Exploring the Effects of Virtual Reality-based Learning on Motivation and Academic Achievement in Elementary Education

Deefallah Alshorman [1,*], Hebah Alkhasoneh [2], Wael Mohammad Alshurman [3], and Rakez Al-Ararah [1]

[1] Department of Elementary Teacher Education, Al-Zaytoonah University of Jordan, Amman, Jordan
[2] Department of Geography, School of Arts, The University of Jordan, Amman, Jordan
[3] Faculty of Educational Sciences, Department of Psychological Sciences and Special Education, Al al-Bayt University, Mafraq, Jordan
Email: d.alshorman@zuj.edu.jo (D.A.); h.alkhasoneh@ju.edu.jo (H.A.); malak1942004@aabu.edu.jo (W.M.A.); r.alararah@zuj.edu.jo (R.A.-A.)
*Corresponding author

Manuscript received May 18, 2026; revised June 5, 2026; accepted July 9, 2026; published November 12, 2026

***Abstract*—With the integration of immersive technologies into education, teachers and students have gained new opportunities to foster student engagement, boost student motivation, and enhance conceptual understanding. Using a quasi-experimental pretest–posttest design, this study examined the effects of Virtual Reality (VR)-based learning environments on elementary students' academic achievement and motivation in a science education program. Participants were 46 sixth-grade students at a public elementary school in Amman, Jordan, divided into an experimental group and a control group. Students in the control group received traditional science instruction, whereas those in the experimental group participated in a program that introduced them to the Solar System through an immersive VR-based learning environment. Scores on the academic achievement test and motivation scale showed that, after the intervention, students in the experimental group attained higher short-term academic achievement and reported greater motivation toward science learning than those in the control group. The responses from students in the experimental group on the post-intervention questionnaire reflected high levels of engagement, enjoyment, and curiosity during the VR sessions. Within the constraints of this small-scale, quasi-experimental design, these findings provide preliminary evidence that participation in a VR-supported Solar System unit was associated with higher short-term academic achievement and stronger motivation toward science learning in this specific context, rather than establishing the general effectiveness of VR in transforming science learning.**

***Keywords*—Virtual Reality (VR), immersive learning, elementary education, science motivation, academic achievement, Solar System, educational technology**

I. Introduction

Virtual Reality (VR) and Augmented Reality (AR) are at the forefront of rapid technological advancements. These technologies enhance student learning through interactive experiences that go beyond traditional classroom boundaries [1, 2]. Although these two technologies are often discussed together, they differ in important ways: immersive VR fully replaces the user's visual field with a computer-generated environment; AR overlays digital content onto the real world; and non-immersive or desktop-based VR presents 3D content on a conventional screen. In reviewing prior work, we therefore draw on evidence from AR, desktop-based VR, and higher-education contexts to inform broader points about visualization, engagement, and technology-supported science learning, while recognizing that such findings are not directly equivalent to the present immersive VR intervention with elementary students.

In the last ten years, virtual reality has progressed from an experimental technology to a powerful tool in education that reshapes the entire learning experience. VR can turn lessons into interactive experiences, improving learning outcomes and engagement across a variety of topics [1, 3–6]. VR aligns with experiential learning theory by encouraging students' active participation and improving learning through direct engagement with content [7, 8]. Moreover, VR-based Three-Dimensional (3D) learning environments enable students to enter and actively engage with immersive spaces, where exploration, manipulation, and immediate feedback become integral to the learning process [2].

Despite this promising potential, not all VR applications yield measurable learning gains. While numerous high-fidelity VR systems are designed for educational use, few have been shown to substantially enhance cognitive outcomes, particularly in Science, Technology, Engineering, and Mathematics (STEM) fields [1, 9, 10]. This is largely because the effectiveness of VR depends on how well it is designed and integrated into instruction, rather than on the technology itself. When well-designed, however, educational VR enables students to experience realistic representations of real-world phenomena—including large-scale or otherwise inaccessible situations [1, 11]. For example, when studying the Solar System , students can virtually travel through space, examine planetary surfaces, and explore the spatial relationships among celestial bodies in ways that no textbook or diagram can replicate [11, 12]. By providing such realistic learning experiences, VR has the potential to engage learners through multidimensional interaction, thereby supporting both Universal Design for Learning (UDL) principles and differentiated instruction by simultaneously catering to visual, auditory, and kinesthetic learners [2]. Furthermore, research has demonstrated that immersive experiences can reduce cognitive load, increase self-efficacy, and foster enthusiasm for learning [1, 2, 5, 13, 14].

