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# Research Trends in the Use of Virtual Reality in STEM Education: A Content Analysis

**Adem Koc**
Mersin University, Turkey

**Pelin Yildirim**
Atatürk University, Turkey

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# Research Trends in the Use of Virtual Reality in STEM Education: A Content Analysis

Adem Koc, Pelin Yildirim

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**Abstract**

The aim of this study was to reveal research trends on the use of virtual reality in the field of K-12 STEM education through descriptive content analysis. Within the scope of the research, first of all, ERIC, Science Direct, Scopus and Web of Science databases were accessed and the key concepts of 'Virtual Reality' and 'STEM Education' were scanned on a topic basis. A total of 364 scientific studies were accessed and for content analysis, a total of 24 articles published between 2008 and 2023 years were included from the ERIC, Science Direct, Scopus, and Web of Science databases. The results show that virtual reality, STEM education, augmented reality, educational technology, and gamification were the most used keywords in scientific research. Content analysis results of articles at the K-12 level showed that 'Learning/Academic Achievement', 'Learning Motivation' and 'Self-Efficacy' have been the most examined variables in the articles. It was found that the most commonly used teaching approaches were experiential learning, digital game based learning and inquiry based learning. It was also observed that the majority of the studies reviewed used desktop VR, because desktop VR applications are less costly and easier to develop than immersive VR applications. In addition, it has been concluded that alternative tests, achievement tests and questionnaires are the most used data collection tools in these studies, and that the study groups generally consist of 31-300 people using easily accessible sampling method. Quantitative studies were the most used research design type. In light of the results obtained, in future studies on the use of VR in STEM education, more comprehensive and holistic results will be obtained in the relevant field by using qualitative and mixed research methods in addition to quantitative methods.

## Introduction

STEM (Science, Technology, Engineering, and Mathematics) education stands out as a significant educational approach aimed at equipping students with the appropriate skills in the rapidly changing technological and scientific landscape of our time. This approach, seemingly comprised of four distinct disciplines, fundamentally represents an integrative approach to teaching and learning (Wan et al., 2021). Developments in the fields of science, technology, engineering, and mathematics have the potential to provide individuals with increased job opportunities and a better understanding. In this context, STEM education is believed to play a critical role in preparing the adults of the future. Given the rapidly evolving science and technology landscape, STEM education must adapt to changing conditions, diverging from its traditional discipline-based trend. Indeed, worldwide government policies emphasize the integration of STEM education in response to these circumstances (Wan et al., 2022). STEM education, regarded as crucial by many countries, is seen as necessary to support innovation, productivity, and economic growth. The importance placed on this educational approach by countries stems from perceived or anticipated deficiencies in relevant fields (Caprile et al., 2015).

In recent years, virtual reality (VR), as a technological field with the potential to contribute to STEM education, has garnered significant attention due to rapid developments in science and technology. The use of VR in the educational process is an effective way to simulate or replicate an environment to enhance students' learning performance (Makransky & Lilleholt, 2018). VR technology, which contributes to the embodiment of scientific concepts that are difficult to concretize in traditional classroom settings, also significantly enhances students' learning performance (Hsiao et al., 2019). VR not only contributes to the visualization of abstract concepts but also facilitates the concretization of abstract ideas and knowledge, thereby aiding in the comprehension of scientific information (Akcayir & Akcayir, 2017; Çakiroglu & Gökoglu, 2019). Along with various other disciplines, the use of this technology in the field of education has rapidly expanded (Johnson-Glenberg, 2018). Its application in STEM education can influence students' cognitive attributes, such as their ability to understand, experience, and apply complex concepts, as well as their affective attributes, including attitudes, motivation, and self-efficacy. Virtual reality technology can also simulate operational environments, allowing students to learn how to use costly equipment (Van Vo & Csapó, 2023). In addition, the impact of the integration of a new technology into the educational process on various learning outcomes, as well as Its usability in terms of functionality should also be evaluated (Jenkinson, 2009). Furthermore, research has shown that this technology's use in STEM education spans various educational levels, from early childhood education (Wan et al., 2021) to middle school (Ng & Chu, 2021), high school (Huang, 2022; Shu & Huang, 2021), and university levels (Lee et al., 2022).

## Literature Review

In this section, the role and significance of VR in STEM education are examined, and related studies on this topic are evaluated. By identifying the gaps in the literature, the importance of the present study is highlighted.

### Virtual Reality

Virtual reality (VR) is an advanced computer technology that enables users to interact with objects in a realistic virtual environment. The term VR first emerged in the 1960s (Sutherland, 1968; 1965) and began to be used in the education sector in the 1990s (Youngblut, 1998). VR is generally categorized into two main types: immersive VR (IVR) and desktop VR (DVR) (Chen et al., 2004); high and low degrees of immersion (Lee & Wong, 2014) or immersive and non-immersive VR (Makransky & Lilleholt, 2018). IVR provides users with a sense of presence in a virtual world by completely isolating them from the real world, often experienced through head-mounted display (HMD) devices. In contrast, DVR does not fully isolate users from the real world, offering lower levels of interaction and immersion; users view the virtual environment through a desktop computer screen and interact with input devices such as keyboards and mice (Chen et al., 2004). The interaction capacity in VR environments enriches the user experience, and the sense of immersion creates a feeling of realism in users' interactions with the virtual environment (Mikropoulos & Natsis, 2011). While some studies have concluded that the degree of immersion or presence enhances learning outcomes (Bric et al., 2016), other studies have found that a higher degree of immersion or presence can lead to lower learning performance (Makransky et al., 2019; Parong & Mayer, 2018).

**Virtual Reality in STEM Education**

Educational institutions are increasingly emphasizing the integration and utilization of digital technologies, particularly innovative tools like VR, into instructional processes (Chang et al., 2020). Debates on how these technologies can be integrated into STEM education and used in classrooms continue to intensify (Cooper et al., 2019). STEM education aims to address the challenges faced by students performing poorly in international assessments and those aspiring to pursue careers in science and technology (Pimthong & Williams, 2020). Consequently, governments and industry stakeholders in many countries advocate for increased participation in STEM education and argue that embracing this process would be beneficial (Cooper et al., 2019). To this end, many countries are transforming their economies into high-skilled, knowledge-based industries and aiming to enhance students' reasoning skills through STEM education (He et al., 2021). Given the belief that entrepreneurship and innovation activities contribute to economic prosperity, STEM education is increasingly gaining importance. In this context, some countries are implementing national policies to increase the number of qualified graduates in STEM fields. Research on the impact of virtual reality technology on education indicates that it can significantly improve students' academic achievement and classroom participation (Liu et al., 2020), contribute to the development of specific skills and attitudes (Cheng & Tsai, 2020), boost motivation (Ng & Chu, 2021), and enhance students' interest and curiosity (August et al., 2016). When examining STEM education specifically, it can be seen that the use of VR in this field has been evaluated in relation to variables such as academic achievement (e.g., Chen et al., 2020), self-efficacy (e.g., Huang, 2022), attitude (e.g., Mou, 2023), motivation (e.g., Ng & Chu, 2021), spatial ability (e.g., Kuznetcova et al., 2023), problem-solving skills (e.g., Moon et al., 2020), and career development (e.g., Jiang et al., 2021). In addition to studies evaluating the effects of VR on various learning outcomes, there are also studies evaluating the usability of this technology, focusing on its functionality (e.g. Mou, 2023; Thompson et al., 2020). These findings highlight various advantages offered by VR in the field of education. Consequently, STEM education has become a strategic priority for governments, industry representatives, and educators. It is anticipated that in the future, the use of VR technologies in STEM education will lead to significant achievements (Cooper et al., 2019). In conclusion, the nature of VR is compatible with STEM education, as it allows students to visualize dynamic virtual objects and produce visible and tangible models (Chen et al., 2020).

**Teaching Approaches Utilized in the Integration of Virtual Reality into STEM Education**

In STEM education, VR emerges as a powerful pedagogical tool that enables students to gain a deeper understanding of abstract concepts. While traditional pedagogical approaches often struggle to effectively convey abstract theories and principles, VR offers students the opportunity to simulate real-world scenarios and explore these concepts through an experiential learning process. Piaget's theory of cognitive development and Vygotsky's sociocultural theory provide valuable insights into how students actively construct knowledge and meaning through their interactions with virtual environments. According to the theory of situated cognition, learning is context-dependent and occurs within real-world settings. In this respect, VR can offer immersive experiences that facilitate deeper comprehension and knowledge transfer for students. Kolb's experiential learning theory emphasizes the importance of concrete experiences and reflection in the learning process, suggesting that VR offers students hands-on and interactive experiences that promote active engagement and reflection. Furthermore, by its nature, VR aligns well with inquiry-based and problem-based learning processes, contributing to students' exploration of complex concepts and problem-solving of real-world issues while constructing knowledge (Bindu & Subin, 2024).

According to the constructivist approach, students actively construct their own knowledge by making sense of sensory experiences they encounter in the world, making their active participation in the learning process critical (Piaget, 1971; Robinson et al., 2008). In this context, VR provides students with the opportunity to immerse themselves in different virtual environments, promoting their active engagement in the learning process (Di Natale et al., 2020). Specifically, IVR allows students to gain first-hand experiences, helping them to concretize abstract concepts and retain knowledge more effectively (Johnson-Glenberg, 2018). When combined with VR environments, learning approaches frequently used in STEM education, such as project-based learning (PBL), inquiry-based learning (IBL), digital game-based learning (DGBL), and problem-based learning (PBL), enhance student engagement and improve learning outcomes (Larkin & Lowrie, 2022; Pellas vd., 2017). Additionally, when these technologies are integrated with socio-cognitive instructional design frameworks to provide practical, hands-on experiences for students at various educational levels, they have a positive impact on learning processes (Asad et al., 2021). The integration of virtual reality into STEM education enhances the effectiveness of learning experiences by increasing students' satisfaction, motivation, and long-term commitment (Apostolellis & Bowman, 2014).

**Impact of VR on Cognitive and Affective Learning Outcomes in STEM Education**

The integration of VR into STEM education has significant impacts on learning outcomes by enhancing students' engagement in learning processes. Studies evaluating the effects of VR on learning outcomes indicate that various types of VR and subject areas may shape this impact (Coban et al., 2022). The authentic and contextual experiences offered by VR simulations bridge the gap between theory and practice in STEM education, enabling students to develop skills relevant to real-world problems. Such simulations present a variety of scenarios, from engineering design challenges to medical simulations, allowing students to apply their knowledge in a hands-on manner (Bindu & Subin, 2024). Furthermore, the potential of virtual environments to provide individualized feedback and adaptive content helps address students' diverse learning needs (Apostolellis & Bowman, 2014).

One of the most important contributions of VR in STEM education is its ability to enhance students' sense of self-efficacy. Self-efficacy refers to individuals' belief in their ability to successfully complete a specific task, which directly influences their motivation and academic achievement (Pintrich & Schunk, 2002). Schunk and DiBenedetto (2016) highlight that when students feel competent, they focus more on tasks and work more effectively. In this context, VR environments can enhance students' self-efficacy by providing personalized and immediate feedback, positively affecting their learning processes (Parong & Mayer, 2018). Specifically, IVR learning environments can offer adaptive feedback, delivering a more effective learning experience compared to traditional approaches (Pulijala et al., 2018).

