the levels of knowledge, comprehension, and application. The test items were evaluated by 1 classroom teacher (head teacher), 1 science teacher (science expert), and 1 faculty member in terms of their effectiveness in measuring the intended behaviors. The agreement values between the experts' evaluations were calculated using a Miles & Huberman (1994) formula and determined as 0.87. At the end of the pilot application, the test, which was reduced to 40 items, was finalized. The reliability coefficient of the test was calculated as $r=0.896$ according to the KR-20 method. The calculated value has a level of reliability considered quite high for an achievement test (Salvucci et al., 1997).

To obtain data related to the qualitative dimension of the study, a semi-structured interview form consisting of three open-ended questions was prepared by the researcher. The questions in the interview form were evaluated by experts in the field of measurement and evaluation. In addition, an academician working in the field of basic education, and a language expert were consulted to evaluate the comprehensibility of the questions by fourth-grade primary school students. Since the students were at the primary school level, the interview form was prepared as semi-structured to determine the students' opinions and thoughts about the implementation process. To evaluate the reliability of the qualitative research, the reliability was calculated using the coder reliability method suggested by Miles and Huberman (1994) and found to be .93.

The questions in the form after the necessary corrections were made in line with the expert opinions: "What are your opinions about the studies we do in Science lessons? Do you think our studies are useful? Please state your

reasons." Do you think using technology in science lessons is useful? In what way do you think the technological products we use (tablet computers, laptops, augmented reality applications, web tools, etc.) are beneficial or harmful? Please indicate with the reasons." "What are your suggestions for making our studies more useful and improving them?"

Implementation Process and Data Collection

Two of the three 4th grade classes, in the private school where the experimental study would be conducted, were selected as the experimental and control groups. The experimental process was initiated while the academic achievement test was administered to the experimental and control groups simultaneously as a pretest. After the pretest application, the researcher conducted the research in the experimental and control groups over 7 weeks, with each group receiving 21 hours, starting in the same week. The reason the researcher took part in the experimental process as a teacher is that he is a classroom teacher, has expertise in the field of curriculum and instruction, and is familiar with the Systematic Planning Model. In addition, according to Creswell & Plano-Clark (2007), the aim of the researcher's proximity to the participants is to increase the validity of the research.

In the experimental process, the experimental group was taught according to a curriculum based on the Systematic Planning Model, while the control group was taught based on the existing curriculum with the resources and activities stipulated by the MoNE curriculum. An augmented reality application called Jigspace, an online presentation and information editing application called Visme, and an electronic classroom application called Google Classroom, were used to teach the topics in the curriculum. At the end of the course, the academic achievement test was given to both groups simultaneously as a posttest. At the end of the experimental process, a semi-structured interview form developed by the researcher was applied to the students in the experimental group. The form was delivered in printed form to the students in the experimental group, who were asked to answer three open-ended questions. The students expressed their opinions about the activities related to the experimental application in writing through printed forms during one 40-minute lesson allocated for this process. Four weeks after the posttest, the academic achievement test was given to both groups as a retention test. The experimental process of the research was completed.

Analysis of Data

The quantitative data obtained from the experimental and control groups were first recorded in Excel and transferred to IBM SPSS (Statistical Package for Social Sciences) 18 for the necessary analysis. In order to determine the appropriate statistical method to be used in analyzing the quantitative data, the homogeneity of variances and the normal distribution of the data were checked. The homogeneity of variances was determined by Levene's Test, and the normal distribution of the pretest, posttest, and retention test scores of the experimental and control groups were assessed using the Shapiro-Wilk test, Skewness-Kurtosis values, coefficients of variation, and histogram graphs. After testing the normal distribution of the data, the Dependent Sample t-Test, Independent Sample t-Test, Mann-Whitney U Test, and Wilcoxon Signed Rank Test were used for the measurements. The effect size of the significant difference between independent groups in the study was calculated using the "r" value, and the effect size of the significant difference between the results within groups was calculated using "Cohen's d" value formula. In this context, Cohen (1988) tried to classify the significance levels of Cohen's d value and r values to calculate the effect size in the model he developed. According to Cohen, the value found as effect size (r) can be interpreted as small if $r < 0.2$; moderate if $0.2 < r < 0.5$; strong if $0.5 < r < 0.8$, and very strong if $r > 0.8$.

In the qualitative dimension of the research, the data in the semi-structured interview forms developed by the researcher were carefully examined, organized, and analyzed. The descriptive analysis technique helped to identify the focal points and main themes of the research and enabled in-depth understanding of the data obtained. Descriptive analysis enabled the data to be evaluated within a broader context and facilitated a meaningful presentation of the main findings of the research. In this study, the analysis of the students' responses to the semi-structured interview questions was conducted independently by the researcher and a field expert.

