

The Science Coaster: A Virtual Reality Journey in Science Education

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Abstract

This study was designed to examine how the science teaching process was conducted using Science Coaster, a virtual reality application developed for fourth-grade primary school students, and to identify the effects of this process on students' academic achievement, motivation, and experiences. The research was structured as a case study, and the participants consisted of 33 fourth-grade students and their classroom teachers. Data collection tools included an observation form, researcher diary, student diary, interview form, academic achievement test, and a motivation scale for science learning. The Science Coaster virtual reality software was specifically developed by the researchers for the unit "Earth's Crust and Movements of Our Planet" in the science curriculum. The implementation process was conducted individually, and students interacted with the content using a virtual reality headset and controller. The findings revealed that the Science Coaster-based instructional process could be successfully implemented in three main phases: lesson preparation, implementation, and assessment-evaluation. Quantitative results indicated a statistically significant increase in students' academic achievement in science and improvements in all sub-dimensions of their motivation. Qualitative data supported these findings, showing that students perceived the virtual reality experience as enjoyable, instructive, immersive, realistic, and motivating. During the research process, specific technical-physical issues and student-experience-based limitations were encountered; however, various solutions were implemented to address these challenges. The findings suggest that virtual reality technology holds pedagogical potential in science education and can be used as an effective instructional tool, particularly at the primary school level.

Keywords:

Primary Science Teaching, Virtual Reality, Technology In Science Teaching.



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Introduction

The digital dimension of the 21st century, driven by rapid technological advancements, is fundamentally transforming individuals' lifestyles and ways of accessing information. Today's students are frequently referred to as "digital natives"; this generation comprises individuals who are innately familiar with online platforms, capable of multitasking, and prefer learning in interactive environments (Bilgiç et al., 2011). The learning styles of this digital generation necessitate instructional approaches that go beyond

traditional teaching methods and actively integrate technology into the learning process. In this context, technology's practical and meaningful use in education is becoming increasingly significant. Particularly, technology-enhanced instructional materials have been shown to increase students' motivation toward learning, direct their attention to the lesson, and support the retention of acquired knowledge (İşman et al., 2002). Integrating technology into instruction transforms the learning environment from a process based solely on transmitting knowledge into one that is experiential, student-centered, and interactive. At this point, science education emerges as one of the disciplines most receptive to the opportunities offered by technology. With its fundamental goals of understanding natural phenomena, conducting experimental processes, and concretizing abstract concepts, the science curriculum benefits from multidimensional visualization, animation, and simulation techniques (Rutten et al., 2012; Smetana & Bell, 2012; Wang et al., 2010). However, the limitations of conventional classroom settings often hinder realizing this potential, making integrating new technologies into instruction inevitable. In particular, abstract content that students are unable to observe or experience firsthand cannot be effectively taught due to constraints related to safety, time, and space (Arıcı, 2013; Hacıeminoğlu, 2019).

In recent years, virtual reality has emerged as one of the technologies capable of addressing these educational needs. Virtual reality refers to computer-generated environments that provide users with a sense of realism while enabling interactive engagement within a three-dimensional space. This technology activates not only users' visual senses but also auditory, tactile, and spatial perceptions, thereby creating a strong sense of "being there" and transforming learning into a multisensory, experiential process (Bayraktar & Kaleli, 2007; Çavaş et al., 2004). The use of virtual reality in education is examined within the context of immersive interfaces that significantly influence learners' cognitive and affective processes. Such environments are suggested to enhance students' attention, deepen information processing, and increase learning motivation (Dede, 2009). Moreover, virtual reality is reported to support the development of empathy, foster social awareness, and enable the experiential construction of abstract concepts, thereby contributing to transformative learning processes (Baillenson, 2018). Research on the use of virtual reality in education has shown that students exhibit higher levels of motivation in science courses where this technology is employed, develop more positive attitudes toward scientific content, and achieve greater academic success (Liang et al., 2025; Liu et al., 2022; Villena Taranilla et al., 2019; Yang et al., 2021). Furthermore, it has been emphasized that students experience significant gains in conceptual understanding, higher-order thinking skills, and visual-

spatial abilities (Sulisworo et al., 2022). However, virtual reality-based science education studies conducted at the primary school level remain limited in number, with most existing research focusing on secondary and higher education (Jensen, & Konradsen, 2018; Merchant et al., 2014). This highlights the need for a more in-depth examination of the implementation processes, educational impacts, and classroom integration strategies of virtual reality applications targeting young learners in primary education.

Primary school students are typically in the concrete operational stage, defined by Piaget's theory of cognitive development, and often face challenges in mentally constructing abstract concepts. Therefore, visualization and experiential learning are important in helping students grasp geological, astronomical, or microscopic-scale concepts essential in science education (Lester et al., 2014). Virtual reality technology offers an environment that directly addresses this need by allowing students to explore at their own pace, focus their attention on content, and actively participate in the learning process. One of the key theoretical frameworks supporting the educational use of virtual reality is Richard E. Mayer's Cognitive Theory of Multimedia Learning. According to this theory, individuals process and learn information more effectively when multiple sensory channels are engaged simultaneously. In particular, the combination of visual elements (images, animations, videos) with auditory elements (narration, sound, music) enhances learning quality and contributes to more effective mental organization during the learning process (Mayer, 2001; 2009). Grounded in cognitive load theory, Mayer's model argues that multimedia materials should be designed according to specific principles to enable more efficient use of learners' limited working memory. These principles include coherence (eliminating extraneous information), signaling (highlighting essential content), redundancy (limiting simultaneous written and spoken explanations), personalization (using conversational rather than formal language), and temporal/spatial contiguity (presenting related visuals and texts together). Multimedia content developed in line with this theory supports meaningful learning by optimizing students' processes of selecting, organizing, and integrating information (Mayer, 2009).

This theoretical approach is exceptionally functional in explaining the impact of multisensory and interactive environments, such as virtual reality, on learning. Virtual reality applications enrich the learning environment through multiple forms of representation by simultaneously presenting visual, auditory, and kinesthetic content, thereby enabling students to establish a deeper cognitive connection with the material. Moreover, this technology allows students to actively participate in the learning environment, take control of their learning process,

and become more highly motivated to engage with the content (Kavanagh et al., 2017). In this context, it is important to evaluate virtual reality-based instructional practices designed for primary school students from both pedagogical and technological perspectives to understand their effects on children's cognitive and affective development. While most studies in virtual reality-supported science education focus on secondary and high school levels (Jensen, & Konradsen, 2018; Merchant et al., 2014; Şevgin, 2024), the present study addresses a systematically implemented instructional process at the primary school level.

This study examines how the virtual reality-based science instruction process, developed for fourth-grade primary school students, is implemented. In line with this aim, the study's main research question is: "How can a virtual reality-based science instruction process developed for fourth-grade primary school students be implemented?" Within this scope, the sub-questions of the research are as follows:

- How is the virtual reality-based instructional process conducted in the fourth-grade primary school science course?
- How does the academic achievement of fourth-grade primary school students change in a virtual reality-based science course?
- How does the motivation level of fourth-grade primary school students change in a virtual reality-based science course?
- What are the views of fourth-grade primary school students and their classroom teachers regarding the virtual reality-based science course?
- What problems are encountered during the implementation of the virtual reality-based science course in the fourth grade of primary school?
- How can the problems encountered during the implementation of the virtual reality-based science course in the fourth grade of primary school be addressed?

This study provides original data on how virtual reality applications can be structured at the primary school level and how they can be functionally utilized in science instruction. Considering that technology integration in education represents not merely an instrumental transformation but also a pedagogical paradigm shift, the instructional model presented in this study serves as a valuable resource for teachers, curriculum developers, and researchers. Furthermore, it contributes to ongoing efforts to develop alternative methods to enhance students' motivation and conceptual understanding in the science learning process.