It is expected that STEM education will positively affect students' motivation, increase their success in science and mathematics, provide meaningful learning, and thus increase the number of students who want to pursue a career in STEM fields (Brown et al., 2011; NAE & NRC, 2014). In this context, motivation, which can be defined as the power that directs an individual to behavior and ensures the intensity and continuation of behavior (Schunk et al., 2014), and learning performance, which can be defined as the achievement of a learning activity in a certain situation (Moccozet, 2012), have an important place in STEM education. In systematic review and meta-analysis studies examining virtual reality applications in STEM education, it has been stated that virtual reality applications facilitate students' learning, increase their motivation, and provide a better understanding of seemingly complex concepts (Tene et al., 2024; Zhang et al., 2024). In addition, there are studies indicating that the use of virtual reality in STEM fields positively affects students' self-efficacy, interest, academic performance, conceptual understanding and motivation (Akgün & Atıcı, 2022; Kuznetcova et al., 2023; Lee at al., 2022; Yildirim et al., 2020). On the other hand, we can say that motivation, self-efficacy, interest and learning performance variables affect each other in the learning process and are affected by each other. In the study conducted by Celcima et al. (2024), it was determined that self-efficacy affects intrinsic and extrinsic motivation and that a high level of self-efficacy enables students to take responsibility for their learning and be interested in what they learn. In the study conducted by Li & Pan (2009), it was stated that interest and motivation are effective on success and that students with high motivation are successful in learning. Arokiaraj et al. (2024) also determined that motivation and academic performance variables are related to each other. Abdulrahman et al., (2023) suggested that motivation is related to self-efficacy and academic performance.

In conclusion, the role of VR simulations in STEM education extends beyond improving learning outcomes; it also enhances student satisfaction, motivation, and long-term engagement in learning. The immersive, interactive, and experiential learning opportunities offered by these technologies serve as powerful tools in preparing students to become capable problem-solvers and innovators in the fields of science, technology, engineering, and mathematics (Parong & Mayer, 2018).

**Present Study**

The rapid increase in the number of individual studies on the use of relevant technologies in the field of education underscores the need for literature reviews on this topic, and the quantity of such studies is growing by the day. Reviewing research within a discipline helps in understanding the current state clearly and assists in guiding future research efforts (Kucuk et al., 2013). In recent years, many review studies on augmented reality have been published. However, a limited number of review studies on the use of virtual reality in STEM education have been reached (Cavdar & Yildirim, 2023; Ebrahimi et al., 2023). In the study conducted by Cavdar & Yildirim (2023), a review of augmented reality, virtual reality and mixed reality studies was conducted. In the study conducted by Ebrahimi et al. (2023), an investigation study was conducted on the augmented reality and virtual reality STEM learning experiences of American K-12 students. At the end of the study, it was stated that there is a tremendous lack of research on VR and AR applications used in the K-12 STEM context. In this study, the use of VR in STEM education at K-12 level was tried to be addressed in depth. In this context, the aim of this study is to examine the methodological research trends of scientific studies published on the use of VR in STEM education at the K-12 level and to identify missing and necessary factors. In this context, it is thought that the comprehensive content analysis findings obtained in this study will contribute to the limited number of review studies on the use of VR in STEM education by providing more comprehensive information. In addition, it is predicted that this study will provide valuable information for researchers investigating VR applications in STEM education. This study is expected to serve as a beneficial resource for researchers in this field in the future. In this context, within the scope of studies on the use of virtual reality in K12 STEM Education, the following general research questions have been tried to be answered:

1) What are the frequently used keywords?
2) What are the commonly observed science domain?
3) What are the commonly observed sample levels?
4) What are the commonly observed sample sizes?
5) What are the commonly observed educational context?
6) What are the commonly observed teaching approaches?
7) What are the duration of instruction reported in?
8) What are the commonly utilized general characteristics of VR applications (VR application, VR features and research type)?
9) What are the research purposes explored?
10) What are the commonly employed research method?
11) What are the commonly observed sampling methods?
12) What are the commonly examined variables?
13) What are the commonly utilized data collection tools?
14) What are the commonly reported findings?

## Method

In this section of the study, the research design and the literature review process are presented.

### Research Design

Within the scope of the first research problem, the distribution of scientific studies in the relevant field based on keywords was analyzed through the data file downloaded from the determined databases. To address the others research questions identified within the scope of this study, descriptive content analysis features were employed.

Descriptive content analysis is an analysis method that allows a systematic and objective examination of the content in scientific studies and the identification of general trends and research results on a particular topic (Stemler, 2001).

In this context, as shown in Figure 1, the key concepts of "STEM Education" and "Virtual Reality" were scanned from the determined databases and the scanning results of the studies were recorded. Then, the data files downloaded from different databases were combined with the R program and the frequently used key concepts were examined according to the years. In the following process, in order to answer other research questions, the researchers examined the scientific article studies carried out at the K-12 level in the context of descriptive content analysis features.

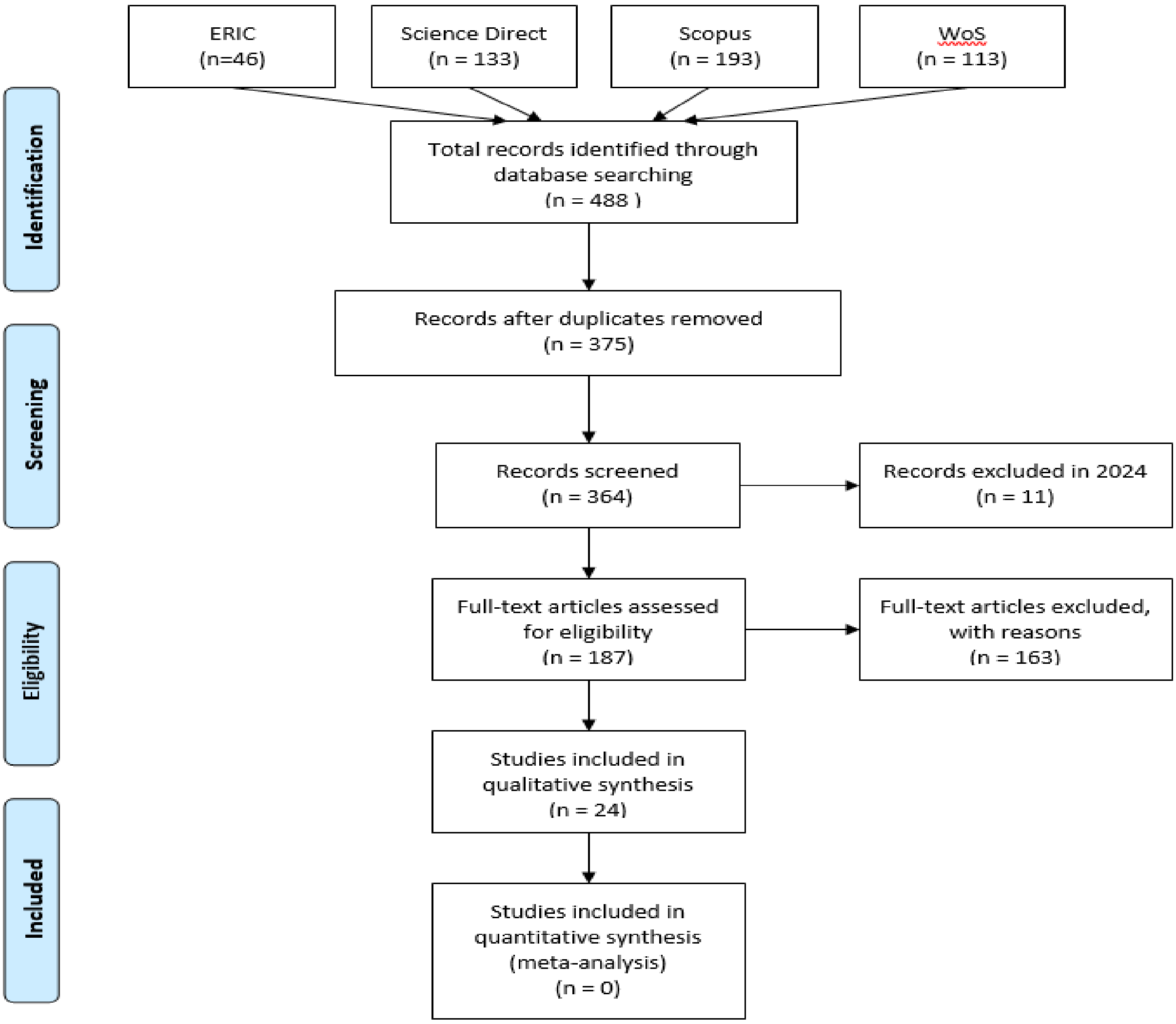


Figure 1. Flowchart of the Study Selection Process

**Literature Review Process**

Within the scope of the research, access was provided to ERIC, Science Direct, Scopus, and Web of Science databases, and the key terms "virtual reality" and "STEM education" were searched based on the topic. In this context, a supplementary search conducted on February 15, 2024, revealed that a total of 364 scientific studies containing the relevant key terms were published between 2008 and 2023. The identified data were first analyzed according to descriptive characteristics such as year, language, author, institution, publishing group, and country. Subsequently, the data obtained for the listed 364 publications were recorded and analyzed using bibliometric analysis programs, Bibliometrix, and VOSviewer, in terms of bibliographic features such as citation counts, co-citation, co-authorship, co-occurrence, and bibliographic coupling, based on authors, institutions, and countries. A total of 24 scientific research articles conducted at the K-12 level within these studies were subjected to content analysis. The number of publications obtained as a result of scanning the relevant key concepts in the databases and the number of articles whose content analysis was carried out as a result of the inclusion-exclusion criteria are presented in the flow chart in Figure 1.

In line with the third research problem identified within the scope of this study, a content analysis was conducted to overcome the mentioned disadvantage of bibliometric analysis. The studies included in the content analysis focused on the use of VR in K-12 STEM education. As part of this approach, it was fundamental that the VR technologies discussed in the included articles adhere to established definitions of virtual reality, yet a study that asserted the application used by the authors as a virtual reality application was also incorporated into the review (Johnson-Glenberg et al., 2015). Furthermore, the inclusion criteria required that the key concepts of 'virtual reality' and 'STEM education' be explicitly listed among the keywords of the articles. This rigorous selection process ensures that the research not only aligns with the objectives of the study but also contributes significantly to a comprehensive understanding of the current state and potential directions in the integration of VR technologies in STEM education.

## Results

The comprehensive view of the dataset obtained from the designated database within the scope of the study, which aims to conduct a bibliometric analysis of scientific research on the utilization of virtual reality in STEM education, is provided in Table 1 through the utilization of the Bibliometrix program.

Table 1. General Information about the Dataset

| Description | Results | Description | Results |
|---|---|---|---|
| Timespan | 2008:2023 | Single-authored docs | 46 |
| Sources (Journals, Books, etc) | 224 | article | 232 |
| Documents | 364 | article; book chapter | 15 |
| Annual Growth Rate % | 22,75 | article; early access | 19 |
| Authors | 1294 | proceedings paper | 93 |
| Authors of single-authored docs | 46 | review | 5 |

When examining Table 1, it is observed that out of the 364 scientific studies included in the dataset, which encompass relevant key concepts, the first publications began in 2008. Since that year, the annual growth rate of scientific publications in this field is also seen to be 22.75%. The field involved contributions from a total of 1294 authors, with 46 of the publications in the field consisting of single-authored works, among other data visible in the table. In terms of the distribution of publication types in the field, articles (232) and conference papers (93) are the majority. Accordingly, based on the data presented and not presented in the table, a general overview of the distribution of publications in terms of descriptive characteristics will be attempted under separate headings, aiming to address the first research problem.

When the common presence of other keywords most frequently found in studies containing the relevant keywords was examined, it was observed that a total of 1738 keywords were included in these publications. While creating the network visualization map with the Vosviewer program for these keywords, a minimum occurrence condition of 5 was set, which was met by 82 keywords. Accordingly, the network visualization map created is presented in Figure 2.