Although virtual reality offers these pedagogical advantages, its integration into classroom teaching faces certain challenges, namely, teachers' readiness to teach and the challenge of designing cost-effective, meaningful immersive content that meets curriculum standards [7, 15–17]. Moreover, empirical research on the educational effects of virtual reality on elementary school

students remains limited [1]. Immersive technologies have been explored at various educational levels, including secondary school and university; however, research on elementary school students remains insufficient [4, 5, 18]. Elementary school students aged 11–12 are at a critical preadolescent developmental stage, characterized by heightened curiosity, imagination, and a gradual transition from concrete operational thinking to early abstract reasoning. Their ability to visualize is progressively enhanced, enabling them to handle abstract phenomena that are constrained by traditional teaching methods [19]. Therefore, it is essential to investigate how immersive virtual environments can strengthen foundational scientific understanding and foster intrinsic motivation during these formative years.

In addition to the previously discussed points, there has been increasing interest in recent years in the potential of pedagogical approaches that combine immersive technologies with constructivist and inquiry-based learning [20, 21]. Within elementary education settings, immersive approaches can provide students with authentic, inquiry-driven experiences that connect abstract content to real-world meaning [20]. This study also draws on Self-Determination Theory (SDT), which treats motivation in learning settings as sustained by three psychological needs: autonomy, competence, and relatedness [22]. Research has demonstrated that immersive VR experiences in STEM learning contexts foster intrinsic motivation and academic achievement, with autonomy support and perceived competence particularly effective at sustaining these outcomes over time [1].

The present work asks how VR-based learning environments relate to motivation and achievement among elementary school students studying science, with the Solar System as the specific content focus. To investigate these outcomes, a pretest/posttest experimental design was employed, comparing students who learned about the Solar System through VR with those taught the same content through traditional instruction. Three sources of evidence were examined: achievement, motivation toward science, and the students' own accounts of the virtual reality sessions. Together these shed light on how immersion relates to affective and cognitive outcomes at the elementary level, adding to the immersive-learning literature and offering practical guidance for teachers who bring virtual reality into primary classrooms.

A. Significance of the Study

Research on immersive technologies in education has expanded quickly, yet the empirical base is still narrow in both method and setting: most published studies have focused on secondary and higher education contexts, with elementary-level learners substantially underexplored [4, 5, 23]. This gap is particularly pronounced in the Arab and Middle Eastern educational context, where little empirical work has examined how young learners respond cognitively and motivationally to immersive virtual environments in science instruction. The present study directly addresses this gap by providing experimental evidence from sixth-grade Jordanian students engaged in VR-based Solar System instruction—a combination of learner age, content domain, and geographic context that remains underexplored in the existing literature.

A second dimension of significance concerns the specific science content targeted. Astronomy, and the Solar System in particular, represents one of the most conceptually challenging domains in elementary science curricula precisely because its core phenomena—planetary scale, orbital mechanics, and spatial relationships among celestial bodies—are neither directly observable nor reducible to concrete manipulation in a traditional classroom [11, 12]. Conventional instructional approaches relying on two-dimensional diagrams or static textbook illustrations are structurally incapable of conveying the three-dimensional spatial realities of the Solar System with sufficient fidelity, a limitation that has been consistently associated with persistent student misconceptions about astronomical scale and motion [24, 25]. Immersive VR environments, by contrast, afford learners the capacity to inhabit and navigate three-dimensional representations of astronomical phenomena, offering a mode of conceptual engagement that is qualitatively distinct from any prior instructional medium—an affordance with developmental significance for children in the 10–12 age range, whose spatial reasoning and capacity for mental model construction are at a critical formative stage [19, 26].

In addition, this study carries significance for the field of educational technology by contributing direct empirical evidence on an instructional design question that remains contested in the literature: whether the motivational and affective benefits of immersive VR translate into measurable academic achievement gains, or whether high presence and engagement come at the cost of cognitive load, potentially displacing the learning outcomes that justify the pedagogical investment [2, 14]. By employing a rigorous pretest-posttest quasi-experimental design with Analysis of Covariance (ANCOVA) controlling for prior knowledge, this study provides preliminary, context-bound evidence of both affective and cognitive outcomes simultaneously—a methodological approach that is absent from many prior intervention studies in this domain, which have relied on single-group or correlational designs [8, 23].

B. Research Questions

The literature reviewed above and the aims set out for this work led to three questions:

RQ1: Do students who learn about the Solar System using virtual reality demonstrate greater academic achievement compared to students who learn about the Solar System from a conventional instructional approach?

RQ2: Is there a statistically significant difference in learning motivation between the experimental group (VR-based instruction) and the control group (traditional instruction)?

RQ3: How do students perceive the use of virtual reality as a learning tool in terms of engagement, enjoyment, and usefulness in studying science concepts?