Method

Research Design

This study explores how the science instruction process, based on a virtual reality application developed for fourth-grade primary school students, is implemented. A qualitative research approach was adopted, and the study was designed as a case study. Case study design is particularly preferred when seeking answers to "how" and "why" questions, especially in situations where the researcher has limited control over events and the focus is on a phenomenon within its real-life context (Yin, 2014). In this context, the study was conducted within the framework of a holistic single-case design, in which a single phenomenon (the instructional process) was examined comprehensively.

Study Group

The study group consisted of 33 fourth-grade students (19 boys and 14 girls) enrolled in a public primary school with a middle socio-economic profile and two classroom teachers. First, schools were identified, and following classroom observations and interviews with teachers, the study group was selected. Participants were chosen using criterion sampling, a purposeful sampling technique. Criteria such as physical facilities, voluntary participation, and location were considered when selecting the school for the research. As for the students, the criteria included high attendance in class, voluntary participation, absence of intellectual disabilities, and parental consent. To ensure confidentiality in presenting findings, each participant was assigned a pseudonym.

Development of the Virtual Reality Software

The instructional process at the center of this study was based on a newly developed virtual reality (VR) application—Science Coaster—which was explicitly designed in alignment with the learning outcomes of the science unit "The Earth's Crust and the Movements of Our Planet." This application was developed for the first time and tailored to the designated instructional content. The ADDIE instructional design model guided the design process, which consists of five phases: Analysis, Design, Development, Implementation, and Evaluation. In the analysis phase, abstract and difficult-to-observe concepts that students typically struggle with were identified, leading to the selection of the unit "The Earth's Crust and the Movements of Our Planet." The need for concretization in science topics was addressed through the three-dimensional modeling and interactive environments afforded by virtual reality technology. During the design phase, scenario development was carried out, and the content was revised based on feedback from six experts and three classroom teachers. All content and voiceovers were structured to be appropriate for the

primary school level and aligned with the cognitive objectives of the unit. In the development phase, Unity software was used to create 3D environments (surface, underground, space, solar system); animations, roller coaster mechanics, voiceovers, and user interaction systems were also integrated. In the Science Coaster application, the student navigates through various environments via a VR headset, listens to narrated explanations, and responds to questions using buttons on the controller. During the implementation phase, a pilot study was conducted to observe student behaviors, and necessary adjustments were made to the content. In the evaluation phase, data collected from students, teachers, and researchers were examined collectively; elements that caused distraction or operational difficulty were revised, and user interaction was improved.

In addition, the design of the Science Coaster virtual reality application was grounded in the Cognitive Theory of Multimedia Learning, and the application was developed based on the twelve core principles proposed by Mayer (2009). The content, audio, and visuals were structured following the principles of Coherence, Signaling, Redundancy, Temporal and Spatial Contiguity, Segmenting, Pre-training, Modality, Multimedia Principle, Personalization, Voice, and Image. To direct students' attention, narrated explanations were synchronized with visuals, and extraneous content was avoided. With its interactive structure, Science Coaster supports meaningful and lasting learning by enabling students to simultaneously engage their visual and auditory channels. The application's language was personalized to be simple, level-appropriate, and guiding for primary school students. After the completion of all ADDIE phases, the final version of the program was produced. An example screenshot from the surface section of the three-dimensional environments is presented in Figure 1, and an example from the space section is shown in Figure 2. By scanning the QR code provided in Figure 3, the first video segment of the Science Coaster application can be accessed, while the QR code in Figure 4 links to the second segment.

Figure 1.
A screenshot from the first section of the Science Coaster application



Figure 2.
A screenshot from the second section of the Science Coaster application

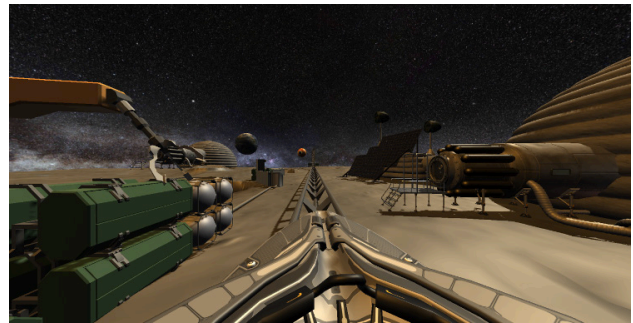


Figure 3.
QR code for accessing the video of the first section of the Science Coaster application



Figure 4.
QR code for accessing the video of the second section of the Science Coaster application



Implementation Process

The program was implemented individually. Due to pandemic conditions, students participated in the application one at a time, interacting with the VR equipment and experiencing the content. Two students participated each day, and the implementation lasted six weeks. The sessions were conducted in the school library, each recorded on video. During the implementation, students' reactions to the content, interactions, and engagement throughout the process were observed in detail.

Data Collection Tools

Achievement Test for the Science Unit “The Earth’s Crust and the Movements of Our Planet”

The achievement test, developed by the researcher for fourth-grade primary school students, consists of 30 items and is a measurement tool whose validity and reliability have been analyzed. The test development followed the steps proposed by Adıgüzel (2016), and the questions were prepared based on Bloom’s taxonomy. Initially, 45 questions were created to address the five learning outcomes of the unit. These 45 items and a specification table were sent to eight experts for review—four experts in science education, one in Turkish language education, one in educational measurement and evaluation, and two classroom teachers. The Content Validity Ratios (CVRs) and the Content Validity Index (CVI) were calculated based on expert feedback. As a result of this evaluation, 10 questions were removed. CVR values ranged between 0.50 and 1.00 for the remaining items, and the CVI was calculated as 0.85. The test was administered to 196 fourth-grade students as part of a pilot study. Following the pilot, item discrimination and difficulty indices were computed. Based on the item analysis, five items were excluded from the test. The discrimination indices for the remaining items were all above 0.20 (Pande et al., 2013), and the difficulty indices ranged between 0.48 and 0.79, with an average difficulty index of 0.70 (Özçelik, 1998). The reliability of the test was calculated using the KR-20 formula, and the reliability coefficient was found to be 0.75. This value indicates that the test scores are highly reliable (Özdamar, 2017). All validity and reliability analyses conducted confirm that the developed achievement test is a valid and reliable measurement tool. The minimum possible score on the test is 0, and the maximum is 30.

Motivation Scale for Science Learning

The scale was initially developed by Tuan et al. (2005) to measure elementary school students’ motivation toward science learning and was adapted into Turkish by Yılmaz and Huyugüzel Çavaş (2007). The scale consists of a total of 33 items grouped under six factors. During the Turkish adaptation process, expert opinions were collected from nine faculty members specialized in science education, educational measurement and evaluation, and foreign languages. Following a pilot study, an Exploratory Factor Analysis [EFA] was conducted, and two items were removed from the scale. The factor analysis results revealed a six-factor structure consistent with the original version of the scale. These six factors were labeled as: self-efficacy, active learning strategies, value of science learning, performance goal, achievement goal, and environmental stimulation. These factors collectively explained 56.49% of the total variance. The Science Attitude Scale was used to assess criterion-related

validity, and the correlation coefficient between the two scales was found to be .73. For internal consistency reliability, Cronbach’s alpha coefficients were calculated for each factor and the overall scale. The reliability coefficients for the individual factors ranged from .54 to .85, while the reliability coefficient for the entire scale was .87. These results indicate that the scale is valid and reliable. The highest possible score on the scale is 165, while the lowest possible score is 33.

Observation Forms

During the implementation process, the researcher acted as a participant observer and conducted systematic observations while taking detailed field notes. Additionally, observations were supported by video recordings throughout the process. The implementation was recorded using a camera to capture the student, the student’s movements, and all virtual reality equipment in use. These video recordings were used to examine students’ physical behaviors, verbal expressions, and actions while using the virtual reality application, as well as the interaction between the student and the researcher, the implementation of the virtual reality-based science instruction process, and students’ thoughts and reflections throughout the process. Students’ behaviors toward the VR application were documented using a structured observation form.