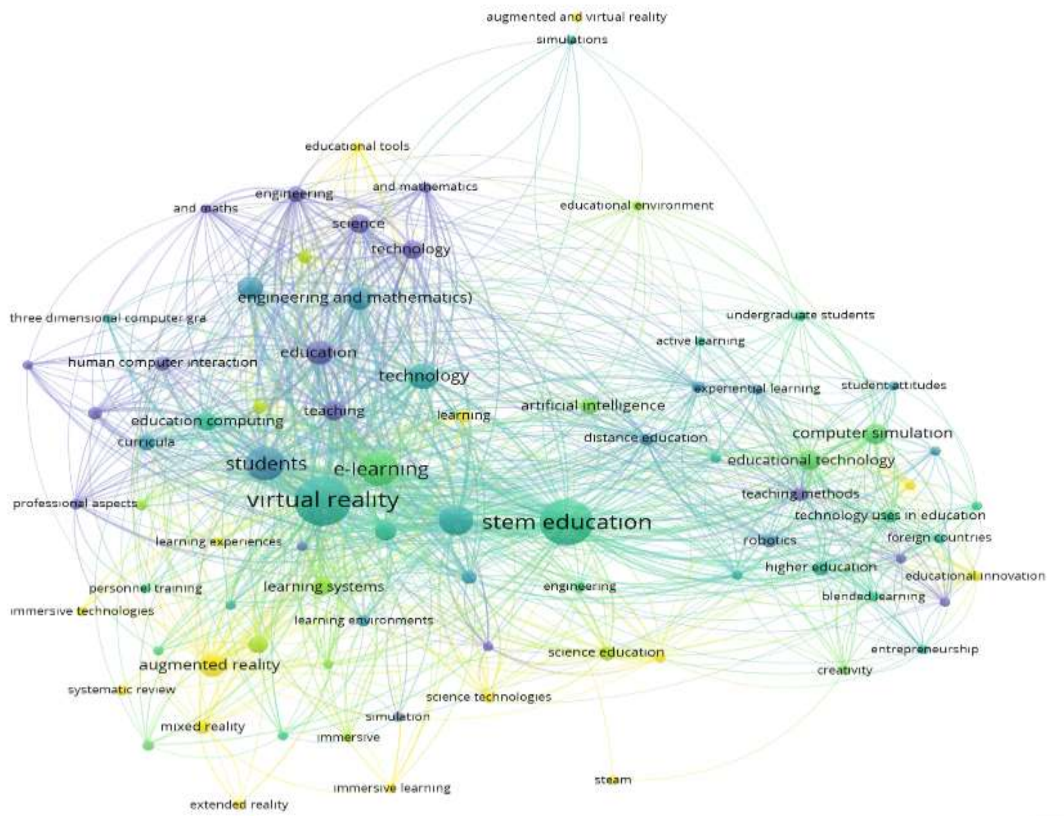


Figure 2. Network Visualization Map for Keywords included in Publications

When examining the network visualization map presented in Figure 7, it is observed that the keyword defined as inclusion criteria in the database, namely 'virtual reality' and 'STEM education,' stand out prominently. Other keyword are also shown in the map in proximity and size relative to their frequency of occurrence in relation to these keywords. The size of the points representing the keywords indicates that the respective keyword appears more frequently in publications in the relevant field. Furthermore, the generated network visualization map also illustrates the evolution of these keywords over the years. In 2018, there was a greater emphasis on keywords such as 'simulation,' 'virtual labs,' and 'game-based learning,' whereas in subsequent years, these keywords evolved towards 'self-efficacy,' 'science education,' and 'systematic review.'

**How is the content analysis of scientific articles on the use of VR in K-12 STEM education?**

This section presents an evaluation of how educators utilize virtual reality to facilitate learning and the impacts of these interventions, as documented in scientific studies on the use of virtual reality at the K-12 level.

*Overview of Reviewed Studies*

Of the 24 studies reviewed from 2015 through 2023, the majority of these studies (20 articles) were published after 2020. National science standards [National Science Teachers' Association, 2014] were used to classify the topics covered in the studies into the following areas: STEM (8 articles), biology (6 articles), physics (5 articles), science (3 articles), geosciences (1article), and geometry (1 article). The preferred educational context was the in-class context (14 articles), followed by laboratory activities with three articles.

The other interventions are online (3 articles), maker class, garden and out of school, one article each, and the environment in which they are carried out is not specified. The participants in the studies were mostly middle school students (14 articles). Other studies focused on high school students (5 articles), elementary school students (1 article), K-12 educators (1 article), or multiple school levels (3 articles). The number of participants in the studies ranged.

from 3 to 406. Most studies were conducted with fewer than 200 participants (19 studies). Other studies were conducted with numbers of participants ranging from 205 to 406 (5 studies). In terms of teaching time, most of the studies were conducted in sessions ranging from 4 to 160 minutes (14 articles), detailed information about the teaching time was not given in three studies, and the study process was explained in general in the other studies (7 articles). An overview of the reviewed articles is given in Table 4.

*General Characteristics of VR Applications in STEM Education*

The features and types of VR applications used in the 24 articles discussing the use of VR in STEM education are presented in Table 3. When describing the VR feature used in the studies, the definition of desktop VR or immersive VR was used. According to the other definition, desktop VR also corresponds to non-immersive, while IVR corresponds to head-mounted display VR. When we look at the VR applications used in the 24 studies examined, it is seen that a different application is used in each study. On the other hand, when looking at the VR feature used, desktop VR is used the most (12 articles), followed by studies using immersive VR (7 articles). In other studies, desktop VR and immersive VR were used together (4 articles) or MR (mixed reality) including virtual and augmented reality was used (1 article). According to the types of VR used in research, it can be divided into three different categories: exploration applications (14 articles), games (6 articles) and simulation (4 articles).

*Methodological Characteristics*

Table 2 presents a methodological analysis of studies conducted on VR implementation in STEM education. Thematic representations of research objectives are provided, along with research and sampling methods, employed measurement tools, and examined variables.

Table 2. Background Information on Reviewed Articles

| Publications | Science domain | Sample level | Sample Sizes | Educational context | Teaching Approaches | Duration of instruction |
|---|---|---|---|---|---|---|
| Blake et al., 2015 | Geosciences | Secondary and high school | 205 | Not specified | Inquiry-Based Learning (IBL) | Part of a 2-year project work |
| Brenner et al., 2021 | Science | Secondary school | 220 | In-class | Collaborative Learning (CL) | 45 min |
| Chen et al., 2020 | STEM (general) | High school | 162 | In-class | The 6E Model | Total 800 min in 3 Stages |
| Damekova et al., 2021 | Science (physics) | Secondary school | 250 | Online | Experiential Learning (EL) | 10 min |
| Holly et al., 2021 | Science (physics) | High school, engineering secondary school and teacher candidates | 85 (26 teacher candidates and 59 students) | In-class | Experiential Learning (EL) | 20 min |
| Huang, 2022 | Sciene (Biology) | High school | 66 | In-class (Laboratory) | Experiential Learning (EL) | 10 min |
| Jiang et al., 2021 | STEM (general) | Secondary school | 39 | Outside of school (garden) | Experiential Learning (EL) | 15 min |
| Johnson-Glenberg et al., 2015 | Science (physics) | Secondary school | 23 | In-class | Digital Game-Based Learning (DGBL) | 4 min |
| Johnson-Glenberg et al., 2023 | Sciene (Biology) | Secondary school | 406 | In-class | Digital Game-Based Learning (DGBL) | 45 min |
| Klingenberg et al., 2023 | Science (biology) | Secondary school | 190 | In-class | Experiential Learning (EL) | 8 min |
| Kuznetcova et al., 2023 | STEM (general) | Secondary school | 169 | In-class | Digital Game-Based Learning (DGBL) | 100 min |
| Moon et al., 2020 | STEM (general) | Secondary school | 4 | In-class | VR-Based Training | 8-16 weeks |
| Mou, 2023 | Science | Secondary school | 56 | In-class | Experiential Learning (EL) | 12 h (4 weeks) |
| Mystakidis & Christopoulos, 2022 | STEM (general) | K-12 educators | 41 | Online | Digital Game-Based Learning (DGBL) | - |
| Ng & Chu, 2021 | STEM (general) | Secondary school | 345 | Out of school | Digital Game-Based Learning (DGBL) | 1.5 h |
| Pathan et al., 2020 | Science (biology) | Secondary school | 3 | In-class | Experiential Learning (EL) | - |
| Pimentel & Kalyanaraman, 2023 | Science (biology) | Secondary school | 100 | In-class | Experiential Learning (EL) | 10 min |
| Poonja et al., | Science | Primary school | 30 | Online | Experiential | 20 min |

| Publications | Science domain | Sample level | Sample Sizes | Educational context | Teaching Approaches | Duration of instruction |
|---|---|---|---|---|---|---|
| 2023 | | | | | Learning (EL) | |
| Puig et al., 2022 | Geometry | Secondary school | 60 | In-class (Laboratory) | Digital Game-Based Learning (DGBL) | 2 h |
| Shu & Huang, 2021 | Science (physics) | High school | 120 | In-class (maker class) | Experiential Learning | 18 weeks |
| Southgate et al., 2019 | STEM (general) | Secondary and high school | 54 | In-class (Laboratory) | Participatory Research Approach | 20 min |
| Thompson et al., 2020 | Science (biology) | High school | 154 | In-class | Inquiry-Based Learning (IBL) | 25 min |
| Wang et al., 2015 | Science (physics) | High school | 145 | In-class | Model-Based Inquiry (MBI) | - |
| Xie & Zhang, 2023 | STEM (general) | Secondary school | 27 | In-class | Project-Based Learning (PBL) | 160 min |

Table 3. General Characteristics of VR Applications in STEM Education

| Publications | Used VR Applications | VR Features | Type |
|---|---|---|---|
| Blake et al., 2015 | Second Life | Desktop VR | Exploration |
| Brenner et al., 2021 | GeoForge | Desktop VR | Exploration |
| Chen et al., 2020 | zSpace AIO computer system | Desktop VR | Exploration |
| Damekova et al., 2021 | 3D Labster virtual laboratory | Desktop VR | Exploration |
| Holly et al., 2021 | Maroon – Virtual learning application. | Desktop VR and Immersive VR | Exploration |
| Huang, 2022 | Head-mounted display virtual reality (The virtual reality application was developed with Unity 5 within the scope of the study). | Immersive VR | Exploration |
| Jiang et al., 2021 | VR 360 videos (Viewing the videos with the Google Cardboard glasses and the iPhone was considered the full VR experience) | Desktop VR and Immersive VR | Exploration |
| Johnson-Glenberg et al., 2015 | 'Tour de Force' and 'Winching Game' | MR | Game |
| Johnson-Glenberg et al., 2023 | Giant screen films (2D Giant Screen, 3D Giant Screen, and Dome formats) | Desktop VR and Immersive VR | Game |
| Klingenberg et al., 2023 | What Happens Inside Your Body? | Immersive VR | Simulation |
| Kuznetcova et al., 2023 | Not specified | Desktop VR and Immersive VR | Game |
| Moon et al., 2020 | Opensimulator | Desktop VR | Simulation |
| Mou, 2023 | Not specified | Desktop VR | Simulation |
| Mystakidis & Christopoulos, 2022 | Room of Keys | Desktop VR | Game |
| Ng & Chu, 2021 | X-Plane<br>Mobile Manual; Aircraft Rotations; X-Plane 10 Flight School Application | Desktop VR | Simulation |
| Pathan et al., 2020 | Human Circulatory System | Immersive VR | Exploration |
| Pimentel & Kalyanaraman, 2023 | Virtual Climate Scientist | Immersive VR | Exploration |
| Poonja et al., 2023 | Vuforia, Unity 3D, and Open-Haptics | Desktop VR | Exploration |

| Publications | Used VR Applications | VR Features | Type |
|---|---|---|---|
| Puig et al., 2022 | VR Math | Desktop VR | Game |
| Shu & Huang, 2021 | VR Makerspace introduction materials | Desktop VR | Exploration |
| Southgate et al., 2019 | Minecraft | Immersive VR | Exploration |
| Thompson et al., 2020 | Cellverse | Immersive VR | Game |
| Wang et al., 2015 | MBI (Model-based inquiry)-VPL (virtual physics lab) pedagogy. | Desktop VR | Exploration |
| Xie & Zhang, 2023 | Immersive virtual reality (IVR) | Immersive VR | Exploration |