Findings

Findings Related to the First Hypothesis

In order to test the first hypothesis of the study, researchers evaluated whether "there is a significant difference between the achievement scores of the experimental group in which the curriculum prepared based on the Systematic Planning Model was applied. Since the data showed a normal distribution, the paired sample t-test was used. The test results are given in Table 3.

Table 3. Comparison of pretest and posttest scores of experimental group students

Group	Test	N	$\bar{x}$	SD	df	t	p
Experimental Group	Pretest	23	23.956	8.182	22	-7.445	.001
	Posttest	23	34.565	5.106			

According to Table 3, the pretest scores for students in the experimental group were $\bar{x}$ pretest = 23.95±8.18, and the posttest scores were $\bar{x}$ posttest = 34.56±5.10. There was a statistically significant difference between the achievement scores of the experimental group ($t(22) = -7.445$, $p < 0.05$), $d = 1.63$. The curriculum prepared and implemented in accordance with the Systematic Planning Model, was effective in increasing the academic achievement of the experimental group students.

Findings Related to the Second Hypothesis

In order to test the second hypothesis of the study, the researchers postulated: "There is a significant difference between the achievement scores of the control group, in which the curriculum prepared based on the Systematic Planning Model was not applied (the current curriculum was applied). The Wilcoxon Signed Ranks Test was used since the data did not show normal distribution. The test results are given in Table 4.

Table 4. Comparison of pre-test and post-test scores of control group students

Group	Pretest-Posttest	N	Mean Rank	Rank Total	Z	p
Control Group	Negative Rank	5	11.90	59.50	-1.447	.148
	Positive Rank	14	9.32	130.50		
	Equal	3				

* Calculated based on negative ranks.

According to Table 4, it was determined that the difference between the achievement scores of the control group students ($z = -1.447$; $p = .148$), $d = 0.15$, was not statistically significant and indicated a very small effect size (Cohen's d). It can be said that the program in force was not effective for improving the academic achievement of the control group students.

Findings Related to the Third Hypothesis

In order to test the third hypothesis of the study, "There is a significant difference between the achievement scores of the experimental group in which the curriculum prepared based on the Systematic Planning Model was applied and the control group in which it was not applied", Mann Whitney U test was used since the data did not show normal distribution. The test results are given in Table 5.

Table 5. Comparison of attainment scores of experimental and control group students

Group	N	Mean Rank	Rank Total	U	p
Experimental	23	33.33	766.50	14.500	.001
Control	22	12.20	268.50		

According to Table 5, it was determined that there was a statistically significant difference between the achievement scores of the experimental group students and the control group students ($U = 14.500$; $p = .001$), with a Cohen's d of 1.94, indicating a very high effect size. The curriculum prepared based on the Systematic Planning Model is more effective than the current curriculum in determining students' achievement levels.

Findings Related to the Fourth Hypothesis

In order to test the fourth hypothesis of the study, "There is a significant difference between the retention scores of the experimental group to which the curriculum prepared based on the Systematic Planning Model was applied

and the control group to which it was not applied," the Mann-Whitney U test was used, since the data did not show normal distribution. The test results are given in Table 6.

Table 6. Comparison of retention scores of experimental and control group students

Group	N	Mean Rank	Rank Total	U	p
Experimental	23	30.13	693.00	89.000	.001
Control	22	15.55	342.00		

According to Table 6, there was a statistically significant difference between the posttest retention scores of the experimental group students and the control group students ($U=89.000$; $p=.001$); the effect size value (Cohen's d) was $d=1.81$, which was quite high. It can be concluded that the curriculum prepared based on the 'Systematic Planning Model' is more effective than the current curriculum in determining students' retention levels.

Findings Related to the Qualitative Dimension of the Study

Student views on the achievement scores of the experimental group in which the curriculum prepared based on the Systematic Planning Model was applied

What are the students' opinions about the practices in the curriculum prepared based on the 'Systematic Planning Model', one of the ICT integration models, in the 4th grade science course in primary school? The opinions of the experimental group students about the implementation process were determined for the sub-problem.