Student and Teacher Interview Forms

In this study, semi-structured interviews were conducted with fourth-grade students identified as participants and their classroom teachers. The interview questions were prepared before the implementation, and expert feedback was obtained from two specialists regarding the semi-structured interview form. Based on the expert feedback, the final version of the interview questions was developed, and the interviews were conducted accordingly. All interviews were audio recorded, and direct quotations from participants were included during the reporting phase. The student interviews aimed to explore how students experienced the virtual reality-based science instruction process, their opinions about the application, and their reflections on their development during the process. The teacher interviews focused on obtaining teachers’ perspectives on the implementation process.

Researcher Diary and Student Diaries

Throughout the implementation process, the researcher maintained a researcher diary, while the students kept student diaries. After each instructional session, the researcher recorded reflections, emotions, observations, and impressions related to the lesson. Students were also asked to keep diaries to document their own experiences. In addition, the researcher

recorded personal reflections before and after interviews and thesis monitoring committee meetings through the researcher diary. This diary included detailed notes from the design phase of the study to the development of the virtual reality application and its implementation with participant students. As such, the diary served as a comprehensive record of the instructional process and captured the researcher's thoughts and emotions. The researcher diary thus became a valuable data source for describing the process in depth. Similarly, the student diaries reflected the students' feelings and thoughts about the lessons, depicting the process from the learners' perspective.

Role of the Researcher

Throughout this study, which was designed and implemented using a case study design, the first researcher acted as both a participant and an integral part of the process. During the implementation, the first researcher served as the program facilitator and participant observer during the observation phase. However, once the student wore the virtual reality headset, all instructional and assessment processes occurred entirely within the VR environment. Therefore, the first researcher did not take an active role during the virtual reality-based science instruction and instead assumed a guiding role. The second researcher supervised all stages of the study.

Data Collection Process

The data collection process was carried out in three stages: pre-tests (achievement and motivation scales), in-process observations and interviews, and post-tests. All data were collected through one-on-one sessions with each student. Quantitative measurement tools were administered both before and after the implementation. Once the student wore the virtual reality headset, all assessment procedures were conducted entirely within the VR environment. Observation data were gathered during the VR implementation, while interview data were collected following the VR experience. Both teacher and student interviews were conducted in the school library, where the application was implemented. Interviews with classroom teachers lasted between 10 and 15 minutes, whereas interviews with student participants ranged from 20 to 25 minutes. Each classroom teacher was interviewed twice—once before and after implementation. Five interviews were conducted for each student: some during the Science Coaster process and others following the application.

Data Analysis

A paired samples t-test was conducted to analyze the data obtained from the achievement test and the motivation scale. The effect size was calculated using the eta-squared (η^2) value. An eta-squared value

between .01 and .06 indicates a small effect; values of .06 and above indicate a moderate effect; and values of .14 and above indicate a large effect (Cohen, 1988, as cited in Akbulut, 2010, p. 114). Qualitative data were analyzed using content analysis. Student and teacher opinions were categorized under thematic codes and supported by observation data.

Findings

This section presents the findings obtained in line with the overall aim and sub-questions of the study. The findings are structured to correspond to each sub-question, and the analysis headings were organized accordingly. An overview of these headings is presented in Figure 5.

Figure 5. Findings related to the virtual reality-based science teaching process



Science Class with Science Coaster

This section presents the findings related to the research question: "How is the virtual reality-based instructional process conducted in the fourth-grade primary school science course?" Based on the analysis of observation notes, the researcher diary, and video recordings, the instructional process was carried out in three main phases: lesson preparation, lesson implementation, and assessment and evaluation.

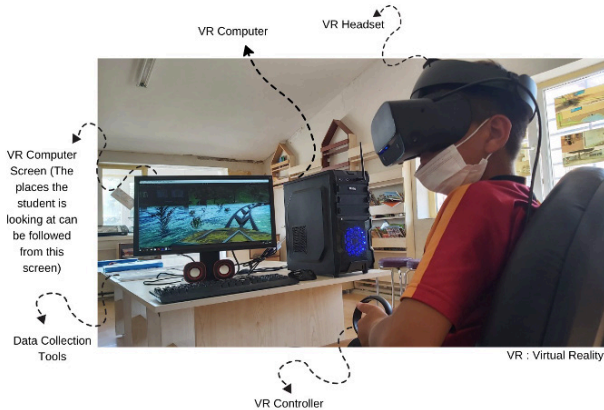
Lesson Preparation Process

Before the implementation, the virtual reality headset, controllers, computer, and software were prepared for each student. The student was introduced to the equipment and informed about the application. It was emphasized that the student could end the application at any time, and any technical or emotional issues were addressed accordingly. Before starting the session, efforts were made to ensure the student was physically and psychologically ready for

the experience. An illustrative example of this process is presented in Figure 6.

Figure 6.

Lesson preparation phase



Lesson Implementation Process

The implementation was carried out using the two-part learning experience offered by the Science Coaster virtual reality software: the underground and space journeys. During this process, the researcher intervened only during data collection intervals. In both parts of the experience, students were asked to share their impressions of the application, including their opinions on its instructive features, engaging aspects, and challenging parts. At various stages of the application, narrated explanations, visuals, and interactive content were used to activate students' prior knowledge and support the construction of new knowledge. The underground section addressed concepts such as layers, rocks, minerals, and fossils, while the space section focused on Earth's movements and the solar system. Each part included interactive activities designed to support student learning.

The student named Umut reflected his thoughts on the lesson process in his diary as follows (Student Diary – Umut):

"...When I entered the classroom, Teacher Fatih was there. There were many different things in front of him... He explained what each item was. There was a computer, a headset, and a controller. There was also a really cool video on the computer. Then he put the headset on me and showed me the video. Then he took it off and explained what I was going to do. Then I put the headset back on. I got on the train. I saw the Earth, houses, and cars. Then I entered a mine. I learned about minerals there. The teacher asked me questions. I answered them. Then I went to space. I saw the sun and the planets. It was great."

Assessment and Evaluation Process

At the end of each section, feedback on students' learning was collected through assessment activities developed within the virtual reality environment. In the underground section, students demonstrated their

knowledge of the topics by using the virtual controller to select the correct boxes displayed on glass domes. In the space section, concepts related to the subject matter were presented visually within the roller coaster environment, and students were asked to indicate the correct locations.

These assessment activities were supported by the screen inside the roller coaster vehicle, auditory instructions, and accompanying visuals.

Journey to Achievement with Science Coaster

In line with the study's second sub-question, "How does the academic achievement of fourth-grade primary school students change in a virtual reality-based science course?", the effect of the virtual reality-based science instruction process on students' academic achievement was examined. For this purpose, the Achievement Test for the Science Unit: The Earth's Crust and the Movements of Our Planet was administered before and after the implementation. The data obtained were analyzed using the SPSS software package. A paired samples t-test was conducted to determine whether the difference between pre-test and post-test scores was statistically significant. The results are presented in Table 1.

Table 1.

Paired samples t-test results for pre-test and post-test scores on the achievement test

Group	n	M	SD	df	t	p	η^2
Pre-test	33	14.75	6.04	32	-9.801	.000*	.75
Post-test	33	21.03	5.30				

* $p < .05$

The mean pre-test score of students on the achievement test was 14.75 ($SD = 6.04$), while the mean post-test score was 21.03 ($SD = 5.30$). According to the paired samples t-test results, there was a statistically significant difference between the pre-test and post-test scores ($t(32) = -9.801$, $p = .000$). Furthermore, the calculated η^2 value was greater than .14, indicating a large effect size. This result demonstrates that the implementation significantly improved students' academic achievement.

Qualitative data also supported quantitative findings. The researcher diary and interviews with students and teachers revealed the positive impact of the process on learning outcomes. Students' explanations of the concepts covered during the application indicated a high level of content comprehension. For example, one student, Hatice, explained the formation of day and night by stating: "The Earth rotates. If it sees the sun, it is daytime; if not, it is night." One of the classroom teachers, Secil, noted that students were inclined to express what they had learned spontaneously and emphasized that even students who struggled academically could grasp the content: "They have

learned quite a lot. I saw that even students who are not academically strong could explain how day and night occur.”