Table 4. Methodological Characteristics of the Reviewed Articles

| Publications | Research purpose | Research method | Sampling method | Examined variables | Measuring tools used |
|---|---|---|---|---|---|
| Blake et al., 2015 | Increasing Interest and Awareness in STEM through VR | Quantitative/ Full experimental | The whole universe | Professional development, summer geoscience research, virtually exploring the geosciences, geoscience exposure events and geoscience community outreach programs. | Satisfaction surveys; Interviews; Pre- and post-knowledge test; Module feedback; Surveys; Satisfaction surveys; Feedback surveys. |
| Brenner et al., 2021 | Design and Use of VR in Educational Technologies | Mixed/ Triangulation | Convenience | Designing and testing of GeoForge | Classroom observation; Teacher interviews; Student survey; Digital science journal entries |
| Chen et al., 2020 | Design and Use of VR in Educational Technologies | Quantitative/ Full experimental | Convenience | Learning performance, hands-on abilities. | Learning performance test (The test was developed for this study and consists of 20 multiple choice questions); The Creative Product Analysis Matrix (CPAM; Besemer, 1998) was used to assess applied ability; Behavioural indicators. |
| Damekova et al., 2021 | Learning and Motivation through VR | Mixed/ Triangulation | Convenience | Children's interest in STEM and general interest in science. | Likert scale specially developed to determine students' increase in interest in STEM and their general interest in science; Semi-structured interview. |
| Holly et al., 2021 | Design and Use of VR in Educational Technologies | Quantitative/ Quasi-experimental | Convenience | Designing VR experiences, expectation for teaching and learning in VR. | Experience with computers, video games and VR on a Likert scale; About their overall experience 22 |

| Publications | Research purpose | Research method | Sampling method | Examined variables | Measuring tools used |
|---|---|---|---|---|---|
| | | | | | questions on a Likert scale and 10 open-ended questions regarding usability; System Usability Scale (SUS) (Brooke, 1996); Computer Emotion Scale (Kay & Loverock, 2008); interview. |
| Huang, 2022 | Learning and Motivation through VR | Quantitative/ Quasi-experimental | The whole universe | Student's self-efficacy in science. | Science self-efficacy scale (developed within the scope of the study.) |
| Jiang et al., 2021 | Increasing Interest and Awareness in STEM through VR | Qualitative/Case study | Convenience | Career development | Semi-structured interviews form. |
| Johnson-Glenberg et al., 2015 | Educational Gamification and Innovative VR Approaches | Quantitative/Full experimental | Convenience | Gameplay and learning performance | Gears knowledge test |
| Johnson-Glenberg et al., 2023 | Increasing Interest and Awareness in STEM through VR | Quantitative/Full experimental | Random | Science identity', 'science knowledge' and 'change in performance on the natural selection | Science identity scale; Science knowledge test; Catch a mimic – Natural selection butterfly videogame |
| Klingenberg et al., 2023 | Evaluation and Assessment in VR Learning Environments | Quantitative/Full experimental | Random | Learning performance | Questionnaire assessing prior knowledge about the human body (Parong & Mayer, 2018); Binary response scale with the options "yes" and "no" |
| Kuznetcova et al., 2023 | Increasing Interest and Awareness in STEM through VR | Quantitative/ Quasi-experimental | Random | Visuospatial self-efficacy, Visuospatial performance, STEM performance | Visuospatial performance data (Ramful et al., 2017); Visuospatial self-efficacy (VSSE) (Kuznetcova et al., 2022); Demographic and STEM performance data were gathered from the school district official records (gender, age, grade level, ethnicity, gaming experience and mean STEM course grade pre- |

| Publications | Research purpose | Research method | Sampling method | Examined variables | Measuring tools used |
|---|---|---|---|---|---|
| | | | | | intervention and post-intervention) |
| Moon et al., 2020 | Design and Use of VR in Educational Technologies Evaluation and Assessment in VR Learning Environments | Quantitative/Full experimental | Convenience | Problem solving skill flexibility | Natural language processing; Machine-learning techniques |
| Mou, 2023 | Learning and Motivation through VR | Mixed/Triangulation | Convenience | Attitudes toward science learning, animation integration in science class, and understanding level in science | Focus group interview; attitudes toward science learning; attitudes toward animation integration; knowledge test (Measurement tools were developed within the scope of the study.) |
| Mystakidis & Christopoulos, 2022 | Educational Gamification and Innovative VR Approaches | Mixed/Triangulation | The whole universe | Teacher view and perceptions (perceived enjoyment, motivation, cognitive benefits, learning effectiveness,satisfaction) | Open-ended questions; informal discussions during the online debriefing session; Questionnaire regarding participants' VR perceptions |
| Ng & Chu, 2021 | Learning and Motivation through VR | Quantitative/Quasi-experimental | Convenience | Motivation to learning STEM (intrinsic motivation, extrinsic motivation, self-efficacy motivation and peer learning motivation) | A modified version of the 31-item Science Motivation Questionnaire II (SMQ II) |
| Pathan et al., 2020 | Design and Use of VR in Educational Technologies<br><br>Challenges and Accessibility in VR-Based Learning | Quantitative/Weakly experimental | Convenience | Learner's interaction in VR-based learning environment | VR-learners interaction analysis |
| Pimentel & Kalyanaraman, 2023 | Increasing Interest and Awareness in STEM through VR | Quantitative/Full experimental | Random | Science self-efficacy | Social presence scale (Bente et al., 2008); Attitudes towards the simulation scale (Kalyanaraman & Sundar, 2006); The Thinking about Science |

| Publications | Research purpose | Research method | Sampling method | Examined variables | Measuring tools used |
|---|---|---|---|---|---|
| | | | | | Instrument v1 (TSSI-v1) (Cobern & Loving, 2002). |
| Poonja et al., 2023 | Design and Use of VR in Educational Technologies<br><br>Evaluation and Assessment in VR Learning Environments | Quantitative/ Quasi-experimental | Convenience | Student engagement | PANAS Questionnaire; The NASA Task Load Index |
| Puig et al., 2022 | Educational Gamification and Innovative VR Approaches | Quantitative/ Quasi-experimental | Not specified | Gamified learning, gamification, teacher opinion | Questionnaire regarding their perception of the experience in terms of learning and fun; Questionnaire on students' perception of the learning process and satisfaction |
| Shu & Huang, 2021 | Increasing Interest and Awareness in STEM through VR | Quantitative/Full experimental | Convenience | Maker knowledge, maker self-efficacy, maker works and effect of VR and maker course. | Makerspace test; Knowledge test; Material knowledge test; Scale of Maker self-efficacy; Profile assessment |
| Southgate et al., 2019 | Challenges and Accessibility in VR-Based Learning | Mixed/ Triangulation | Conditional | The ethical and safety issues of using IVR in classrooms, | Observation; audio and video recording of students in IVR and screen capture; student engagement surveys; student work samples which included reflection on the IVR experience and grades; semi-structured student interviews conducted in class 'vox pop' style with students directly out of IVR; written teacher and researcher reflection. |
| Thompson et al., 2020 | Learning and Motivation through VR<br><br>Challenges and | Quantitative/Full experimental | Convenience | Learning performance, Cell drawing and VR experience of students | Cell biology knowledge; Cell drawing |

| Publications | Research purpose | Research method | Sampling method | Examined variables | Measuring tools used |
|---|---|---|---|---|---|
| | Accessibility in VR-Based Learning | | | | |
| Wang et al., 2015 | Learning and Motivation through VR | Quantitative/Quasi-experimental | Not specified | MBI (Model-based inquiry)-VPL (virtual physics lab) classroom-based learning model, scientific inquiry skills | Scientific Inquiry Assessment Questionnaire (developed within the scope of the study) |
| Xie & Zhang, 2023 | Learning and Motivation through VR Increasing Interest and Awareness in STEM through VR | Quantitative/Weakly experimental | Convenience | Students' comprehension of scientific knowledge, students' design and the acceptance of teacher and students | Knowledge test; Observation sheet; Design worksheet; Interview outline (Measurement tools were developed within the scope of the study.) |

By analyzing the research aims on the use of VR in STEM education, it was seen that these research aims could be grouped under 6 different themes. These themes are Increasing Interest and Awareness in STEM through VR (7 articles), Learning and Motivation through VR (7 articles), Design and Use of VR in Educational Technologies (6 articles), Educational Gamification and Innovative VR Approaches (3 articles), Challenges and Accessibility in VR-Based Learning (3 articles) and Evaluation and Assessment in VR Learning Environments (3 articles). It is seen that 5 articles can be placed under two of the determined themes and the other articles can be grouped under one theme each.

In general, in the reviewed articles, different VR applications were integrated into the teaching process according to various teaching approaches and various measurement tools were used to observe and evaluate their effects on variables such as academic achievement, learning motivation, attitude, self-efficacy and others among the students in the study group. Accordingly, a visual representation of which VR applications and which learning outcomes were examined in the reviewed studies is presented in Figure 3.

As presented in Figure 3 the relationships between these variables are primarily mediated by the unique characteristics of VR—such as immersive experiences, interactive interfaces, and the ability to visualize otherwise abstract concepts—which can support different learning approaches. As shown in the study by Wang et al. (2015), inquiry-based learning, when enhanced through VR, can provide a deeper, more interactive exploration of scientific phenomena, leading to more significant gains in student acceptance and understanding. In summary, VR has been integrated into STEM education in diverse ways, with applications such as "VR Bird Feeder," "Virtual Physics Lab," and "Flight Simulation" demonstrating significant impacts on student engagement, understanding, and motivation. These applications serve as powerful tools to mediate the relationships between learning approaches (as independent variables) and student outcomes (as dependent variables). By leveraging the immersive and interactive qualities of VR, these studies collectively highlight the potential for VR to enhance both the effectiveness and equity of STEM education.

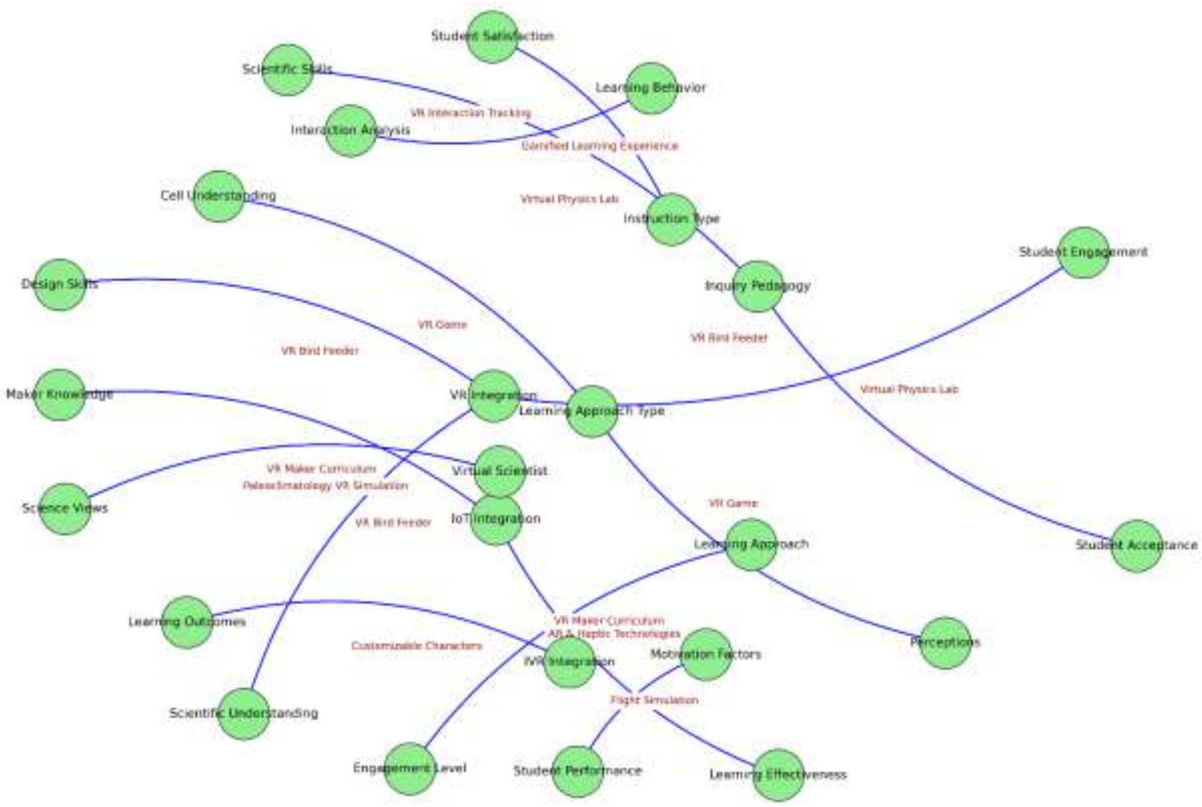


Figure 3. Visual Representation of which VR Applications and which Learning Outcomes were Examined

It is observed that 15 of the 24 research articles were designed according to quantitative methods, 8 according to mixed methods and only one according to qualitative research methods. Experiential Learning (10) and Digital Game-Based Learning (6) were the most used teaching approaches.