In the qualitative dimension of the study, the views and opinions of the experimental group students about the implementation process were determined. The data obtained from the semi-structured interview form were subjected to content analysis and coded. The first question of the interview form was "What are your opinions about the studies we did in science lessons? Do you think that our studies are useful? Please state your reasons. A total of 59 codes were produced in 12 different categories from the answers given by 22 students in the experimental group. The codes were evaluated under two themes: "Positive Opinions" and "Negative Opinions". Among these codes under the "Positive Opinions" theme, the "fun" code ranked first in terms of frequency and percentage value with a frequency of 17. This code corresponds to 28.81% of the codes generated from all responses. It was determined that the code "useful" ranked second with 11 frequencies, and a value of 18.64%, and the code "instructive" ranked third with 10 frequencies and a value of 16.94%. The code "permanent" was ranked fourth with a frequency of 6 and a value of 10.16%. There were only two codes under the theme of "Negative Opinions. The first of these was "took a long time" with a frequency of 4 and a value of 6.78%. In the second row of the theme, "Temporary" was included with only 1 occurrence and a value of 1.69%. This situation indicates that the students found the practices and activities in the experimental process fun, useful, and instructive. The positive experiences of the students, observed by the researcher during the experimental process, were further corroborated by data collected through the interview form. Some of the answers given by the students are presented below, with the method of direct quotation.

S1: *"The studies we did in science class were useful. The educators encouraged playful activities because learning in a fun way was more permanent."*

S5: *"I think it was useful. We both had fun and learned as a class through comprehensive explanations. It was enjoyable and permanent. I want the lessons to be taught in this way."*

S8: *"It was useful. My curiosity was satisfied; it was fun and instructive. I liked it very much."*

S12: *"The lessons were very enjoyable, instructive, and informative."*

S16: *"I think it was useful because it was both fun and instructive."*

The second question of the interview form, "Do you think it is useful to use technology in science lessons? In what ways do you think the technological products we use (tablet computers, laptops, augmented reality applications, web tools, etc.) are beneficial or harmful? Please state with the reasons." It was observed that 55 codes were generated in 18 different categories from the answers given by students in the experimental group. The codes were evaluated under three themes: "Useful Aspects," "Harmful Aspects," and "Necessity and Importance. Among these codes within the scope of the first theme "Useful Aspects", the code "It is useful" ranked first by frequency and percentage, with a frequency of 17. This code corresponds to 30.90% of the codes generated from all responses. The code "It makes it fun" ranked second with 4 frequencies and 7.27%, and the code "It helps us learn better" ranked third with 3 frequencies and 5.45%. Within the scope of the second "Harmful Aspects" theme, the code "Using it for a long time causes harm" ranked first with a frequency of 9 and a value of 16.36%, while the code "It should be short" ranked second, with a frequency of 2 and a value of 3.63%. Thirdly,

within the scope of the theme of "Necessity and Importance", the code "It should be used in all courses" ranked first with a frequency of 5, accounting for 9.09%. In this case, it can be said that students find technology-supported science education useful. However, the students also stated that using educational technologies for a long time would be harmful. Some of the students' answers to the second question are presented below using the direct quotation method.

S3: *"Yes, it is useful. It should be used in all courses."*

S10: *"Technology is necessary in science lessons. The harm caused by it leads to addiction. The benefit is that it helps us acquire knowledge."*

S14: *"It is useful for education because it enhances learning outcomes. The use of technology in science lessons enhances memory retention more effectively than traditional methods."*

S17: *"It is considered useful. Fast and practical learning. I think technology will be useful in every lesson."*

S20: *"The use of technology is beneficial. Technology is indispensable for obtaining useful information."*

In the third question of the interview form, "What are your suggestions for making our studies more useful and improving them?", 34 codes were generated from the answers given by the students in the experimental group, grouped into 8 different categories. The codes were evaluated under three themes: "In terms of quantity," "In terms of quality," and "Neutral. Among these codes within the scope of the first theme "In terms of Quantity", the code "It should be used in all courses" ranked first in terms of frequency with a frequency value of 14. This code corresponds to 41.17% of the codes generated from all answers. The code "The number of devices should be increased" ranked second with 3 frequencies and 8.82% while "It should be done more frequently" ranked third with 2 frequencies and 5.88%. Within the scope of the second theme, "In terms of quality", among the codes, the code "It should be shorter" ranked first with 11 frequencies, and a value of 32.35%. It was determined that the code "There is no need for improvement" which is the only code within the scope of "Neutral" as the third theme, has a frequency of 1 and a value of 2.94%. In this case, students demanded the widespread use of technology in all courses. However, as a criticism of the experimental process carried out within the scope of this research, they stated that technology-supported activities should be shorter and the amount of technological equipment was insufficient. Some of the students' answers to the third question, are presented below using the direct quotation method.