These findings indicate that the virtual reality-based instructional process enhanced students’ cognitive gains in the science course and supported learning content retention.

Journey to Motivation with Science Coaster

Within the scope of the study’s third sub-question, “How does the motivation level of fourth-grade primary school students change in a virtual reality-based science course?”, the study investigated whether students’ motivation levels changed during the virtual reality-based science instruction process. For this purpose, the Motivation Scale for Science Learning was administered before and after the implementation, and the data were analyzed using the SPSS software package. The scale consists of six factors: self-efficacy, active learning strategies, value of science learning, performance goal, achievement goal, and environmental stimulation. Pre-test and post-test scores for all factors were compared, and according to the results presented in Table 2, statistically significant increases were observed across all factors.

In the self-efficacy factor, the students’ mean pre-test score was 16.30 ($SD = 2.99$), while the mean post-test score was 24.24 ($SD = 5.16$). The result showed that this difference was statistically significant ($t(32) = -7.751, p = .000$). The calculated effect size was $\eta^2 > .14$, indicating a large effect. Qualitative data also support this finding. For example, in his student diary, Enes stated: “Science isn’t that difficult. When schools open and I go back to class, I think I will get good grades in science...”, expressing a positive shift in his self-efficacy beliefs regarding the subject. Observational notes by the researcher also support this finding: “Even when students struggled during data collection or

application phases in the Science Coaster activity, they did not give up and persistently tried to find the correct answers.” In the active learning strategies factor, the mean pre-test score was 23.09 ($SD = 4.78$), and the post-test mean was 26.97 ($SD = 3.83$). This difference was statistically significant ($t(32) = -7.141, p = .000$) and had a large effect size ($\eta^2 > .14$). Qualitative data indicated that students continued to make efforts to learn even when they encountered difficulties during the application. For instance, a student named Alparslan reflected on the experience: “I did not understand the topic at first. It was hard. I wanted to see it again, to hear and see it one more time... When I listened again, I understood.” This statement shows that the student took control of his learning process and exhibited strategic learning behavior.

In the value of science learning factor, the students’ mean pre-test score was 18.28 ($SD = 4.20$), while the mean post-test score was 20.93 ($SD = 2.90$). The difference was found to be statistically significant ($t(32) = -5.245, p = .000$), with a large effect size ($\eta^2 > .14$). A student named Nisa articulated the connection between the content learned and daily life as follows: “Actually, the topics we learn in science exist in real life too. I realized in this lesson that if I learn them here, I can also use them in real life.” In the performance goal factor, the mean pre-test score was 7.18 ($SD = 2.50$), and the mean post-test score was 10.27 ($SD = 1.91$). This statistically significant difference ($t(32) = -5.245, p = .000$) also demonstrated a large effect size ($\eta^2 > .14$). The researcher reflected on this in the diary as follows: “All of the students were very eager to participate and experience the application... They did everything simply because they wanted to and enjoyed it.” This statement highlights those students engaged in the process with intrinsic motivation, without needing external rewards or supervision.

In the achievement goal factor, the mean pre-test score was 16.09 ($SD = 3.90$), while the post-test mean

Table 2.

Paired samples t-test results for pre-test and post-test scores on the Motivation Scale for Science Learning

Factor	Group	n	\bar{M}	SD	df	t	p	η^2
Self-efficacy	Pre-test	33	16.30	2.99	32	-7.751	.000*	.65
	Post-test	33	24.24	5.16				
Active Learning Strategies	Pre-test	33	23.09	4.78	32	-7.141	.000*	.61
	Post-test	33	26.97	3.83				
Value Of Science Learning	Pre-test	33	18.28	4.20	32	-5.148	.000*	.45
	Post-test	33	20.93	2.90				
Performance Goal	Pre-test	33	7.18	2.50	32	-5.245	.000*	.46
	Post-test	33	10.27	1.91				
Achievement Goal	Pre-test	33	16.09	3.90	32	-8.582	.000*	.70
	Post-test	33	20.33	2.54				
Environmental Stimulation	Pre-test	33	14.33	3.53	32	-16.308	.000*	.89
	Post-test	33	25.90	1.96				
Overall Motivation	Pre-test	33	95.27	13.40	32	-14.481	.000*	.87
	Post-test	33	128.66	12.50				

* $p < .05$

was 20.33 ($SD = 2.54$). This difference was statistically significant ($t(32) = -8.582, p = .000$), and the η^2 value of .70 indicates a large effect size. A student named Ömer expressed his motivation to re-engage with the application, stating: "I learned so many new things. I had never seen them before. Moreover, I did it, like, I got it right, and I was happy. That is why I want to do it again." One of the most remarkable increases was observed in the environmental stimulation factor. The mean pre-test score in this category was 14.33 ($SD = 3.53$), while the post-test score was 25.90 ($SD = 1.96$). This difference was highly statistically significant ($t(32) = -16.308, p = .000$) and indicated a very large effect size ($\eta^2 = .89$). These results suggest that students found the virtual reality environment highly engaging and encouraging for learning. A student named Bilal described the experience: "It was exciting... It was very different. Different from other lessons... It was not just a lesson -I saw it and lived it." The researcher also noted in the diary: "Most students showed interest in the science content, commented, and wanted to touch the materials. Even after the session ended, they were reluctant to take off the VR headset and wanted to keep exploring the content."

Regarding overall motivation scores, the students' mean pre-test score was 95.27 ($SD = 13.40$), while the mean post-test score was 128.66 ($SD = 12.50$). This difference was statistically significant ($t(32) = -14.481, p = .001$) and demonstrated a large effect size ($\eta^2 > .14$). Observations made by the classroom teachers also confirmed the increase in students' motivation levels. Teacher Leyla noted a marked increase in students' interest in the subject and their enthusiasm for further science instruction: "They asked me, 'Teacher, when are we going to do another science lesson? Can we also study the seasons?' So they were motivated." Likewise, students directly expressed the impact the experience had on them. For example, a student named Turan stated: "Now I like science lessons even more...", indicating a positive change in his attitude toward learning.

These findings show that virtual reality-based science instruction led to significant improvements across multiple dimensions of student motivation. In particular, the learning environment's structure, the interaction level, and the way content was presented increased students' self-efficacy, effort, perceived value of the subject, and willingness to engage with the lesson.

Science Coaster Through the Perspectives of the Participants

This section presents the findings related to the study's fourth sub-question: "What are the views of fourth-grade primary school students and their classroom teachers regarding the virtual reality-based science course?" Qualitative data were collected through

student diaries, interview forms, observation notes, and teacher interviews. The following themes were identified based on the content analysis of these data sources.

The Realistic and Immersive Nature of the Application

Students perceived the virtual reality environment as highly realistic and engaging. Burak remarked, "I think lessons are better with virtual reality because it feels like you are actually there." Similarly, Esra stated, "It does not feel real when watching videos, but here it was very realistic." Ayşe, reflecting on the space section, said, "The feeling of being in space was extraordinary. It felt like I was actually there." Observation notes also indicated that students physically responded to the experience. For instance, Enes lifted his feet when encountering a sea scene; Sena ducked, thinking she might hit a sign in the mine; and Betül expressed the immersive nature of the experience by saying, "I want to get off the vehicle, but I cannot. It feels like I am going to fall." Classroom teacher Ms. Seçil shared her observations as follows: "Even I felt like I was there. It was as if the whole system was beneath my feet. It felt real." Participants' perception of the application as realistic and immersive supports the potential of virtual reality to create student-centered, experience-based learning environments in science education.