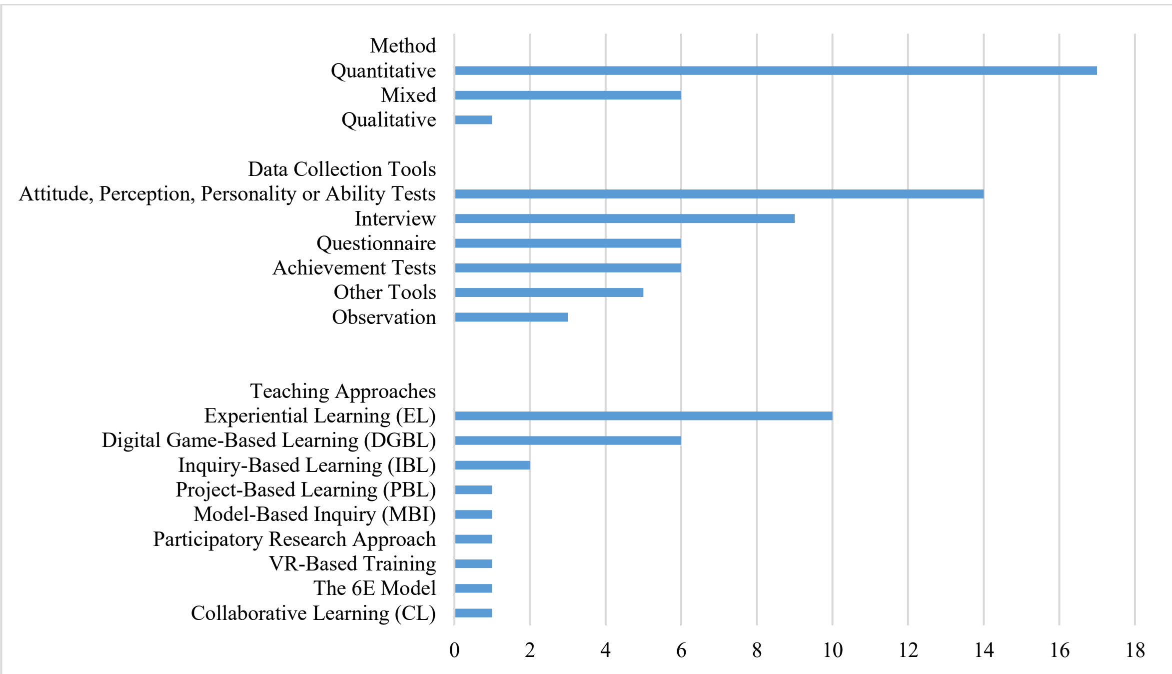


Figure 4. Distribution of Studies conducted at the K-12 Level according to Research Method and Data Collection Tools

According to Figure 4, it is observed that the vast majority of the studies (70.83%) were conducted according to quantitative research methods. Furthermore, it is noted that both full and quasi-experimental research designs were preferred in these studies to examine the effects of any intervention on the determined variables. In the studies conducted according to mixed research methods, the basis of the design adopted has not been specified. In addition, it is seen that the majority of the studies are designed according to Experiential Learning and Digital Game-Based Learning teaching approaches. Furthermore, upon examining Figure 4, it is observed that studies typically address multiple variables, and to examine the changes in these variables, multiple measurement tools are utilized. In this context, the relevant studies make use of observation, various achievement tests, alternative instruments (performance tests, diagnostic tests, concept maps, portfolios), interviews/focus group discussions, surveys (open-ended, multiple-choice, Likert scale), as well as attitude, perception, personality, or aptitude tests (open-ended, multiple-choice, Likert scale). On the other hand, in the studies examined, it was seen that alternative tests (attitude, perception, personality or ability tests), achievement tests and questionnaires were the most frequently used quantitative data collection tools. Additionally, it is noted that applied skill assessment indicators, behavioral indicators, emotion detection, behavioral detection, and head pose estimation measurement tools are referred to as 'other tools'.

The distribution of sampling methods employed for determining the sample and the sample sizes in these studies is presented in Figure 5.

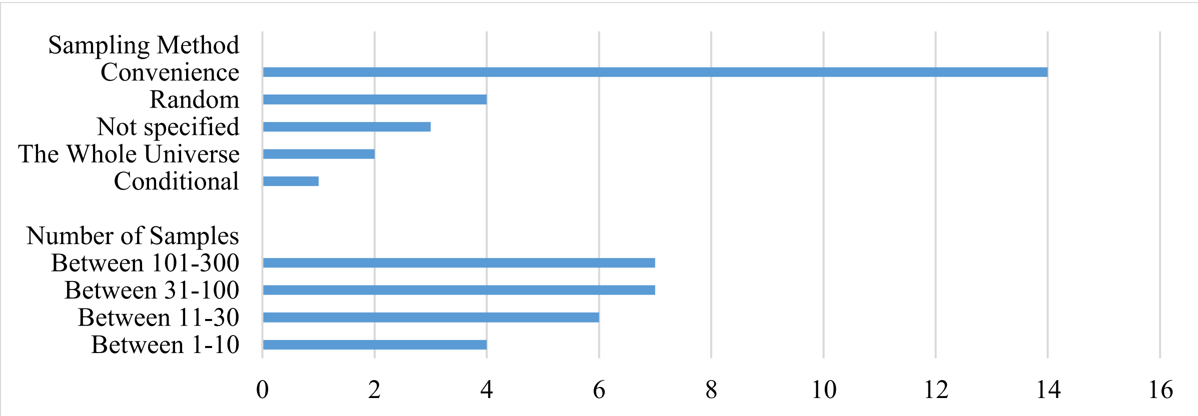


Figure 5. Sampling Details for Studies conducted at the K-12 Level

According to Figure 5, it is evident that in the majority of the studies conducted in this field (%58.33), convenience sampling methods have been utilized for determining the study groups. It was also observed that studies were conducted more with study groups consisting of 31-100 and 101-300 participants, and studies were conducted less with 1-10 participants.

## Discussion and Conclusion

In this study, a content analysis of scientific studies related to the use of virtual reality in K-12 STEM education has been carried out. In this context, within the framework of the defined sub-objectives, studies that include the keywords 'virtual reality' and 'STEM education' in the ERIC, Science Direct, Scopus, and Web of Science databases were analyzed in terms of content analysis characteristics of the publications. Accordingly, it has been observed that a total of 364 scientific studies were published in the fields of interest within the databases between the years 2008-2023.

The use of VR in education not only increases student motivation and engagement but also supports the concretization of abstract concepts and experiential learning (Radianti et al., 2020). This situation has led researchers to examine VR technologies more deeply and enrich the literature in this field. Moreover, this result is considered to provide a significant roadmap for future research. It is evident that more research is needed to understand the impacts of VR technologies in education comprehensively and to develop strategies for their most effective use (Makransky & Lilleholt, 2018). In this context, interdisciplinary collaborations and evaluations of long-term effects are deemed critical in fully realizing the potential of VR technologies in education.

When examining the most frequently used keywords in scientific studies conducted in the relevant field, it is observed that the terms 'virtual reality' and 'STEM education' take the forefront. The emergence of this situation is a natural and expected outcome, as these keywords have been used to access relevant publications. The prevalence of these keywords underscores the focused and specialized interest in the integration of virtual reality within STEM education (Chen & Hirschheim, 2004).

Out of a total of 364 scientific studies conducted in the relevant field, it was observed that 232 were article studies, of which only 24 were found to be associated with the K-12 level. Accordingly, it is noteworthy that the most frequently addressed variables in studies on the use of virtual reality in the field of STEM education are learning performance, self-efficacy, and different types of motivation. This is an expected situation since these are the most frequently included variables in studies (Chen et al., 2020; Johnson-Glenberg et al., 2023; Huang, 2022; Klingenberg et al., 2023; Kuznetcova et al., 2023; Mou, 2023; Mystakidis & Christopoulos, 2022; Ng & Chu, 2021; Pimentel & Kalyanaraman, 2023; Shu & Huang, 2021; Thompson et al., 2020; Xie & Zhang, 2023). A similar situation emerges in the studies conducted in the literature (Arici et al., 2019; Sirakaya and Alsancak-Alsancak, 2022). Since learning performance is greatly affected by motivation and self-efficacy, it is understandable that these variables are considered together in the studies examined (Bong et al., 2012; Klomegah, 2007; Kriegbaum et al., 2015; Prast et al., 2018; Spinath et al., 2006; Valentina et al., 2004; Yusuf, 2011; Živčić-Bećirević et al., 2017). On the other hand, the most important question to be asked when incorporating any new technology into education is whether this technology contributes to academic success (Middleton & Murray, 1999). However, one of the important factors affecting the use of new technologies is the motivation variable (Baydas & Goktas, 2016), and understanding students' motivational tendencies and cognitive development plays an important role in the success of their individualized education at school (Van Vo & Csapó, 2023). In this context, it can be said that it is important to examine the effect of virtual reality technology, which constantly renews itself with the innovations in developing technology, on variables such as motivation, learning performance and self-efficacy. On the other hand, it was observed that virtual reality technologies had a positive effect on the variables of motivation, learning performance and self-efficacy, the effects of which were most frequently examined in this study (Chen at al., 2020; Mou, 2023; Mystakidis & Christopoulos, 2022; Ng & Chu, 2021). For example, in the study conducted by Ng and Chu (2021), it was determined that students' self-efficacy, intrinsic and extrinsic motivation were positively affected by STEM activities implemented with flight simulation activities. In the study conducted by Mystakidis and Christopoulos (2022), it was stated that virtual reality escape rooms can provide cognitive benefits for students in STEM education and increase learning outcomes. There are also studies in the literature that are consistent with the findings of this research indicating that virtual reality applications positively affect students' success, learning performance and motivation (Brij and Belhadaoui, 2021; Makransky and Lilleholt, 2018; Pellas et al., 2021). In this context, it can be said that virtual reality technology positively affects learning by concretizing abstract knowledge and enabling students to take an active role in the learning process by doing and experiencing, and that this technology motivates students to learn. This situation can also be put forward as one of the reasons why variables such as learning performance, motivation and self-efficacy related to virtual reality technology in STEM education at the K-12 level are most frequently addressed. Finally, since studies on VR applications in STEM education generally focus on motivation, success and self-efficacy, it is thought that examining these variables may reach a saturation point. For this reason, it is recommended that different cognitive and affective variables such as 21st century skills be examined in future studies on STEM education and VR applications.