II. Methodology

A. Research Model

This study evaluates the use of virtual reality in teaching

elementary-level students in a sixth-grade space unit. A quasi-experimental design was adopted, with both conditions completing a pretest and a posttest [27, 28]. The study was conducted at a public elementary school in Amman, Jordan, as part of the Solar System instructional unit. The school enrolled three intact sixth-grade regular-education classes that followed the same national curriculum. Two of the three classes were drawn at random to take part. Following intact-group quasi-experimental sampling procedures [29], whole classes—rather than individual students—served as the units of assignment. The two selected classes were then randomly assigned to the experimental and control conditions. One class of 23 students formed the experimental group, and the other, also of 23 students, formed the control group. Baseline comparability between the two groups was examined empirically prior to the intervention Neither pre-test achievement, $t(44) = -0.24$, $p = 0.81$, nor pre-test motivation, $t(44) = 0.22$, $p = 0.82$, separated the two groups, and were comparable in age and gender distribution, supporting their initial equivalence on the measured variables. The control group used conventional teaching resources (textbooks, handouts, pictures, diagrams, and class discussions) together with short, non-interactive instructional videos to learn the space unit, whereas the experimental group engaged in an innovative virtual reality-based learning environment to increase engagement and enhance understanding of scientific concepts.

In line with international research ethics guidelines [30, 31], the study followed established ethical procedures for research involving children. Formal institutional ethics-committee approval was not required for this type of classroom-based educational study in the national context the school administration nevertheless granted formal permission for the work to proceed. Before any data were collected, a signed consent form was secured from every participating child's parent or guardian, and the children themselves gave verbal assent in front of their teacher and the school principal. Taking part was entirely voluntary, and the children understood that they could stop at any point without any consequence. Throughout the study, the children's privacy was protected by ensuring their complete confidentiality and anonymity.

B. Participants

This study involved 46 sixth-grade students (age 11–12) from a public elementary school in Amman, Jordan, during the 2025 academic year. Both groups were equivalent in age and gender distribution. The same science teacher taught the classes to ensure consistency in content delivery.

C. Instruments

Academic Achievement Test: To assess both prior knowledge and student learning at pre-test and post-test, an Achievement Test on the Solar System was developed. Initially, the test consisted of 30 multiple-choice items designed to measure student knowledge of the Solar System against the learning objectives of the Jordanian national science curriculum set by the Ministry of Education. After review by three experts, including two science educators and one measurement specialist, three items were revised, and five were deleted to improve item clarity and discrimination. The pilot version was administered to 25 students at a nearby school and returned a Kuder–Richardson Formula 20 (KR-20) coefficient of 0.86, which points to strong internal consistency. In the final version of the 25-item test, the discrimination indices ranged from 0.36 to 0.79 Items were spread across the content areas that the national sixth-grade curriculum sets out for the Solar System unit: how the Solar System and the Sun are structured; the planets and what distinguishes them; the comparative sizes, distances, and orbital positions of celestial bodies; and planetary rotation and revolution. Each item was mapped to a specific curricular learning objective to ensure content alignment, and the three expert reviewers confirmed this alignment during the content validity review. The difficulty indices of the final items ranged from 0.25 to 0.72, indicating a balanced distribution of easy, moderate, and difficult items. Sample items included questions such as "Which planet is closest to the Sun?" and "What causes the change between day and night?" For scoring, each of the 25 multiple-choice items was scored dichotomously (1 = correct, 0 = incorrect), yielding a raw score ranging from 0 to 25. To facilitate interpretation, each student's raw score was then converted to a percentage of correct answers on a 0–100 scale. Accordingly, all pre-test and post-test achievement scores reported in this study, including the adjusted means, are expressed as percentages (0–100).

Motivation Scale: Motivation toward science was captured with the Motivation for Science Learning Scale of Dede and Yaman [32], which comprises 23 items across five sub-dimensions (research curiosity, performance motivation, participation motivation, communication motivation, and cooperation motivation) on a five-point Likert scale ranging from "Strongly Disagree" (1) to "Strongly Agree" (5). The instrument was adopted from its previously published English version and translated into Arabic for use with Jordanian students. The Arabic translation was reviewed by two English-language specialists, who checked its accuracy and clarity against the English version, and minor wording adjustments were made accordingly. The Cronbach's α reliability coefficient in this study was 0.83.

VR Application Evaluation Questionnaire: Immediately after the posttest, the experimental group filled in a 15-item Student Opinion Questionnaire ($\alpha = 0.84$) written by the research team, covering how useful, enjoyable, easy to use, and engaging they had found the VR sessions.

The questionnaire was developed by the researchers based on established constructs in the technology acceptance and immersive learning literature, as well as the researchers' expertise in computer science and instructional technology. The usefulness and ease-of-use dimensions come from technology-acceptance research, whereas enjoyment and engagement were added because they are central to how immersive experiences are described in the literature. An initial item pool was generated for the four subdimensions and reviewed by two experts in instructional technology, who evaluated the items for clarity, relevance, and alignment with their intended subdimension; items were revised based on their feedback to produce the final 15-item version. In addition to the overall internal consistency ($\alpha = 0.84$), each subdimension demonstrated acceptable internal consistency: perceived usefulness ($\alpha = 0.81$), enjoyment ($\alpha = 0.78$), ease of

use ($\alpha = 0.75$), and engagement ($\alpha = 0.79$).