The Enjoyable Nature of the Application

One of the most frequently expressed views was that the application was enjoyable. Masal stated, "It was so much fun. I wish we could do it again." Zeynep remarked, "You are having fun and seeing everything come alive simultaneously." Ahmet described his experience: "I was inside the vehicle... sometimes it sped up, sometimes it slowed down. It felt like I would fall- it was so much fun." The researcher also reflected on this in the diary: "Above all else, the students truly enjoy the application... the fact that it is not only instructive but also entertaining makes them even more eager to participate." The fact that students found the application enjoyable contributed to developing positive attitudes toward the science course and increased their willingness to engage voluntarily in the learning process.

The Instructive Nature of the Application

A large portion of the participants emphasized the instructive aspect of the application. Nisa stated, "In regular lessons, you do not really understand what is going on, but here you can see it up close and understand it better." Ömer commented, "Actually, if all lessons were like this, they would be more instructive." Alparslan expressed the educational potential of the application by saying, "I can learn new things with this application. Everything is alive." Classroom teacher Ms. Leyla described the instructive

quality of the application as follows: "It takes on the role of a teacher... It teaches abstract topics by concretizing them in the students' minds." Similarly, the researcher noted in the diary: "The students were very excited, but they also learned. Even though the topic was unfamiliar, they could answer nearly all the questions." Participants' perception of the application as instructive highlights the effectiveness of virtual reality in concretizing abstract and conceptual topics, particularly in science education.

The Opportunity to Experience Events/Phenomena for the First Time

Students stated that they experienced many concepts and phenomena for the first time during the application. Turan remarked, "It was the first time in my life I saw a volcano... but this time I saw it for real." Emine said, "I went to space and saw the sun and Mars for the first time." Ali emphasized his experiential gain by stating, "I always heard about the layers, but I had never seen them. Now I know what they look like." Field notes also supported this observation. According to the notes, Ali exclaimed, "Wow, we are in space! This is my first time in space," while Ömer said, "There are planets here... I am seeing them now." The researcher summarized this phenomenon in the diary: "Although they had previously seen these things in books, videos, or pictures, the fact that they said it was the first time they were seeing them seems to be related to the way they experienced the application as a real event." The participants' expressions of encountering many concepts for the first time through the application illustrate that virtual reality allows students to engage with content that is otherwise difficult to access.

The Motivating Nature of the Application

Students demonstrated high eagerness and excitement to participate in the application. Emine stated, "I was very excited to come here... Science lessons are actually fun." Yunus expressed, "It was something different. That is why I really enjoyed participating in the lesson." Deniz emphasized his effort to understand a complex topic by saying, "I told myself I could do it... Then, after thinking about it carefully, I understood the topics." The researcher reflected on this in the diary: "Tuncay said, 'If you explain all the topics with these glasses, I will learn everything.' This indicates that students' belief in their ability to understand the content has increased." In Bilal's student diary, he wrote, "Now I like science lessons. Science is important, so now I like it." This statement shows that the application transformed the student's attitude toward science learning. Students' enthusiastic participation and their efforts to learn highlight the intrinsic motivational effect of the virtual reality application. These findings reveal that both students and teachers positively evaluated science instruction conducted through virtual reality.

The lesson was found to be effective, particularly due to features such as realism, instructiveness, enjoyment, and motivational quality.

Challenges Encountered During the Journey

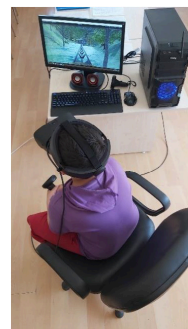
This section presents the findings related to the study's fifth sub-question: "What problems were encountered during the virtual reality-based science course conducted in the fourth grade of primary school?" The findings were examined under two main themes: technical and physical issues, and student- and experience-related problems.

Technical and Physical Issues

Due to the inherent nature of virtual reality technology, various technical and physical problems were encountered during the implementation process. The most frequently observed issues included software updates, internet connectivity, power outages, hardware malfunctions, and adjustments related to using the virtual reality headset. For example, the researcher noted in the diary: "At the beginning of the application, I noticed that the virtual reality headset was not displaying any visuals... The Oculus software requested an update, but due to insufficient internet at the school, I had to use mobile data... After the update, the Unity software also produced errors... All these processes took approximately one hour." According to the findings, power outages also directly affected the process: "Today, the electricity went out... Despite waiting three hours, the power did not return, so I had to send the students home. The program was seriously disrupted." One hardware-related issue involved the graphics card: "The graphics card malfunctioned... I turned off the devices and waited for a while, suspecting overheating... After adjustments, the system stabilized, but we still lost significant time." Although the virtual reality headset used during the application can track the student's gaze direction, it is impossible to observe externally whether the image inside the headset is clear (see Figure 7).

Figure 7.

Screenshot from the virtual reality application implementation phase - 1



As a result, whether the student had a clear view inside the headset could only be determined based

on the student's feedback. The headset's failure to properly fit the shape of the head emerged as a significant physical issue. In particular, for some students with smaller head sizes, the headset did not fit securely, negatively affecting the image quality: "No matter what I did, the student reported that the image was not clear... The student's head is quite small, and the headset does not fully fit even at the narrowest setting." Additionally, issues related to hair styling or wearing a headscarf prevented the proper placement of the headset. For some students who wore glasses, it was noted that using the headset and glasses was difficult, diminishing the image quality.

Student- and Experience-Related Issues

Findings indicate that some students exhibited anxiety at the beginning of the application. This apprehension was often rooted in prior negative virtual reality experiences. Students had developed prejudices due to fast and frightening content encountered in a VR truck previously available at the school. A student coded as Hatice expressed this in her diary: "I liked everything about the application, but I was afraid because it was fast. I thought it would be like the truck at school before. However, it was not like that; it was slow..." Conversely, students with prior positive VR experiences participated in the application with greater enthusiasm and excitement. This suggests that past experience is a significant variable influencing student attitudes. Another issue identified was negative parental attitudes toward the process. Despite informed consent forms being sent before the study, some families opposed the application, and misconceptions about the research arose. The researcher noted in the diary: "Among families, false information such as 'They are from X University and will conduct experiments on our children' spread... This negatively affected participation rates." Notably, a student named Sena was initially unable to participate but later convinced her family to allow her involvement, underscoring the fragility of the process.

The technical, physical, and pedagogical challenges encountered during the study highlight the necessity for planned and flexible integration of virtual reality technologies into educational settings. Applications carried out without consideration of factors such as technical infrastructure, hardware compatibility, student experience, and parental attitudes were found to disrupt the process. These findings offer important insights for future implementations of similar applications.

Overcoming Challenges Encountered During the Journey

This section presents the findings related to the study's sixth sub-question: "How can the problems encountered during the virtual reality-based science course conducted in the fourth grade of primary

school be addressed?" The findings were examined under two main themes: solutions to technical and physical issues, and solutions to student- and experience-related problems.

Solutions to Technical and Physical Issues

Strategies to address the technical and physical problems encountered during the research process were shaped within the framework of hardware backups, system checks, and alternative planning. The researcher took various precautionary measures to prevent disruptions caused by software updates, hardware failures, or power outages. In this context, the use of backup devices proved to be an effective solution to systemic issues experienced during the operation of the virtual reality application. The researcher noted in the diary: "Due to a problem with the graphics card, no image was displayed. I activated the backup computer and continued the application." This experience highlights the importance of having backups for high-performance hardware components, especially in virtual reality systems. However, not all technical problems could be resolved. For instance, due to the inflexibility of the headset, students with smaller head sizes experienced improper fitting of the headset, resulting in unclear images. This problem remained unresolved throughout the application. Similarly, students who wore glasses faced technical limitations, as the headset could not accommodate their glasses, leading to difficulties in achieving clear visuals; no solution was found for this issue during the implementation. Preventive measures, alternative plans, and hardware backups facilitate the smooth execution of the process in resolving technical problems. Nonetheless, structural limitations such as the ergonomic design of virtual reality equipment may hinder the equal functionality of the process for all participants.