On the other hand, although different VR types were used in the examined studies, it is seen that the majority of the studies used desktop VR (Blake et al., 2015; Brenner et al., 2021; Chen et al., 2020; Damekova et al., 2021; Moon et al., 2020; Mou, 2023; Mystakidis & Christopoulos, 2022; Ng & Chu, 2021; Poonja et al., 2023; Puig et al., 2022; Shu & Huang, 2021; Wang et al., 2015). For example, while examining the VR types used in the studies, Brenner et al. (2021) stated that multi-user VR environments encourage collaborative behaviors and positive learning experiences. In Huang's (2022) study, it was emphasized that HMD VR learning environments did not significantly increase students' science self-efficacy, but the integration of physical movements and gestures was an important factor. The use of different simulation types and different environments in the relevant simulations also allowed the immersion feature of VR to be examined on the variables examined. For example, in the study conducted by Klingenberg et al. (2023), it was found that adding segmentation or summarization to IVR lessons increased knowledge transfer, but did not cause an increase in actual knowledge acquisition. Although the use of different VR features in studies is important in terms of testing the effectiveness and usability of different VR types in the teaching process, the general use of desktop VR may be due to the fact that this VR type is more accessible than others. In addition, the fact that desktop VR is the appropriate VR type for the specified level of education may have caused this result (Merchant et al., 2014). Finally, when compared to immersive VR applications, desktop VR applications are relatively easier to develop and more cost-effective since they do not require expensive software and hardware (Furth 2008). Therefore, another reason why desktop VR applications are preferred the most may be that desktop VR applications are less costly, easier to develop and more practical than immersive VR applications. On the other hand, in this study, it was determined that desktop VR applications applied in STEM fields are mostly in the exploration type. In this context, it can be said that desktop VR applications are preferred more by researchers than immersive VR applications in providing detailed exploration of a subject or situation related to STEM fields. In the studies examined, it was seen that this exploration type can be related to a theoretical scientific subject/phenomenon or it can include an exploration related to STEM careers. For example, in the study conducted by Blake et al. (2015), concepts related to geology were taught to middle and high school students via desktop VR, which provides a three-dimensional and online virtual environment, and students were allowed to explore these concepts, and as a result of the research, it was determined that students' knowledge and awareness of geology increased. Similarly, in the study conducted by Brenner et al. (2021), where GeoForge-supported desktop VR applications were implemented with middle school students, it was observed that middle school students made discoveries about planetary science and as a result of the research, students' collaborative behaviors improved. Unlike these examples, in the study conducted by Jiang et al. (2021), virtual reality technology was not used for a specific scientific subject/phenomenon, but was used to encourage students to explore careers in STEM fields, and as a result of the study, it was determined that virtual reality technology and VR 360 videos increased middle school students' interest in STEM careers. Based on the findings, it can be stated that VR technologies applied in STEM fields can be used for cognitive purposes such as concretizing abstract theoretical knowledge related to a certain discipline and enabling students to discover these subjects, as well as for affective purposes such as providing career guidance to students.

In the studies examined, it was seen that the most frequently used teaching approaches were experiential learning and digital game-based learning. In STEM education, when students encounter a problem situation, they review their previous knowledge as in the constructivist approach and build the newly learned information by establishing relationships on their previous knowledge. In this context, the fact that these teaching approaches, which are frequently preferred in STEM education (Larkin and Lowrie, 2023), are compatible with the constructivist approach (Robinson et al., 2008) may be one of the reasons why these approaches are preferred. In addition, adopting an experiential approach in STEM education allows students to be involved in what is being learned. Experiential learning provides a deeper understanding of STEM concepts and provides students with superior skills in applying these concepts in various situations (The Sphero Team, 2024). On the other hand, the fact that the subject to be taught in different disciplines in STEM education is abstract and multidimensional strengthens learning these disciplines (Corredor et al., 2014). Digital games have a profound potential to overcome this challenge and positively affect students' learning outcomes (Wang et al., 2022). The reason why experiential learning and digital game-based learning are the most preferred approaches in STEM education in the studies examined in this research may be that these approaches are pedagogically compatible with STEM education and support STEM education. As in STEM education, in both approaches, students are active in the learning environment and theoretical knowledge is concretized, which may have caused them to be preferred more in the studies conducted by researchers.

Since the aim of the relevant research is to reveal the effect on a variable, experimental studies were naturally used. As a result of this situation, it is seen that 18 out of 24 scientific research articles were conducted using various experimental designs within quantitative research methods. This finding is consistent with the literature. It has been determined that quantitative studies are mostly preferred in compilation studies on virtual reality (Cavdar and Yildirim, 2023; Pellas et al., 2021). It is thought that this prevalence is due to the concern of objectively testing the effect of VR technology on students' determined variables (Hranstinski and Keller, 2007) and the fact that educational studies are more suitable for quasi-experimental studies due to their nature (McMillan and Schumacher, 2014). In addition, although mixed method studies are difficult and time-consuming to conduct (Küçük et al., 2013) and the use of quantitative methods is generally more convenient in terms of time and cost (Arici et al., 2019), these may be among the reasons why quantitative methods are preferred in the reviewed studies. Another reason may be that in recent years, qualitative studies have been less preferred and the tendency towards quantitative and mixed studies has increased (Chen et al., 2017). Radianti et al. (2020) emphasized that quantitative and qualitative research methods should be used together and evaluated more comprehensively in educational VR studies. It is thought that in future studies on the use of VR in STEM education, more comprehensive and holistic results will be obtained in the relevant field by using qualitative and mixed research methods in addition to quantitative methods.

In the reviewed studies, it was found that alternative tests (attitude, perception, personality or ability tests), achievement tests, and scales were the most frequently used quantitative data collection tools. The findings are similar to the literature. In the study conducted by Cavdar and Yildirim (2023), it was found that achievement tests and alternative tests were the most frequently used quantitative data collection tools. In studies on the use of AR, a similar technology, in science education (Arici et al., 2019) and STEM education (Sirakaya and Alsancak-Sirakaya), achievement tests were found to be the most frequently used data collection tool, and the finding obtained from the study is consistent with the literature. In the studies reviewed in the research, it is seen that convenience sampling methods were determined in sample selection and small groups were generally studied. The findings are similar to the literature (Arici et al., 2019); Sırakaya and Alsancak-Sirakaya, 2022; Cavdar and Yildirim, 2023). This sampling method is generally preferred because it enables easy access to the sample group (Baydas et al., 2015). In addition, it is thought that the more frequent use of experimental methods in the reviewed studies may have been effective in the selection of this sampling method. On the other hand, it was determined that more studies were conducted with study groups consisting of 31-300 participants, and fewer studies were conducted with 1-10 participants. This finding may be due to the fact that quantitative methods were mostly preferred in the reviewed studies.

In conclusion, the integration of VR into STEM education, guided by constructivist, experiential, and situated learning theories, enhances both cognitive and affective learning outcomes. By employing inquiry-based, problem-based, project-based, and game-based learning approaches within immersive VR settings, educators can create engaging and impactful learning experiences. These technologies not only improve students' academic achievement and knowledge retention but also foster motivation, self-efficacy, and long-term engagement. As VR continues to evolve, its potential to transform STEM education will undoubtedly expand, preparing students to address complex real-world challenges as innovative thinkers and problem-solvers.

## Practical Applications and Recommendations

It is considered that practical application recommendations can be developed based on the bibliometric analysis of scientific studies on the use of VR in STEM education and the content analysis of scientific articles conducted at the K-12 level. When integrating VR into STEM education, it is crucial to align technological applications with appropriate instructional approaches to maximize learning outcomes. The findings emphasize the importance of active learning strategies, such as project-based and inquiry-based learning, which leverage VR’s immersive potential to engage students in meaningful problem-solving and exploratory activities. By incorporating real-world scenarios—such as designing sustainable engineering solutions or simulating scientific experiments—

educators can foster deeper conceptual understanding, critical thinking, and collaboration among learners. As studies like those by Johnson-Glenberg et al. (2016) and Pellas et al. (2017) suggest, active participation in VR environments enhances academic achievement by encouraging students to interact with content in meaningful ways.

Furthermore, VR's capacity to provide scaffolded learning experiences tailored to diverse student needs is significant. Teachers should be equipped with professional development opportunities that not only build technical proficiency but also promote the effective use of VR tools to support differentiation. This is especially vital in reducing cognitive load and ensuring equitable access to quality education for all students, as highlighted by Lee and Nersesian (2020). The motivational benefits of VR are equally noteworthy; by creating engaging and visually stimulating environments, VR can spark interest in STEM fields, particularly among underrepresented groups, thereby addressing gaps such as the gender disparity in STEM participation (Christopoulos et al., 2018).

Lastly, aligning VR activities with specific learning outcomes is essential to ensure that its use transcends novelty. By explicitly tying VR-based lessons to curriculum goals, educators can achieve measurable gains in knowledge and skills, as demonstrated by Freina and Ott (2015). Moreover, incorporating socio-cognitive instructional design principles—such as collaborative and reflective activities within virtual environments—can amplify VR's effectiveness. Group-based tasks requiring students to share perspectives and negotiate solutions not only enhance critical thinking and communication but also prepare students for complex real-world challenges (Asad et al., 2021). Collectively, these strategies underscore VR's transformative potential in STEM education, empowering students to become innovative thinkers and problem-solvers.

**Research Limitations**

The articles examined in this research are limited to studies in ERIC, Science Direct, Scopus and Web of Science databases. By examining the studies in national databases, more specific results can be obtained according to the countries and publication languages of the publications. The content analysis section of this research is limited to research articles on the use of virtual reality technology at the K-12 level.

## References

Abdulrahman, K. A. B., Alshehri, A. S., Alkhalifah, K. M., Alasiri, A., Aldayel, M. S., Alahmari, F. S.,Alothman, A.M., & Alfadhel, M. A. (2023). The relationship between motivation and academic performance among medical students in Riyadh. *Cureus*, *15*(10).

Akcayir, M., & Akcayir, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational research review*, *20*, 1-11. https://doi.org/10.1016/j.edurev.2016.11.002

Akgün, M., & Atıcı, B. (2022). The Effects of ımmersive virtual reality environments on students' academic achievement: A meta-analytical and meta-thematic study. *Participatory Educational Research*, *9*(3), 111-131. http://dx.doi.org/10.17275/per.22.57.9.3

Apostolellis, P., & Bowman, D. A. (2014, November). Evaluating the effects of orchestrated, game-based learning in virtual environments for informal education. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology* (pp. 1-10).

Arokiaraj, K. A., Prakash, K., Sibi, M. S., Tamilselvi, R., Shanmugapriya, R., & Ali, M. S. (2024). Investigating The Relationship Between Student Motivation And Academic Performance. *Educational Administration: Theory and Practice*, *30*(5), 2713-2727. https://doi.org/10.53555/kuey.v30i5.3327

Asad, M. M., Naz, A., Churi, P., & Tahanzadeh, M. M. (2021). Virtual reality as pedagogical tool to enhance experiential learning: a systematic literature review. *Education Research International*, *2021*(1), 7061623. https://doi.org/10.1155/2021/7061623

August, S. E., Hammers, M. L., Murphy, D. B., Neyer, A., Gueye, P., & Thames, R. Q. (2015). Virtual engineering sciences learning lab: Giving STEM education a second life. *IEEE Transactions on Learning Technologies, 9*(1), 18-30.

Arici, F., Yildirim, P., Caliklar, Ş., & Yilmaz, R. M. (2019). Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis. *Computers & education*, *142*, 103647.