D. Virtual Reality Application

A custom-designed virtual reality learning module titled Exploring Our Solar System 3D was utilized to enhance science learning outcomes for the experimental group of this study (see Fig. 1). The module was created using the CoSpaces EDU platform and experienced through Oculus Meta Quest head-mounted displays, which provided a fully immersive view of the simulated environment. In terms of user experience and interaction design, learners navigated the three-dimensional space through the headset and interacted directly with the content: selecting a planet or object triggered informational elements, such as labels and short explanations, about its characteristics. The learning experience combined guided sequences—in which learners followed a structured path through the Solar System, its planets, and their relative sizes, distances, rotation, and revolution—with periods of free exploration, in which learners could move through the immersive space at their own pace and complete a short quiz that provided immediate feedback to reinforce their learning. The module was reviewed by two teachers and an instructional technology expert to confirm its content accuracy and alignment with the current curriculum and student age.

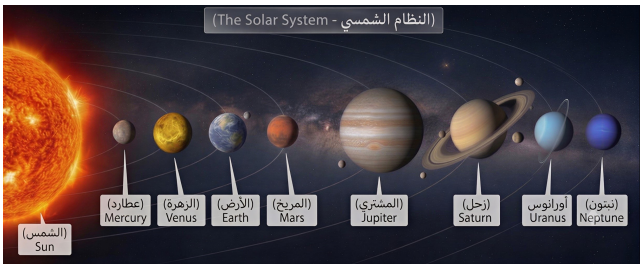


Fig. 1. The immersive Virtual Reality (VR)-based solar system learning module was developed for the study using CoSpaces EDU and viewed with standalone Virtual Reality (VR) headsets.

E. Implementation Procedure

The implementation lasted six weeks, including orientation, pilot, and testing phases (Table 1).

Table 1. Timeline of the solar system intervention

Week	Process
1	Pilot test of the VR system and administration of pre-tests (achievement and motivation)
2–5	Instructional sessions (four weeks × two lessons per week) using VR for the experimental group and traditional instruction for the control group
6	Administration of post-tests (achievement and motivation) and the Student Opinion Questionnaire for the experimental group

The instructional content was not static across the sessions but followed a progressive, scaffolded structure delivered through two sequential VR learning experiences. The first VR experience, used in Weeks 2–3, introduced the structure of the Solar System and the planets, while the second VR experience, used in Weeks 4–5, addressed the relative sizes, distances, and the rotation and revolution of celestial bodies. Each experience built on the content of the previous one, extending and consolidating prior learning rather than repeating it.

Both groups covered identical learning objectives under the same teacher and received the same amount of instructional time, with each session lasting 40 minutes of collective classroom instruction rather than individual exposure time per student. In the experimental group, five Oculus Meta Quest headsets were available for the class, and students took turns using them during the VR phase of each session, so that all learners engaged with the immersive content within the shared 40-minute lesson. Across both conditions, every session followed the same instructional sequence—a brief review of prior content, presentation of the new material, a structured student activity, and a closing whole-class discussion with questioning and feedback—and differed only in the medium through which the content was delivered. In the experimental group, the presentation and activity phases were delivered via the immersive VR module, in which students explored relevant Solar System phenomena. In the control group, the same content and activities were presented through the conventional resources described above, including teacher explanations supported by textbook readings, diagrams, class discussions, and short, non-interactive instructional videos. Both groups received equivalent opportunities for practice, questioning, and teacher feedback, with no additional test-specific preparation beyond the shared lesson plan.

Instruction in both conditions was provided entirely by the same classroom teacher, who led all explanations, activities, discussions, and feedback. The researcher did not deliver instruction or interact with students on academic content in either group; in the experimental group, the researcher's involvement was limited to technical support (distributing and configuring the VR headsets and resolving occasional operational issues), and in the control group, the researcher was present only as a non-participant observer to monitor fidelity of implementation.

F. Data Analysis

All quantitative analyses were carried out in IBM SPSS Statistics 29.0. Before analysis, the dataset was screened for missing entries, outlying values, and departures from distributional assumptions. Descriptive statistics (mean, Standard Deviation (SD), skewness, and kurtosis) were computed to characterize students' quantitative achievement and motivation scores in both groups.

Before conducting the inferential analyses, the underlying assumptions were examined. The Kolmogorov–Smirnov statistic was used to verify that the dependent variables were normally distributed, Levene's statistic to verify equality of variances, and the covariate × group interaction term to verify that the regression slopes were parallel. These checks were carried out for both the independent-samples t-tests used for baseline comparison and the ANCOVAs, and they indicated no significant violations of the assumptions; parametric analyses were therefore retained for both outcomes. Two separate one-factor Analyses of Covariance (ANCOVAs) compared the academic achievement and motivation of students who received VR-based instruction with those of students who received traditional classroom-based instruction, while controlling for pre-test achievement measures. The effect size for each ANCOVA was expressed as partial eta squared (η^2), and significance was set a priori at $p < 0.05$ for all tests.