Solutions to Student- and Experience-Related Issues

Most of the anxieties experienced by students during the implementation process stemmed from prior negative experiences. In particular, a previous VR truck experience at the school involving fast and frightening content led some students to develop prejudices against the current application. To address this, detailed information about the content was provided before the application, and students were assured that they could stop the process at any time. The researcher noted the following in the diary: "Before starting, Ahmet asked whether the application would be too fast and if it contained frightening elements. I explained the content in detail, and afterwards, I observed that he felt more at ease." This approach efficiently ensured the children's emotional security and increased participation. Similarly, some parents misunderstood the application upon seeing the university's name, which disrupted the process. Classroom teachers and school administration

intervened to resolve this issue and provided reassuring information. This highlights the influential role of trusted social actors in students' participation decisions. The researcher's diary reflected this: "Sena could not obtain permission from her family for a long time. She observed the application from outside during the process but ultimately convinced her family and participated." As the findings indicate, comprehensive pre-application information for students and parents, strengthening trust relationships, and active use of teacher support are critical to the success of the process in reducing prejudices.

Discussion and Conclusion

The primary aim of this study was to explore how the virtual reality-based science instruction process developed for fourth-grade primary school students is conducted. The first finding revealed that the process can be implemented in three main phases: lesson preparation, lesson delivery, and assessment and evaluation. During the lesson preparation phase, introducing students to virtual reality technology and providing instructions related to the application process were found to be important for ensuring students' readiness to use the technology. In the lesson phase, students' interactive engagement using the virtual reality controller and ongoing communication with the teacher supported active learning and maintained the pedagogical integrity of the process. The assessment and evaluation phase conducted at the end of the lesson contributed systematically to the instructional process by identifying students' learning gains and detecting learning gaps.

The quantitative and qualitative data collected throughout the study demonstrated a significant increase in students' academic achievement in the science course. The achievement tests administered at the beginning and end of the application, along with observation forms, researcher and student diaries, and interviews with students and teachers, supported this result. The visual and auditory presentations facilitated by virtual reality technology, its interactive content, and the high level of immersion provided contributed to deepening students' learning processes. These findings are consistent with existing literature demonstrating the positive effects of virtual reality applications on academic achievement (Akkaya, 2016; Çakır, 2019; Evci, 2022; Karataş, 2020; Özer, 2017; Sakız et al., 2014; Uysal, 2020).

Similar findings regarding the positive impact of virtual reality technology on academic achievement have been reported in numerous studies (Akman & Çakır, 2020; Bouta & Retalis, 2013; Değirmenci Kurt, 2022; Kim & Kei, 2017; Villena Taranilla et al., 2019; Yang et al., 2010; Yang et al., 2021). Aktamış and Arıcı (2013) determined that virtual reality-supported science instruction increases academic achievement, while

Sarioğlu (2019) emphasized that science instruction conducted with virtual reality is particularly effective in concretizing abstract concepts. A meta-analysis conducted by Villena Taranilla et al. (2019) also concluded that virtual reality applications enhance students' academic achievement. Liu et al. (2022) reported that virtual reality-based science instruction developed at the primary school level significantly increased students' academic success. Similarly, studies by Fokides and Chachlaki (2020), Liou et al. (2017), and Sun et al. (2010) demonstrate the positive effects of virtual reality applications in science education.

Another key finding of the study is that students' motivation toward science learning improved across factors such as self-efficacy, active learning strategies, the value of science learning, performance and achievement goals, and environmental stimulation. This result is supported by quantitative data obtained from the motivation scale and observation forms, researcher and student diaries, and interviews. The materials used in virtual reality environments, which offer highly realistic world simulations, fostered a strong desire to learn among students, thereby enhancing their motivation (Laver et al., 2015). Similarly, studies by Garduño et al. (2021), Fokides and Chachlaki (2020), Liou et al. (2017), and Liu et al. (2022) have demonstrated that virtual reality increases motivation in learning environments. Değirmenci Kurt (2022) reported that virtual reality-supported mathematics instruction elevated students' motivation, a finding supported by both test data and parental interviews. Beyoğlu et al. (2020) found that mixed reality applications increase motivation, while Yang et al. (2021) highlighted contributions to writing motivation. Motivational benefits of virtual reality have also been identified in history and language learning contexts (Villena Taranilla et al., 2019; Yang et al., 2010). Additionally, Boda and Brown (2020) and Sun et al. (2010) showed positive effects of virtual reality on attitudes and motivation toward science lessons. However, some studies (Pateraa et al., 2008; Uysal, 2022) have indicated that virtual reality does not always produce significant motivational effects. This suggests that contextual factors, such as the type of software used, duration of application, and student age, may play a determining role in its motivational impact.

Another significant finding of the study is that participants perceived the virtual reality application as realistic, immersive, enjoyable, instructive, and motivating. The vast majority of participants reported that the content presented in the virtual reality environment was impressive and conducive to learning. Additionally, students expressed that through this application, they could observe phenomena and events for the first time that they had not previously

experienced. The sense of “presence,” a fundamental characteristic of virtual reality, plays a decisive role in enhancing the instructional effectiveness of such applications. Beyoğlu et al. (2020) demonstrated that mixed reality applications generate high levels of excitement and motivation among students, while Dilmen (2020) found that augmented reality makes lessons more enjoyable. Yang et al. (2021) reported that virtual reality-based instructional methods are more satisfying than traditional methods; Sulisworo et al. (2022) noted that students found virtual reality applications highly immersive. Similar to this study, Liu et al. (2022) emphasized that virtual reality-based instruction positively affects students’ academic achievement, science motivation, and attitudes toward learning, while reducing cognitive load. Students reported positive experiences with the application and indicated a high level of interest in lessons conducted using virtual reality.

Another key finding of the study is that technical and physical issues and student- and experience-related problems were encountered during the implementation process. Technical and physical problems primarily stemmed from hardware and infrastructure elements such as computers, virtual reality headsets, software, internet connectivity, and electricity. Student- and experience-related issues were associated with students’ apprehensions due to prior experiences and parental prejudices toward virtual reality technology. These findings are consistent with studies conducted by Sulisworo et al. (2022) and Lim et al. (2006). Lim et al. (2006) emphasized that factors such as time constraints, school infrastructure, and parental involvement pose significant barriers to integrating virtual reality technology into educational programs. Solutions to the technical and physical problems encountered in the study were implemented using backup devices and software. Using wireless and standalone virtual reality headsets with their own operating systems is recommended, as these battery-powered devices also offer advantages against issues such as power outages. Additionally, flexible fabric-based and adjustable headsets are preferred over rigid plastic headsets that do not fit securely, and compatible lens adapters should be used for students who wear glasses. Such strategies are considered important to prevent problems that may arise in similar studies.

This study comprehensively examined the effects of virtual reality-based science instruction on fourth-grade primary school students. The results indicate that the instructional process can be effectively conducted within a three-phase structure consisting of preparation, implementation, and evaluation. Also, the results revealed a significant increase in students’ academic achievement in the science course. Additionally, students’ motivation toward science

learning showed improvement across dimensions such as self-efficacy, active learning strategies, the value of science learning, achievement goal, performance goal, and environmental stimulation. Qualitative findings supported this development, demonstrating that students perceived the application as realistic, instructive, enjoyable, and motivating. Various challenges were observed throughout the process, including technical issues related to the VR headset, hardware incompatibilities, and students’ apprehensions from prior experiences. However, practical solutions were implemented through the use of backup equipment, flexible planning, and collaboration between families and teachers.

This study suggests that virtual reality technology is not merely a technical innovation but also a pedagogically valuable instructional tool. It possesses strong potential in primary science education, particularly concerning concretization, experiential learning, and motivation enhancement. The planned, structured, and student-centered integration of virtual reality in educational settings may provide significant contributions toward making learning processes more meaningful and enduring.