Baydas, O., Kucuk, S., Yilmaz, R. M., Aydemir, M., & Goktas, Y. (2015). Educational technology research trends from 2002 to 2014. *Scientometrics, 105*(1), 709–725.

Baydas, O., & Goktas, Y. (2016). Teachers and preservice teachers intentions to use ICT: The keys to ICT integration in school. *Mersin University Journal of the Faculty of Education, 12*(1), 145–162. https://doi.org/10.17860/efd.24292

Bindu, D., & Subin, K. S. (2024). The Impact Of Virtual Reality Simulations On Learning Outcomes In Stem Education. *Educational Administration: Theory and Practice*, *30*(5), 12933-12937. https://doi.org/10.53555/kuey.v30i5.5618

*Blake, R. A., Liou-Mark, J., & Lansiquot, R. D. (2015). Promoting the geosciences among grades 8–12 minority students in the urban coastal environment of New York City. *Journal of Geoscience Education, 63*(1), 29-40. https://doi.org/10.5408/13-101.1

Bong, M., Cho, C., Ahn, H. S., & Kim, H. J. (2012). Comparison of self-beliefs for predicting student motivation and achievement. Journal of Educational Research, 105, 336–352. https://doi.org/10.1080/00220671.2011.627401

Boyd, F. B. (2002). Motıvatıon To Contınue: Enhancıng Lıteracy Learnıng For Strugglıng Readers And Wrıters. *Reading & Writing Quarterly*, *18*(3), 257–277. https://doi.org/10.1080/07487630290061818

*Brenner, C., DesPortes, K., Ochoa Hendrix, J., & Holford, M. (2021). GeoForge: Investigating integrated virtual reality and personalized websites for collaboration in middle school science. *Information and Learning Sciences, 122*(7/8), 546-564. https://doi.org/10.1108/ILS-12-2020-0254

Bric, J. D., Lumbard, D. C., Frelich, M. J., & Gould, J. C. (2016). Current state of virtual reality simulation in robotic surgery training: a review. *Surgical endoscopy*, *30*, 2169-2178. https://doi.org/10.1007/s00464-015-4517-y

Brij, Y., & Belhadaoui, H. (2021) Virtual and Augmented Reality in school context: A literature review. *ICCSRE'2021, E3S Web of Conferences*, 297, 01027. https://doi.org/10.1051/e3sconf/202129701027

Brown, R., Brown, J., Reardon, K., & Merrill, C. (2011). Understanding STEM: Current perceptions. *Technology and Engineering Teacher, 70*(6), 5-9.

Cakiroglu, Ü., & Gokoglu, S. (2019). Development of fire safety behavioral skills via virtual reality. *Computers & Education*, *133*, 56-68. https://doi.org/10.1016/j.compedu.2019.01.014

Caprile, M., Palmen, R., Sanz, & Dente, G. (2015). Encouraging STEM studies for the labour market (Directorate-General for Internal Policies: European Parliament). Brussels, Belgium: European Union. Retrieved from http://www.europarl.europa.eu/RegData/etud

Cavdar, O., & Yildirim, B. (2023). Mixed, Augmented and Virtual Reality in STEM Education in The Context of Text Mining: A Bibliometric Map Analysis and Systematic Review: STEM Education in The Context of Text Mining. *International Journal of Curriculum and Instruction, 15*(3), 2108-2131.

Celcima, D., Osmani, F., Bardhi, E. K., & Icka, E. M. (2024). The relationship between academic motivation and self-efficacy in undergraduate students: Kosovo case. *Revista de Gestão Social e Ambiental*, *18*(1), 1-17. https://doi.org/10.24857/rgsa.v18n1-193

Chang, S. C., Hsu, T. C., & Jong, M. S. Y. (2020). Integration of the peer assessment approach with a virtual reality design system for learning earth science. *Computers & Education, 146*: 103758. https://doi.org/10.1016/j.compedu.2019.103758

Chen, W., & Hirschheim, R. (2004). A paradigmatic and methodological examination of information systems research from 1991 to 2001. *Information systems journal*, *14*(3), 197-235. https://doi.org/10.1111/j.1365-2575.2004.00173.x

Chen, C. J., Toh, S. C., & Fauzy, W. M. (2004). The theoretical framework for designing desktop virtual reality-based learning environments. *Journal of Interactive Learning Research, 15*(2), 147.

Chen, P., Liu, X., Cheng, W., & Huang, R. (2017). A review of using augmented reality in education from 2011 to 2016. *Innovations in smart learning* (pp. 13–18). Singapore: Springer.

*Chen, J. C., Huang, Y., Lin, K. Y., Chang, Y. S., Lin, H. C., Lin, C. Y., & Hsiao, H. S. (2020). Developing a hands-on activity using virtual reality to help students learn by doing. *Journal of Computer Assisted Learning, 36*(1), 46-60. https://doi.org/10.1111/jcal.12389

Cheng, K. H., & Tsai, C. C. (2020). Students' motivational beliefs and strategies, perceived immersion and attitudes towards science learning with immersive virtual reality: A partial least squares analysis. *British Journal of Educational Technology, 51*(6), 2140-2159. https://doi.org/10.1111/bjet.12956

Coban, M., Bolat, Y. I., & Goksu, I. (2022). The potential of immersive virtual reality to enhance learning: A meta-analysis. *Educational Research Review*, *36*, 100452. https://doi.org/10.1016/j.edurev.2022.100452

Cooper, G., Park, H., Nasr, Z., Thong, L. P., & Johnson, R. (2019). Using virtual reality in the classroom: Preservice teachers' perceptions of its use as a teaching and learning tool. *Educational Media International, 56*(1), 1–13. https://doi.org/10.1080/09523987.2019.1583461

Corredor, J., Gaydos, M., & Squire, K. (2014). Seeing change in time: video games to teach about temporal change in scientific phenomena. *Journal of Science Education and Technology, 23*(3), 324–343. https://doi.org/10.1007/s10956-013-9466-4

Di Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. *British Journal of Educational Technology*, *51*(6), 2006-2033. https://doi.org/10.1111/bjet.13030

*Damekova, S. K., Shuyushbayeva, N. N., Tanasheva, N. N., Altayeva, G. S., & Kaliyeva, A. K. (2021). Additional education of schoolchildren in physics at the Children's University. *Bulletin of the Karaganda*

*University" Physics Series", 101*(1), 63-70. https://doi.org/10.31489/2021Ph1/63-70

Di-Natale, A. F., Repetto, C., Riva, G., & Villani, D. (2020). Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research. *British Journal of Educational Technology*, *51*(6), 2006-2033. https://doi.org/10.1111/bjet.13030

Ebrahimi, M., Simmons, D. & Clark, J.S. (2023). Exploring Virtual and Augmented Reality STEM Learning Experiences with American K-12 Students: A Scoping Review. *Journal of Interactive Learning Research, 34*(4), 575-604. https://www.learntechlib.org/primary/p/222799/

Furht, B. (2008). *Encyclopedia of Multimedia*. Springer, Boston, MA.

He, X., Li, T., Turel, O., Kuang, Y., Zhao, H., & He, Q. (2021). The impact of STEM education on mathematical development in children aged 5-6 years. *International Journal of Educational Research, 109*: 101795. https://doi.org/10.1016/j.ijer.2021.101795

Hranstinski, S., & Keller, C. (2007). An examination of research approaches that underlie research on educational technology: A review from 2000 to 2004. *Journal of Educational Computing Research*, 36(2), 175–190. https://doi.org/10.2190/H16L-4662-6000-0446

*Holly, M., Pirker, J., Resch, S., Brettschuh, S., & Gütl, C. (2021). Designing VR experiences–expectations for teaching and learning in VR. *Educational Technology & Society, 24*(2), 107-119. https://www.jstor.org/stable/27004935

Hsiao, H. S., Chen, J. C., Lin, C. Y., Zhuo, P. W., & Lin, K. Y. (2019). Using 3D printing technology with experiential learning strategies to improve preengineering students' comprehension of abstract scientific concepts and hands-on ability. *Journal of Computer Assisted Learning*, *35*(2), 178-187. https://doi.org/10.1111/jcal.12319

*Huang, W. (2022). Examining the impact of head-mounted display virtual reality on the science self-efficacy of high schoolers. *Interactive Learning Environments, 30*(1), 100-112. https://doi.org/10.1080/10494820.2019.1641525

*Jiang, Y., Popov, V., Li, Y., Myers, P. L., Dalrymple, O., & Spencer, J. A. (2021). “It’s like I’m really there”: Using VR experiences for STEM career development. *Journal of Science Education and Technology, 30*, 877-888. https://doi.org/10.1007/s10956-021-09926-z

Jenkinson, J. (2009). Measuring the Effectiveness of Educational Technology: what are we Attempting to Measure?. *Electronic Journal of e-learning*, *7*(3), pp273-280.

Johnson, M. C., Birchfield, D., & Megowan-Romanowicz, C. (2023). If the Gear Fits, Spin It Again!: Embodied Education, Design Components, and In-Play Assessments. In *Research Anthology on Game Design, Development, Usage, and Social Impact* (pp. 1097-1120). IGI Global. https://doi.org/10.4018/978-1-6684-7589-8.ch052

Johnson-Glenberg, M. C. (2018). Immersive VR and education: Embodied design principles that include gesture and hand controls. *Frontiers in Robotics and AI, 5*, 81. https://doi.org/10.3389/frobt.2018.00081

*Johnson-Glenberg, M. C., Birchfield, D. A., Megowan-Romanowicz, C., & Snow, E. L. (2015). If the gear fits, spin it!: Embodied education and in-game assessments. *International Journal of Gaming and Computer-Mediated Simulations (IJGCMS), 7*(4), 40-65. https://doi.org/10.4018/IJGCMS.2015100103

*Johnson-Glenberg, M. C., Kosa, M., & O'Rourke, H. P. (2023, January). STEM learning, science identity and immersivity: Giant screen films comparing 2D, 3D, and dome formats including a videogame assessment. *In Frontiers in Education, 7*. https://doi.org/10.3389/feduc.2022.1096889

*Klingenberg, S., Fischer, R., Zettler, I., & Makransky, G. (2023). Facilitating learning in immersive virtual reality: Segmentation, summarizing, both or none?. *Journal of Computer Assisted Learning, 39*(1), 218-230. https://doi.org/10.1111/jcal.12741

Klomegah, R. Y. (2007). Predictors of academic performance of university students: An application of the goal efficacy model. *College Student Journal, 41*(2), 407–415.

Kriegbaum, K., Jansen, M., & Spinath, B. (2015). Motivation: A predictor of PISA's mathematical competence beyond intelligence and prior test achievement. *Learning and Individual Differences*, 43, 140–148. https://doi.org/10.1016/j.lindif.2015.08. 026.

Kucuk, S., Aydemir, M., Yildirim, G., Arpacik, O., & Goktas, Y. (2013). Educational technology research trends in Turkey from 1990 to 2011. *Computers & Education, 68*, 42-50. https://doi.org/10.1016/j.compedu.2013.04.016

*Kuznetcova, I., Glassman, M., Tilak, S., Wen, Z., Evans, M., Pelfrey, L., & Lin, T. J. (2023). Using a mobile virtual reality and computer game to improve visuospatial self-efficacy in middle school students. *Computers & Education, 192*, 104660. https://doi.org/10.1016/j.compedu.2022.104660

Larkin, K., & Lowrie, T. (2022). *STEM Education in the Early Years: Thinking about Tomorrow*. Singapore: Springer.

Lee, E. A. L., & Wong, K. W. (2014). Learning with desktop virtual reality: Low spatial ability learners are more positively affected. *Computers & Education, 79*, 49–58. https://doi.org/10.1016/j.compedu.2014.07.010

Lee, T., Wen, Y., Chan, M. Y., Azam, A. B., Looi, C. K., Taib, S., Ooi, C.H., Huang L.H., Xie, Y., & Cai, Y. (2022). Investigation of virtual & augmented reality classroom learning environments in university STEM education. *Interactive Learning Environments*, *32*(6), 2617-2632. https://doi.org/10.1080/10494820.2022.2155838

Li, P., & Pan, G. (2009). The relationship between motivation and achievement--a survey of the study motivation of English majors in Qingdao Agricultural University. *English language teaching*, *2*(1), 123-128.