Students' responses to the VR Experience Opinion Questionnaire were analyzed using descriptive statistics and frequency distributions to determine participants' quantitative perceptions of ease of use, enjoyment, and engagement with the virtual learning environment, and then used as a basis for further interpretation of the quantitative results to determine the overall effectiveness of VR-based learning to motivate and improve academic performance.

III. Results

A. Research Question 1

This first question concerned whether VR-based instruction was accompanied by higher achievement than the conventional approach.

A one-factor Analysis of Covariance (ANCOVA) tested for a difference in post-test achievement between the two forms of instruction once prior attainment was taken into account. Instructional condition (VR or traditional) served as the fixed factor, the post-test score as the outcome, and the pre-test score as the covariate.

All achievement scores are reported on a 0–100 percentage scale Mean pre-test scores stood at $M = 27.65$ (SD = 5.10) in the experimental group and $M = 28.35$ (SD = 4.16) in the control group. The gap was not significant on an independent-samples t-test, $t(44) = -0.24$, $p = 0.81$, so the two classes entered the study with comparable knowledge of the Solar System. Post-intervention achievement was then compared across the two groups with pre-test scores entered as the covariate. Because the regression slopes proved parallel, the ANCOVA model could be applied. The adjusted mean post-test achievement score was 88.27 for the experimental group (Standard Error (SE) = 1.49, 95% Confidence Interval (CI) [85.26, 91.28]) and 67.13 for the control group (SE = 1.49, 95% CI [64.12, 70.14]); the non-overlapping confidence intervals further support the difference between conditions. The difference between groups was significant and favoured the experimental condition, $F(1, 43) = 86.96$, $p < 0.001$, partial $\eta^2 = 0.67$. Within this quasi-experimental design, this result indicates that the group receiving VR-based instruction attained significantly higher adjusted post-test achievement scores than the group receiving traditional instruction (Table 2).

Taken together, these results show that studying the Solar System in the virtual reality environment was accompanied by markedly higher adjusted achievement than the traditional lessons.

Table 2. ANCOVA summary table for posttest academic achievement scores

Source	Sum of Squares	df	Mean Square	F	p	Partial η^2
Corrected Model	8923.44	2	4461.72	87.03	<0.001	0.80
Intercept	2174.56	1	2174.56	42.42	<0.001	0.50
Achievement Pre-test	1520.31	1	1520.31	29.65	<0.001	0.41
Group (VR vs. Control)	4458.12	1	4458.12	86.96	<0.001	0.67
Error	2204.47	43	51.27	-	-	-
Total	260314.00	46	-	-	-	-
Corrected Total	11127.91	45	-	-	-	-

Note: ANCOVA = Analysis of Covariance; df = degrees of freedom; η^2 = eta squared.

B. Research Question 2

The second question turned to motivation toward science learning across the two conditions. Motivation was examined with the same one-factor ANCOVA model used for achievement, this time entering post-test motivation as the outcome, pre-test motivation as the covariate, and instructional condition as the fixed factor.

The students' mean pre-test motivation scores were $M = 3.18$ (SD = 0.46) for the experimental group ($n = 23$) and $M = 3.15$ (SD = 0.49) for the control group ($n = 23$). This baseline gap was again non-significant, $t(44) = 0.22$, $p = 0.82$, indicating comparable motivation across the two conditions at the outset. Because the slopes were again parallel, the model assumptions were satisfied and the analysis proceeded as described above.

The adjusted post-test mean motivation score was 4.36 for the experimental group (SE = 0.05, 95% CI [4.26, 4.46]) and 3.57 for the control group (SE = 0.05, 95% CI [3.47, 3.67]); as with achievement, the confidence intervals for the two groups did not overlap Here too, the adjusted difference favored the experimental condition and reached significance, $F(1, 43) = 31.75$, $p < 0.001$, partial $\eta^2 = 0.42$. These results indicate that, in this context, the group that experienced VR-based learning reported significantly higher post-test motivation toward learning science than the group that received traditional instruction (Table 3).

Table 3. ANCOVA summary table for posttest motivation scores

Source	Sum of Squares	df	Mean Square	F	p	Partial η^2
Corrected Model	3.42	2	1.71	31.03	<0.001	0.59
Intercept	6.88	1	6.88	124.83	<0.001	0.74
Motivation Pre-test	1.05	1	1.05	19.05	<0.001	0.31
Group (VR vs. Control)	1.75	1	1.75	31.75	<0.001	0.42
Error	2.37	43	0.055	-	-	-
Total	698.43	46	-	-	-	-
Corrected Total	5.79	45	-	-	-	-

Note: ANCOVA = Analysis of Covariance; df = degrees of freedom; η^2 = eta squared.