Limitations and Suggestions for Future Research

This study was conducted with fourth-grade students from a single school and did not include a control group. This limitation restricts the ability to draw causal inferences. Future studies should employ larger samples, incorporate different types of schools and socioeconomic levels, and adopt experimental designs that include control groups. The virtual reality application named Science Coaster used in this study was developed solely for the Earth’s Crust and the Movements of Our Planet unit. Developing virtual reality software for other science units and other subject areas and conducting studies to evaluate their effectiveness would make important contributions to the literature. Moreover, this study was limited to the fourth-grade level. Implementing similar applications across different age groups would be meaningful in revealing the age-related effects of virtual reality applications. The study utilized structured data collection instruments such as achievement tests and motivation scales. Future research could enrich the scope by incorporating alternative data collection tools, particularly game-based assessment systems, process-oriented evaluation instruments, and biometric data collection techniques (e.g., eye tracking, galvanic skin response). Technical and physical issues and some limitations related to student experience were encountered during the research process. While some problems were resolved with the researcher’s technical knowledge and hardware support, others remained unaddressed. Accordingly, future studies are expected to achieve more effective results by

developing applications through interdisciplinary teams consisting of professional software developers, graphic designers, sound engineers, programmers, and educational technology experts.

For future virtual reality-based applications, it is recommended to develop multi-user support, task-based content that enables user interaction, AI-supported learning systems, personalized learning pathways, feedback systems to monitor students' progress, and designs compatible with low-cost hardware. Additionally, social learning processes in virtual reality environments can be supported through systems that encourage collaboration among students by enabling synchronous multi-user modes. Finally, offering elective courses focused on virtual reality in teacher education faculties can enhance prospective teachers' knowledge and skills regarding virtual reality technologies, thereby strengthening their competencies to integrate these technologies into instructional practices. Field applications conducted in collaboration with schools through virtual reality laboratories established within universities will further support this process.

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References

- Adıgüzel, O.C. (2016). *Eğitim programlarının geliştirilmesinde ihtiyaç analizi el kitabı* [Handbook on needs analysis in the development of education programs]. Anı Yayıncılık.
- Akbulut, Y. (2010). *Sosyal bilimlerde SPSS uygulamaları* [SPSS applications in social sciences]. İdeal Kültür Yayıncılık.
- Akkaya, G. (2016). *Rol model içerikli animasyonların üstün yetenekli 4. sınıf öğrencilerinin fen bilimleri dersinde zihinsel risk alma davranışları ve öğrenmelerine etkisi* [The effect of animations involving models on fourth grade gifted students' intellectual risk taking and learning in science courses] [Unpublished master's thesis]. İnönü University.
- Akman, E., & Çakır, R. (2020). The effect of educational virtual reality game on primary school students' achievement and engagement in mathematics. *Interactive Learning Environments*, 31(13), 1467-1484. <https://doi.org/10.1080/10494820.2020.1841800>
- Aktamış, H. & Arıcı, V. (2013). Sanal gerçeklik programlarının astronomi konularının öğretiminde kullanılmasının akademik başarı ve kalıcılığa etkisi [The effects of using virtual reality software in teaching astronomy subjects on academic achievement and retention]. *Mersin Üniversitesi Eğitim Fakültesi dergisi*, 9(2), 58-70.
- Arıcı, V. A. (2013). *Fen eğitiminde sanal gerçeklik programları üzerine bir çalışma: "güneş sistemi ve ötesi: uzay bilmecesi" ünitesi örneği* [A study on 3D-virtual reality in science education programs: 'Solar system and beyond: Space puzzle' unit sample] [Unpublished master's thesis]. Adnan Menderes University.
- Bailenson, J. (2018). *Experience on demand: What virtual reality is, how it works, and what it can do*. W. W. Norton & Company.
- Bayraktar, E., & Kaleli, F. (2007). Sanal gerçeklik ve uygulama alanları [Virtual reality and its application areas]. In M. Akgül, E. Derman, U. Çağlayan, & A. Özgüt (Eds.), *Proceedings of the 9th Academic Informatics Conference (Akademik Bilişim '07)* (pp. 253-258). Dumlupınar University. <https://ab.org.tr/ab07/>
- Beyoğlu, D., Hürşen, Ç., & Nasiboğlu, A. (2020). Use of mixed reality applications in teaching of science. *Education and Information Technologies*, 25, 4271-4286. <https://doi.org/10.1007/s10639-020-10166-8>
- Bilgiç, H. G., Duman, D., & Seferoğlu, S.S. (2011). Dijital yerlilerin özellikleri ve çevrim-içi ortamların tasarlanmasındaki etkileri [Characteristics of digital natives and their implications for the design of online environments]. In *Proceedings of the 13th Academic Informatics Conference (Akademik Bilişim '11)* (pp. 257-263). İnönü University. <https://ab.org.tr/ab11/>
- Boda, P.A., & Brown, B. (2020). Designing for relationality in virtual reality: context-specific learning as a primer for content relevancy. *Journal of Science Education and Technology*, 29, 691-702. <https://doi.org/10.1007/s10956-020-09849-1>
- Bouta, H., & Retalis, S. (2013). Enhancing primary school children's collaborative learning experiences in maths via a 3D virtual environment. *Education and information technologies*, 18, 571-596. <https://doi.org/10.1007/s10639-012-9198-8>
- Çavaş, B., Huyugüzel Çavaş, P. & Taşkın Can, B. (2004). Eğitimde sanal gerçeklik uygulamaları [Virtual reality in education]. *The Turkish Online Journal of Educational Technology*, 3(4), 110-116.

- Çakır, S. (2019). 4. sınıf fen bilimleri dersi "mikroskopik canlılar ve çevremiz" ünitesinde robotik kodlama uygulamalarının öğrenme ürünlerine etkisi [The effect of robotic coding practices on learning products on microscopic living and environment unit at 4th grade science lesson] [Unpublished master's thesis]. Zonguldak Bülent Ecevit University.
- Dede, C. (2009). Immersive interfaces for engagement and learning. *Science*, 323(5910), 66–69. <https://doi.org/10.1126/science.1167311>
- Hacıeminoğlu, E. (2019). Students and school level variables related to elementary school students' attitude toward science. *Eurasian Journal of Educational Research*, 80, 59-88. <https://doi.org/10.14689/ejer.2019.80.4>
- Değirmenci Kurt, A. (2022). *Sanal gerçeklik uygulamalarının öğrenme güçlüğü yaşayan öğrencilerin matematik başarılarına etkisi* [The effect of virtually reality practice on mathematic success of students with learning disabilities] [PhD Thesis]. Mehmet Akif Ersoy University.
- Dilmen, E. (2020). *Fen bilimleri dersinde artırılmış gerçeklik uygulamasının 21. yüzyıl becerilerine ve temel becerilere etkisi* [The effect of augmented reality application in science course on 21st century skills and basic skills] [Unpublished master's thesis]. Ömer Halisdemir University.
- Evci, M. (2022). *Fen bilimleri dersi öğretiminde ters yüz sınıf modelinin öğrencinin akademik başarısına etkisi* [The effect of Flipped Classroom Model on student academic achievement in science teaching] [Unpublished master's thesis]. Ankara University.
- Fokides, E., & Chachlaki, F. (2020). 3D multiuser virtual environments and environmental education: The Virtual Island of the Mediterranean Monk Seal. *Technology, Knowledge and Learning*, 25, 1–24. <https://doi.org/10.1007/s10758-019-09409-6>
- Garduño, H.A.S., Martínez, M.I.E., & Castro, M.P. (2021). Impact of virtual reality on student motivation in a high school science course, *Applied Sciences*, 11(20), 9516. <https://doi.org/10.3390/app11209516>
- İşman, A., Baytekin, Ç., Balkan, F., Horzum, M. B., & Kıyıcı, M. (2002). Fen bilgisi eğitimi ve yapısalcı yaklaşım [Science education and the constructivist approach]. *The Turkish Online Journal of Educational Technology-(TOJET)*, 1(1), 41-47.
- Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, 23(4), 1515–1529. <https://doi.org/10.1007/s10639-017-9676-0>
- Karataş, F. (2020). *İlkokul 3. sınıf fen bilimleri dersinde dijital hikâye kullanımının akademik başarı ve kalıcılığa etkisi* [The effect of using digital storytelling on academic achievement and permanence in primary school 3rd grade science course] [Unpublished master's thesis]. Gazi University.
- Kavanagh, S., Luxton-Reilly, A., Wuensche, B., & Plimmer, B. (2017). A systematic review of virtual reality in education. *Themes in Science & Technology Education*, 10(2), 85–119. <http://files.eric.ed.gov/fulltext/EJ1165633.pdf>
- Kim, H., & Kei, F. (2017). Effects of game-based learning in an OpenSim-supported virtual environment on mathematical performance. *Interactive Learning Environments*, 25(4), 543–557. <https://doi.org/10.1080/10494820.2016.1167744>
- Laver, K., George, S., Thomas, S., Deutsch, J., & Crotty, M. (2015). Virtual reality for stroke rehabilitation. *Cochrane Database of Systematic Reviews*, 2, Article No.: CD008349. <https://doi.org/10.1002/14651858.CD008349.pub3>
- Lester, J., Spires, H., Nietfeld, J., Minogue, J., Mott, B., & Lobene, E. (2014). Designing game-based learning environments for elementary science education: A narrative-centered learning perspective. *Information Sciences*, 264, 4–18. <https://doi.org/10.1016/j.ins.2013.09.005>
- Liang, Y., Wang, L., & Wu, T. (2025). The development and verification of the VRFT learning model for the virtual reality classroom: a proof-of-concept study. *Interactive Learning Environments*, 1–21. <https://doi.org/10.1080/10494820.2025.2511251>
- Lim, C.P., Nonis, D., & Hedberg, J. (2006). Gaming in a 3D multiuser virtual environment: Engaging students in science lessons. *British Journal of Educational Technology*, 37(2), 211–231. <https://doi.org/10.1111/j.1467-8535.2006.00531.x>
- Liou, H. H., Yang, S. J. H., Chen, S. Y., & Tarng, W. (2017). The influences of the 2D image-based augmented reality and virtual reality on student learning. *Educational Technology & Society*, 20(3), 110–121. <https://www.jstor.org/stable/26196123>