Liu, R., Wang, L., Lei, J., Wang, Q., & Ren, Y. (2020). Effects of an immersive virtual reality-based classroom on students' learning performance in science lessons. *British Journal of Educational Technology, 51*(6), 2034-2049. https://doi.org/10.1111/bjet.13028

Makransky, G., & Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Educational Technology Research and Development*, *66*(5), 1141-1164. https://doi.org/10.1007/s11423-018-9581-2

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and instruction*, *60*, 225-236. https://doi.org/10.1016/j.learninstruc.2017.12.007

Mcmillan, J. H., & Schumacher, S. (2014). *Research in education: Evidence-based inquiry [with myeducationlab].* Prentice Hall PTR.

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & education*, *70*, 29-40. https://doi.org/10.1016/j.compedu.2013.07.033

Middleton, B. M., & Murray, R. K. (1999). The impact of instructional technology on student academic achievement in reading and mathematics. *International Journal of Instructional Media, 26*(1), 109.

Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & Education, 56*(3), 769–780. https://doi.org/10.1016/j.compedu.2010.10.020

*Moon, J., Ke, F., & Sokolikj, Z. (2020). Automatic assessment of cognitive and emotional states in virtual reality-based flexibility training for four adolescents with autism. *British Journal of Educational Technology, 51*(5), 1766-1784. https://doi.org/10.1111/bjet.13005

Moccozet, L. (2012, July). Introducing learning performance in personal learning environments. In *2012 IEEE 12th International Conference on Advanced Learning Technologies* (pp. 702-703). IEEE. https://doi.org/10.1109/ICALT.2012.75

*Mou, T. Y. (2023). Science learning with designed animation: Investigation of primary school children's attitudes toward science learning, animation integration, and understanding level. *International Journal of Educational Research Open, 4*, 100246. https://doi.org/10.1016/j.ijedro.2023.100246

*Mystakidis, S., & Christopoulos, A. (2022). Teacher perceptions on virtual reality escape rooms for stem education. *Information, 13*(3), 136. https://doi.org/10.3390/info13030136

National Academy of Engineering and National Research Council (NAE and NRC). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. The National Academies Press. https://doi.org/10.17226/18612

*Ng, D. T. K., & Chu, S. K. W. (2021). Motivating students to learn STEM via engaging flight simulation activities. *Journal of Science Education and Technology, 30*(5), 608-629. https://doi.org/10.1007/s10956-021-09907-2

Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology*, *110*(6), 785. https://doi.org/10.1037/edu0000241

*Pathan, R., Rajendran, R., & Murthy, S. (2020). Mechanism to capture learner's interaction in VR-based learning environment: design and application. *Smart Learning Environments, 7*, 1-15. https://doi.org/10.1186/s40561-020-00143-6

Pellas, N., Kazanidis, I., Konstantinou, N., & Georgiou, G. (2017). Exploring the educational potential of three-dimensional multi-user virtual worlds for STEM education: A mixed-method systematic literature review. *Education and Information Technologies*, *22*, 2235-2279. https://doi.org/10.1007/s10639-016-9537-2

Pellas, N., Mystakidis, S., & Kazanidis, I. (2021). Immersive Virtual Reality in K-12 and Higher Education: A systematic review of the last decade scientific literature. *Virtual Reality*, *25*(3), 835-861. https://doi.org/10.1007/s10055-020-00489-9

Piaget, J. (1971). *Science of education and the psychology of the child*, London, UK: Penguin Books.

*Pimentel, D., & Kalyanaraman, S. (2023). Virtual climate scientist: A VR learning experience about paleoclimatology for underrepresented students. *Interactive Learning Environments, 31*(7), 4426-4439. https://doi.org/10.1080/10494820.2021.1969582

Pimthong, P., & Williams, J. (2020). Preservice teachers' understanding of STEM education. *Kasetsart Journal of Social Sciences, 41*(2), 289–295. https://doi.org/10.1016/j.kjss.2018.07.017

Pintrich, P. R., & Schunk, D. H. (2002). *Motivation in education: Theory, research, and applications* (2nd ed.).

Prentice Hall.

*Poonja, H. A., Shirazi, M. A., Khan, M. J., & Javed, K. (2023). Engagement detection and enhancement for STEM education through computer vision, augmented reality, and haptics. *Image and Vision Computing, 136*, 104720. https://doi.org/10.1016/j.imavis.2023.104720

Prast, E. J., Van de Weijer-Bergsma, E., Miočević, M., Kroesbergen, E. H., & Van Luit, J. E. (2018). Relations between mathematics achievement and motivation in students of diverse achievement levels. *Contemporary Educational Psychology*, *55*, 84-96. https://doi.org/10.1016/j.cedpsych.2018.08.002

*Puig, A., Rodríguez, I., Baldeón, J., & Múria, S. (2022). Children building and having fun while they learn geometry. *Computer Applications in Engineering Education, 30*(3), 741-758. https://doi.org/10.1002/cae.22484

Pulijala, Y., Ma, M., Pears, M., Peebles, D., & Ayoub, A. (2018). Effectiveness of immersive virtual reality in surgical training: A randomized control trial. *Journal of Oral and Maxillofacial Surgery, 76*(5), 1065–1072. https://doi.org/10.1016/j.joms.2017.10.002

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Robinson, R., Molenda, M., & Rezabek, L. (2008). Facilitating learning. In A. Januszeswki & M. Molend (Eds.), *Educational Technology: A Definition with Commentary* (pp. 15–48). New York and London: Routledge.

Schunk, D. H., & DiBenedetto, M. K. (2016). Self-efficacy theory in education. In *Handbook of motivation at school* (pp. 34–54). Routledge.

Schunk, D. H., Meece, J., & Pintrich, P. R. (2014). *Motivation in education: Theory, research, and application* (4th ed.). Pearson Education.

*Shu, Y., & Huang, T. C. (2021). Identifying the potential roles of virtual reality and STEM in Maker education. *The Journal of Educational Research, 114*(2), 108-118. https://doi.org/10.1080/00220671.2021.1887067

Sirakaya, M., & Alsancak Sirakaya, D. (2022). Augmented reality in STEM education: A systematic review. *Interactive Learning Environments, 30*(8), 1556-1569. https://doi.org/10.1080/10494820.2020.1722713

*Southgate, E., Smith, S. P., Cividino, C., Saxby, S., Kilham, J., Eather, G., Scevak, J., Summerville, D., Buchanan, R., & Bergin, C. (2019). Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice. *International Journal of Child-Computer Interaction, 19*, 19-29. https://doi.org/10.1016/j.ijcci.2018.10.002

Spinath, B., Spinath, F. M., Harlaar, N., & Plomin, R. (2006). Predicting school achievement from general cognitive ability, self-perceived ability, and intrinsic value. *Intelligence,* 34, 363–374. https://doi.org/10.1016/j.intell.2005.11.004.

Stemler, S. (2001). An overview of content analysis. *Practical Assessment, Research & Evaluation, 7*(17), 137–146.

Sutherland, I. E. (1965). *The ultimate display*. Proceedings of International Federation for Information Processing 1965, vol 2, 506–508.

Sutherland, I. E. (1968). A head-mounted three dimensional display. Proceedings of AFIPS 1968, 757–764.

The Sphero Team. (2024, November, 12*). How experimential learning in STEM develops critical thinking skills*

[Web log comment]. https://sphero.com/blogs/news/experiential-learning-in-stem

Tene T, Marcatoma Tixi JA, Palacios Robalino MdL, Mendoza Salazar MJ, Vacacela Gomez C and Bellucci S. (2024). Integrating immersive technologies with STEM education: a systematic review. *Frontiers in Education*, 9, 1410163. https://doi.org/10.3389/feduc.2024.1410163

*Thompson, M. M., Wang, A., Uz Bilgin, C., Anteneh, M., Roy, D., Tan, P., Eberhart, R., & Klopfer, E. (2020). Influence of virtual reality on high school students' conceptions of cells. *Journal of Universal Computer Science, 26*(8), 929-946. https://hdl.handle.net/1721.1/130512

Valentine, J. C., DuBois, D. L., & Cooper, H. (2004). The relation between self-beliefs and academic achievement: A meta-analytic review. *Educational psychologist*, *39*(2), 111-133.

Van Vo, D., & Csapó, B. (2023). Exploring inductive reasoning, scientific reasoning and science motivation, and their role in predicting STEM achievement across grade levels. *International Journal of Science and Mathematics Education, 21*(8), 2375-2398. https://doi.org/10.1007/s10763-022-10349-4

Wan, Z. H., Jiang, Y., & Zhan, Y. (2021). STEM education in early childhood: A review of empirical studies. *Early Education and Development, 32*(7), 940-962. https://doi.org/10.1080/10409289.2020.1814986

Wan, Z. H., So, W. M. W., & Zhan, Y. (2022). Developing and validating a scale of STEM project-based learning experience. *Research in Science Education, 52*(2), 599-615. https://doi.org/10.1007/s11165-020-09965-3

*Wang, J., Guo, D., & Jou, M. (2015). A study on the effects of model-based inquiry pedagogy on students' inquiry skills in a virtual physics lab. *Computers in Human Behavior, 49*, 658-669. http://dx.doi.org/10.1016/j.chb.2015.01.043

Wang, LH., Chen, B., Hwang, G.J., Guan, J.O, & Wang, Y.Q. (2022). Effects of digital game-based STEM education on students' learning achievement: A meta-analysis. *International Journal of STEM Education,* **9**, 26 . https://doi.org/10.1186/s40594-022-00344-0

*Xie, Y., & Zhang, X. (2023). Research on the design and implementation of primary school STEM project based on VR coursewares. *International Journal of Technology and Design Education*, 1-17. https://doi.org/10.1007/s10798-023-09848-4

Yildirim, B., Sahin-Topalcengiz, E., Arikan, G., & Timur, S. (2020). Using virtual reality in the classroom: Reflections of STEM teachers on the use of teaching and learning tools. *Journal of Education in Science, Environment and Health (JESEH), 6*(3), 231-245. https://doi.org/10.21891/jeseh.711779

Youngblut, C. (1998). Educational uses of virtual reality technology. https://apps.dtic.mil/sti/pdfs/ADA339438.pdf

Yusuf, M. (2011). The impact of self-efficacy, achievement motivation, and self-regulated learning strategies on students' academic achievement. *Procedia-Social and Behavioral Sciences*, *15*, 2623-2626. https://doi.org/10.1016/j.sbspro.2011.04.158

Zhang, Y., Feijoo-Garcia, M. A., Gu, Y., Popescu, V., Benes, B., & Magana, A. J. (2024). Virtual and augmented reality in Science, Technology, Engineering, and Mathematics (STEM) education: An umbrella review. *Information*, *15*(9), 515. https://doi.org/10.3390/info15090515

Živčić-Bećirević, I., Smojver-Ažić, S., & Dorčić, T. M. (2017). Predictors of university students' academic achievement: A prospective study. *Društvena istraživanja*, *26*(4), 457-476. https://doi.org/10.5559/di.26.4.01

## Author Information


| **Adem Koc** | **Pelin Yildirim** |
|---|---|
| https://orcid.org/0000-0002-2721-3781 | https://orcid.org/0000-0002-1114-681X |
| Ph.D. | Assoc Prof. Dr. |
| Mersin University | Atatürk University |
| Education Faculty | Education Faculty |
| Mersin | Erzurum |
| Turkey | Turkey |
| Contact e-mail: *ademkoc@mersin.edu.tr* | |