C. Research Question 3

The third question asked how the students themselves viewed virtual reality as a tool for studying science. The questionnaire results below describe students' self-reported perceptions of the VR experience and should be interpreted as descriptive evidence of perceived usefulness, enjoyment, ease of use, and engagement, rather than as independent confirmation of learning outcomes. A descriptive analysis of the student opinion questionnaire on the virtual learning experience indicated that students had very positive impressions of learning about the Solar System through virtual reality. Scores on the four subdimensions—perceived usefulness, enjoyment, ease of use, and engagement—ranging from 4.18 to 4.45 on a five-point Likert scale, suggested strong agreement with positive statements about VR-based learning [1, 33]. Similar findings have been reported in previous research, which found that immersive and augmented environments increase motivation and conceptual understanding in science [14, 16, 23, 34].

As shown in Table 4, nearly nine out of ten students held positive opinions of virtual reality as an educational tool.

Items one and four received the highest ratings, indicating that students perceived the VR experience as helpful for understanding and remembering Solar System concepts. As these are self-reported perceptions rather than independent measures of learning, they describe how useful students found the experience rather than demonstrating actual retention; this perceived usefulness is nonetheless consistent with research on immersive visualizations in science [35, 36].

Table 5 represents students' evaluations of virtual reality lessons in terms of excitement and enjoyment. As seen in the table, most students reported that virtual reality lessons were quite exciting and enjoyable. Students scored highest for items 1 and 3. This aligns with Delello [37] and, in the related context of augmented reality, Özeren and Top [16], who reported that immersive and augmented experiences can promote curiosity and sustain motivation for learning

According to Table 6, roughly three-quarters to four-fifths of the students agreed that VR was easy to use. The highest rating was given to the first item, reflecting comfort and confidence with the equipment. Similar findings have been reported in studies emphasizing that technical orientation and support enhance accessibility of immersive tools [38, 39].

As shown in Table 7, nearly nine out of ten students reported that VR kept them attentive and motivated. The fourth and second items had the highest mean scores, indicating that students reported strong curiosity and interest in science during the VR experience. Because these are self-reported impressions collected immediately after the intervention, they reflect students' perceived engagement rather than evidence of lasting interest in science, which the present design cannot establish. This reported engagement is consistent with studies highlighting VR's capacity to promote presence and active learning [16, 36].

Table 4. Perceived usefulness of the VR-based learning environment

Items	N	M	SD	No of Agree / Strongly Agree	Percentage of Agree / Strongly Agree
The VR lessons helped me better understand the Solar System.	23	4.48	0.69	21	91.3%
Using VR made learning science easier and more interesting for me.	23	4.39	0.71	20	87.0%
I think VR activities improved my performance in science.	23	4.28	0.76	19	82.6%
What I learned through VR will help me remember science concepts for a long time.	23	4.48	0.63	21	91.3%

Note: Overall $M = 4.41$, SD = 0.70 (high perceived usefulness).

Table 5. Enjoyment toward learning with VR

Items	N	M	SD	No of Agree / Strongly Agree	Percentage of Agree / Strongly Agree
I enjoyed learning with VR more than with regular classroom lessons.	23	4.43	0.68	21	91.3%
The VR lessons made me feel excited and motivated to learn.	23	4.35	0.74	20	87.0%
I would like to have more science lessons that use VR.	23	4.39	0.72	20	87.0%
I felt that time passed quickly while learning with VR.	23	4.26	0.80	18	78.3%

Note: Overall $M = 4.36$, SD = 0.73 (high enjoyment).

Table 6. Ease of use of the VR system

Items	N	M	SD	No of Agree / Strongly Agree	Percentage of Agree / Strongly Agree
It was easy for me to use the VR equipment and follow the instructions.	23	4.22	0.79	18	78.3%
I felt comfortable and confident using the VR headset during the lessons.	23	4.13	0.81	17	73.9%
I did not face any serious technical problems while using VR.	23	4.17	0.77	18	78.3%

Note: Overall $M = 4.18$, SD = 0.79 (good ease of use).

Table 7. Engagement during the VR experience

Items	N	M	SD	No of Agree / Strongly Agree	Percentage of Agree / Strongly Agree
VR lessons kept my attention focused on the science topic.	23	4.43	0.70	20	87.0%
I actively explored and interacted with the VR environment during the lessons.	23	4.48	0.65	21	91.3%
I felt like I was really part of the Solar System while using VR.	23	4.39	0.68	21	91.3%
The VR experience made me want to learn more about space and science.	23	4.52	0.59	22	95.7%

Note: Overall $M = 4.45$, SD = 0.66 (very high engagement).