- Liu, R., Wang, L., Koszalka, T.A., & Wan, K. (2022). Effects of immersive virtual reality classrooms on students' academic achievement, motivation and cognitive load in science lesson. *Journal of Computer Assisted Learning*, 38(5), 1422-1433. <https://doi.org/10.1111/jcal.12688>
- Mayer, R.E. (2001). *Multimedia learning*. Cambridge University Press. <https://doi.org/10.1017/CBO9781139164603>
- Mayer, R.E. (2009). *Multimedia learning* (2nd edition). Cambridge University Press. <https://doi.org/10.1017/CBO9780511811678>
- 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>
- Özçelik, D.A. (1998). *Ölçme ve değerlendirme [Measurement and evaluation]*. ÖSYM Yayınları.
- Özdamar, K. (2017). *Ölçek ve test geliştirme-Yapısal eşitlik modellenmesi [Scale and test development -Structural equation modeling]*. Nisan Kitabevi Yayınları,
- Özer, F. (2017). *Ciddi oyunların ilkököl 4. sınıf öğrencilerinin Fen Bilimleri dersi akademik başarılarına, derse yönelik motivasyonlarına ve problem çözme becerilerine etkisi [The impact of serious games on science course academic achievement, motivation and problem-solving skills of primary school 4th grade students]* [Unpublished master's thesis]. Anadolu University.
- Pande, S. S., Pande, S. R., Parate, V. R., Nikam, A. P., & Agrekar, S. H. (2013). Correlation between difficulty & discrimination indices of MCQs in formative exam in physiology. *South-East Asian Journal of Medical Education*, 7(1), 45-50. <https://doi.org/10.4038/seajme.v7i1.149>
- Pateraa, M., Draperband, S., & Naef, M. (2008). Exploring Magic Cottage: A virtual reality environment for stimulating children's imaginative writing. *Interactive Learning Environments*, 16(3), 245-263. <https://doi.org/10.1080/10494820802114093>
- Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education*, 58(1), 136-153. <https://doi.org/10.1016/j.compedu.2011.07.017>
- Sakız, G., Özden, B., Aksu, D. & Şimşek, Ö. (2014). Fen ve teknoloji dersinde akıllı tahta kullanımının öğrenci başarısına ve dersin işlenişine yönelik tutuma etkisi [The effect of the use of interactive whiteboard on students' achievement and attitude toward instruction in science and technology classrooms]. *Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 18(3), 257-274.
- Sarioğlu, S. (2019). *İlköğretim 6. sınıf fen bilimleri dersi hücre konusunda sanal gerçeklik kullanımının öğrencilerin akademik başarısı ve derse karşı tutumuna etkisi [The effect of using virtual reality in 6th grade science course the cell topic on students' academic achievements and attitudes towards the course]* [Unpublished master's thesis]. Gazi University.
- Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, 34(9), 1337-1370. <https://doi.org/10.1080/09500693.2011.605182>
- Sulisworo, D., Erviana, V.Y., Robiin, B., Sepriansyah, Y., & Soleh, A. (2022). The feasibility of enhancing environmental awareness using virtual reality 3D in the primary education. *Education Research International*, 1-10. <https://doi.org/10.1155/2022/4811544>
- Sun, K.-T., Lin, C.-L., & Wang, S.-M. (2010). A 3-D virtual reality model of the sun and the moon for e-learning at elementary schools. *International Journal of Science and Mathematics Education*, 8(4), 689-710. <https://doi.org/10.1007/s10763-009-9181-z>
- Şevgin, Z. (2024). *Fen eğitiminde sanal gerçeklik kullanımı ile ilgili yapılan araştırmalar üzerine bir metasentez çalışması [A metasynthesis study on research on the use of virtual reality in science education]* [Unpublished master's thesis]. Van Yüzüncü Yıl University.
- Uysal, M.R. (2020). *İlkokul 4. sınıf fen bilimleri dersinde web 2.0 animasyon araçları kullanımının çeşitli değişkenlere etkisi [The effect of using web 2.0 animation tools in the science course for 4th grade students on various variables]* [Unpublished master's thesis]. Niğde Ömer Halisdemir University.
- Villena Taranilla, R., Cozar-Gutierrez, R., Gonzalez-Calero, J. A., & Lopez Cirugeda, I. (2019). Strolling through a city of the Roman Empire: An analysis of the potential of virtual reality to teach history in primary education. *Interactive Learning Environments*, 30(4), 608-618. <https://doi.org/10.1080/10494820.2019.1674886>

- Wang, F., Kinzie, M. B., McGuire, P., & Pan, E. (2010). Applying technology to inquiry-based learning in early childhood education. *Early Childhood Education Journal*, 37(5), 381–389. <https://doi.org/10.1007/s10643-009-0364-6>
- Yang, G., Chen, Y., Zheng, X., & Hwang, G. (2021). From experiencing to expressing: A virtual reality approach to facilitating pupils' descriptive paper writing performance and learning behavior engagement. *British Journal of Educational Technology*, 52(2), 807–823. <https://doi.org/10.1111/bjet.13056>
- Yang, J. C., Chen, C. H., & Chang Jeng, M. (2010). Integrating video-capture virtual reality echnology into a physically interactive learning environment for English learning. *Computers & Education*, 55(3), 1346–1356. <https://doi.org/10.1016/j.compedu.2010.06.005>
- Yılmaz, H. & Huyugüzel Çavaş, P. (2007). Fen öğrenimine yönelik motivasyon ölçeğinin geçerlik ve güvenirlik çalışması [Reliability and validity study of the students' motivation toward science learning (SMTSL) questionnaire]. *İlköğretim online*, 6(3), 430-440. <https://dergipark.org.tr/tr/download/article-file/90999>
- Yin, R.K. (2014). *Case study research: Design and methods* (5th edition). Sage Publications Thousand Oaks.