S2: *"I think the studies we did could have been shorter, and included in all lessons."*

S4: *"It could be shorter. It can be applied to every lesson."*

S7: *"It should be used in every lesson; tablets should be given to every student."*

S19: *"It may be beneficial to integrate technology into science lessons. Augmented reality should be considered for implementation in all lessons."*

S22: *"I think it is good; however, it takes too long. It can be accelerated. It should be used in all lessons."*

Student views on the retention scores of the experimental group in which the curriculum prepared based on the Systematic Planning Model was applied

In the study, the data obtained from the students' views on the effect of the course taught using the systematic planning model on retention were analyzed by content analysis. As a result of the analysis of the answers given by the students about retention, three themes and codes related to these themes were determined. When the findings were examined, the main themes were determined as "Retention and Recall", "Embodiment and Understanding" and "Motivation and Increased Interest". The majority of the students stated that the retention of information increased in the lessons taught in line with the systematic planning model. In particular, it was observed that visual and experiential learning provided by the technological elements used in the lessons contributed to the long-term recall of the information learned. In this context, the prominent codes were determined as "keeping the information in mind for a long time", "retention of visual elements in memory", "learning through experience is not forgotten", "learning becomes fun". Students emphasized that especially abstract concepts became more concrete and understandable thanks to the technologies used in the lessons. Supporting difficult-to-learn concepts with three-dimensional virtual models and visual content facilitated understanding and contributed to the retention of learning. In addition, the different and fun structure of the augmented reality application used in the lesson made it easier for students to pay attention, which had a positive impact on the learning process. Some of the student responses are presented below by direct quotation method.

S1: *"The things we learn in this course stay in my mind because it is as if I discovered them myself."*

S3: *"I have a lot of fun and the information stays in my mind because the things we only see pictures of in the book appear three-dimensional and moving thanks to the application we use on the tablet computer."*

S6: *"When I took this lesson, I felt like I was on an adventure, not in a lesson, so I can say that everything I learned was engraved in my brain."*

S9: *"Thanks to these lessons, I can visualize even abstract things. When I see and do it, it stays in my mind, I didn't understand much when I just listened to it."*

S11: *"Normally, the subjects in science class were difficult for me. But now I understand better and what I have learned stays in my mind."*

S18: *"Since this method is very different, I now listen to the lessons more carefully and remember what I have learned for longer."*

S21: *"We both had fun and never forgot what we learned."*

As a result of the analysis of the data collected for the qualitative dimension of the research, it was determined that the students in the experimental group expressed positive opinions about the activities and lessons taught within the scope of the curriculum prepared based on the 'Systematic Planning Model'. They stated that they found the lessons fun and useful, that the hardware and software used facilitated their learning, that what they learned was permanent, that they remembered for a long time, and that although the activities took a long time, they should be used in every lesson. It was also observed that the students thought that the number of equipment was insufficient and the activities took a long time, and that the students made various suggestions for the development of the curriculum.

Discussion and Conclusion

In line with the findings, the results of the research were determined. The effectiveness of the curriculum prepared based on the Systematic Planning Model in the Primary School 4th Grade Science course was discussed, and suggestions were made. When the findings related to the first hypothesis of the research were examined, it was revealed that the curriculum prepared and implemented in accordance with the Systematic Planning Model was effective in increasing students' academic achievement. These findings coincide with the studies in the existing literature. Ghavifekr and Rosdy (2015) found that teachers' preparation and implementation of technology-supported curricula equipped with ICT tools and facilities are effective in learning and increase achievement. Tak (2013) found that ICT integration of instructors increases effectiveness in teaching. Bayezit (2019) developed an instructional design that integrated the ADDIE model and the Systematic Planning Model in mathematics education. Teachers supported this program. Kul (2019) determined that augmented reality applications increased students' academic achievement and motivation towards science learning. Sevimli (2020) reported that the online teaching module developed according to the ADDIE model and Systematic Planning Model created a significant difference in favor of the experimental group after the application, and that the participants' beliefs about the use of ICT changed positively. Omurtak and Zeybek (2022) revealed that augmented reality-based activities increased student achievement and motivation in biology courses.

The findings related to the second hypothesis of the study show that the activities based on the current program are not effective in increasing students' academic achievement. The control group data revealed that the current program was insufficient to increase achievement, therefore, this hypothesis was not confirmed. These results coincide with Chambers' (2011) study in which he found that the use of ICT in a primary school increased efficiency and achievement in teaching. It also coincides with the results of Dikkartin Ovez's and Sezginsoy Seker's (2022) research in which they found that activities designed for the application of AR-supported materials significantly increased the achievement of experimental group students in social studies and mathematics courses.