IV. Discussion

Based on empirical data analysis, the study found that participation in virtual reality-based learning was associated with higher academic achievement and learning motivation among elementary students in space science [1, 33]. Once pretest differences were held constant through the ANCOVA models, the VR group stood out from the traditional group on both achievement and motivation to explore the Solar System. This pattern echoes earlier work suggesting that VR-based environments can offer rich, interactive settings that deepen conceptual understanding in science [1, 14, 16, 23, 33, 35].

A. Learning Achievement and Conceptual Understanding

The higher academic achievement observed in the VR group in this study fits evidence that virtual reality can encourage deeper learning by letting students handle demanding scientific ideas inside an immersive setting. Abstract material of this kind is notoriously hard to grasp from conventional two-dimensional resources. The results of this study indeed show significantly higher adjusted achievement scores in the VR group than in the control group. This result is consistent with findings from previous studies [2, 8]. Immersive classrooms, for example, have been linked to stronger performance alongside a lighter cognitive load while learning. Immersive visualization can facilitate knowledge building more efficiently than two-dimensional technologies [1]. Immersive virtual environments can also support cognitive engagement and facilitate better understanding of complex information through enhanced presence and greater contextual realism [33]. In this case,

students were able to visualize and engage with planetary motion in a dynamic VR environment. Most importantly, this experience may have supported the students' development of more accurate mental models of the Solar System through greater engagement than would have been possible in more traditional two-dimensional learning environments. In general, 3D interactive educational media and immersive learning environments support the visualization of information related to size, movement, and spatial relationships [2, 12, 35, 36].

B. Motivation and Affective Engagement

Alongside these cognitive gains, the motivational outcomes of this study align with existing findings showing that immersive learning environments positively affect students' interest, engagement, and enjoyment in science and science-related fields [4, 16, 34, 40]. Students in the experimental condition rated enjoyment, engagement, and the perceived benefits of virtual reality highly. These outcomes show that VR-based learning experiences can be emotionally and cognitively stimulating, sustaining students' interest and engagement throughout the learning process. The Cognitive-Affective Model of Immersive Learning (CAMIL) [33] offers a way of accounting for this pattern, treating the sense of presence and the enjoyment felt during immersive simulations as direct contributors to intrinsic motivation and engagement. Moreover, students' engagement scores align with findings from studies on immersive technologies in science education, where technology-enhanced scaffolding has been shown to support inquiry-based learning and improve conceptual understanding [34, 41]. Finally, visual immersion and control over the simulation environment transformed the highly teacher-centered learning environment into one in which students were at the center of the activity, which has been shown to increase students' motivation [1, 2].

C. Interpretation and Broader Implications

While prior research has demonstrated the benefits of VR for older learners and pre-service teachers [20, 42], the present study extends these findings to elementary students. Although part of the supporting evidence derives from AR or higher-education contexts [16, 23], the present results add immersive-VR evidence specific to elementary learners, suggesting that well-designed VR environments may be associated with cognitive and motivational gains even following a relatively short intervention [2]. This convergence is further supported by recent work applying immersive VR with elementary learners; for example, Astutik *et al.* [18] found that a VR environment enhanced vocabulary acquisition among elementary students, paralleling the achievement and motivation gains observed here in a science context. Such convergence suggests that the benefits of immersive VR documented at secondary and higher-education levels may extend to younger learners, although the elementary-level evidence base remains limited and warrants further replication. The findings suggest that VR effectiveness depends less on the technology's immersive features than on its pedagogical design. Specifically, alignment with curriculum goals, a clear instructional framework, and thoughtful integration into teaching practice appear to be the decisive factors [14, 35, 36]. As an instructional medium, virtual potential to transform abstract scientific content into tangible, memorable experiences—provided it is embedded within a coherent pedagogical framework.

Even within immersive VR environments, effective teacher facilitation remains essential for directing students toward meaningful learning objectives, maintaining classroom focus, and supporting learners' emotional engagement. Such factors weigh heavily on how well VR-based instruction works in practice [1, 2, 33]. On the whole, the present results point to virtual reality as a promising pedagogical tool when it is combined with sound teaching practice that may support learner presence, spatial awareness, and intrinsic motivation in this context. Such findings support the idea that teachers are not being replaced by virtual reality but are instead given a powerful pedagogical ally to ensure engagement and foster learning [8].