Regarding the third hypothesis, it was determined that the achievement scores of the experimental group were significantly higher than those of the control group. This shows that the experimental process was effective in increasing the students' learning levels. This result coincides with the findings of Donmus's (2012) study, which found that activities supported by educational computer games significantly increased students' achievement levels, and Piper et al.'s (2015) study, in which teachers' use of tablet computers and students' use of e-book readers had positive effects on learning outcomes.

The findings obtained within the scope of the fourth hypothesis, showed that the retention scores of the students in the experimental group were significantly higher compared to the control group. These results are similar to the results of Ozgur (2016) and Kıyıcı (2018) and Gurbuz et al. (n.d.). The results of Turksoy's (2019) study, which determined that the use of AR in science courses increased students' academic achievement and retention of knowledge, and Simonova & Kolesnichenko's (2022) study, which showed that using AR applications had a positive effect on learning outcomes, were found to be similar to the results of Ozgur (2016) and Kıyıcı (2018) and Gürbüz et al. (n.d.).

In line with the qualitative findings of the study, according to the achievement and retention scores of the experimental group, the majority of the students stated that they found the in-class activities fun and useful, and some of them stated that the duration of the activities was long. The students expressed their desire for similar activities to be used in other lessons. These findings are similar to the results of Izgi-Onbasli's (2018) study, which found that lessons taught with AR applications increased students' motivation; Purbudak and Usta's (2019) study, which found that the use of digital stories positively affected students' attitudes towards the course; and Tak's (2013) study, in which instructors believed that effectiveness in teaching would increase as a result of their ICT usage levels and their opinions on the subject. In addition, it was determined that most of the students stated that the applied method increased their retention levels. In this context, the results of the study overlap with the findings of Simsek and Hamzaoglu's (2020) study in which Simsek and Hamzaoglu (2020) determined that teaching enriched with models in science teaching increased the retention level and Tekdal and Taskin's (2021) study in which Tekdal and Taskin (2021) determined that dynamic and interactive computer-aided science and technology teaching increased the retention level.

As a result, it was concluded that the lessons taught in line with the technology-supported curriculum implemented in the research were found to be fun and useful by the students, facilitated the learning process. It was also concluded that similar applications should be carried out in different courses. This supports the quantitative findings of the study. While quantitative data revealed that there was a significant increase in the academic achievement of the experimental group, qualitative data showed that students developed positive views towards the course and were satisfied with the experimental practices that facilitated learning. The findings reveal that systematic planning based on technology integration is effective in increasing both students' achievement and their motivation in the course.

Recommendations

In line with the research findings, planned and model-based approaches to technology integration in education are observed to have positive effects on student achievement and learning motivation. In this framework, it is important to consider theoretically based integration models such as the Systematic Planning Model in the design of curricula. Considering that technology integration, especially at the meso level, supports students' in-depth comprehension and permanent learning of subjects, teachers should be encouraged to combine content and pedagogy with digital tools in a structured way.

The qualitative findings show that students developed positive attitudes towards technology-supported learning activities, reflecting their increasing interest in the lessons. In this context, technology integration should be planned to create student-centered, interactive and experience-oriented learning environments without reducing it to the use of tools. Based on the students' views, it can be suggested that technology-supported activities should be expanded not only in science but also in other courses. Making such activities routine in the teaching process will allow students to experience multiple ways of learning and contribute to their cognitive development.

The study was limited to the application of the Systematic Planning Model at the meso (subject) level. The applicability of this model at the micro (in-class implementation) and macro (integration across the curriculum) levels can also be examined in future research. In particular, in-class strategies, material use, and student-technology interaction can be analyzed in detail through course-based (micro-level) applications. At the macro level, more holistic integration approaches can be developed by establishing interdisciplinary connections.

In addition, similar studies can be conducted at different grade levels, in different disciplines, and in educational institutions with various technological infrastructure in order to increase the traceability of the effect of the research. It is recommended that ICT integration models be included in pre-service and in-service training programs in order to improve pre-service teachers' knowledge and skills for technology integration. In addition, longitudinal studies should be conducted to monitor the sustainability of student achievement and learning quality in the longer term.

Declaration of Scientific Ethics

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

* The ethics committee report from Necmettin Erbakan University, assessing the ethical appropriateness of this

study, was obtained dated 08.07.2022 and numbered 2022/292.

Conflict of Interest

* The authors declare that they have no conflict of interest.

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Author(s) Information

Mustafa Ok

Ok Akademi

Konya, Türkiye

Contact e-mail: doktormustafaok@gmail.com

ORCID ID: <https://orcid.org/0000-0002-8319-9523>

Fusun Gulderen Alacapinar

Necmettin Erbakan University

Konya, Türkiye

ORCID ID: <https://orcid.org/0000-0001-7515-3851>