D. Limitations and Future Research

Several limitations qualify these results. The work was carried out in a single public school with a modest sample (n = 46), so the findings should not be extended beyond comparable settings without further evidence. Moreover, the design included only one intact class per condition, which means the effect of the VR intervention cannot be fully separated from class-level factors such as classroom climate, peer dynamics, or scheduling; this is a constraint on causal interpretation, not only on generalizability. In addition, the six-week duration was insufficient to assess long-term retention or knowledge transfer; hence, the study could not provide evidence of information retention from the VR intervention. It is well established in the empirical literature that the initial motivational boost from immersive interventions does not always lead to lasting learning gains [2, 7]. Long-term learning and sustained engagement with VR-based instruction require a longer intervention and follow-up period. There is a particular need for replication in different teaching contexts. Additionally, future research could explore gender differences within a VR context or how individuals respond differently to certain VR stimuli [43] and compare results from VR-based immersive 3D simulations with non-immersive 3D simulations or Augmented Reality [23]. Longitudinal and qualitative studies are particularly needed to investigate why immersion enhances students' curiosity, fosters their perseverance, and brings about meaningful conceptual change [41].

Furthermore, because the control condition also included short non-interactive instructional videos, the present study contrasts immersive, interactive VR with non-immersive, multimedia-supported instruction rather than with purely text-based teaching. This makes the comparison more conservative and indicates that the VR advantage cannot be attributed solely to the presence of visual content; future research should isolate the specific contributions of interactivity and immersion beyond those of non-interactive video.

In addition, although the motivation scale was translated and its translation was reviewed for linguistic accuracy, its content was not separately re-validated by subject-matter

experts for the Jordanian context; future studies should further examine the cultural and content validity of the Arabic version with this population.

V. Conclusion

This study implemented a virtual reality-based instructional program on the Solar System for elementary school students. In this context, participation in the VR-supported unit was associated with higher short-term academic achievement and stronger motivation to learn science than participation in conventional instruction. Given the quasi-experimental design, the reliance on two intact classes drawn from one school, and the lack of a delayed post-test, these results are best read as preliminary rather than as confirmation that VR instruction raised achievement or motivation. From the learners' perspective, the VR sessions were reported to help them connect abstract knowledge with real-life experiences. The results align with the body of work reviewed earlier in this article, which indicates that virtual reality can support learning through highly interactive simulations and can help students explore abstract scientific concepts by making spatial relationships between objects and phenomena easier to grasp. More broadly, the immersive-learning literature portrays virtual reality less as a technological novelty than as a potentially powerful teaching aid, one capable of strengthening science learning and awakening curiosity. While the present small-scale study cannot establish such broad claims on its own, its findings provide preliminary evidence consistent with the broader literature. For teachers and curriculum planners, weaving such technologies into science instruction, together with training and planning support, can make learning experiences more meaningful. By strategically integrating these experiences into the regular classroom setting, educators can foster scientifically literate students who are excited about science, enthusiastic toward learning, and creative in their approaches to real-world problems—essential qualities for success in the 21st century.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Deefallah Alshorman conceived the study, designed the VR intervention, conducted the research, and wrote the paper. Hebah Alkhasoneh contributed to the literature review and data analysis. Wael Mohammad Alshurman assisted with instrument development and methodology. Rakez Al-Ararah contributed to data collection and manuscript revision. All authors approved the final version.

Acknowledgment

The authors wish to thank the participating school administration, teachers, and students for their cooperation throughout this study.

References

[1] D. Liu, C. Dede, R. Huang, and J. Richards, "Effects of immersive virtual reality classrooms on students' academic achievement, motivation, and cognitive load," *Journal of Computer Assisted Learning*, vol. 38, no. 6, pp. 1421–1435, 2022. doi: 10.1111/jcal.12606

[2] G. Makransky, T. S. Terkildsen, and R. E. Mayer, "Adding immersive virtual reality to a science lab simulation causes more presence but less learning," *Learning and Instruction*, vol. 60, pp. 225–236, 2019. doi: 10.1016/j.learninstruc.2017.12.007

[3] A. Y. Al-Amri, M. E. Osman, and A. S. A. Musawi, "The effectiveness of a 3D-Virtual Reality Learning Environment (3D-VRLE) on the Omani eighth-grade students' achievement and motivation towards physics learning," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 15, no. 5, pp. 4–16, 2020. doi: 10.3991/ijet.v15i05.11890

[4] I. Han, "Immersive virtual reality in education: A case study exploring the learning process of middle school students," *Interactive Learning Environments*, vol. 28, no. 5, pp. 1–15, 2020. doi: 10.1080/10494820.2018.1558252

[5] H. A. S. Garduño, M. I. E. Martínez, and M. P. Castro, "Impact of virtual reality on student motivation in a high school science course," *Applied Sciences*, vol. 11, no. 20, 9516, 2021. doi: 10.3390/app11209516

[6] M. T. Zaatar, N. Masri, M. Alfahel, G. Antar, A. Dayal, H. Khamis, M. Kuruvani, and G. Kachaamy, "Exploring the virtual frontier: The impact of virtual reality on undergraduate biology education at the American University in Dubai," *International Journal of Information and Education Technology*, vol. 14, no. 5, pp. 675–682, 2024. doi: 10.18178/ijiet.2024.14.5.2092

[7] L. Jensen and F. Konradsen, "A review of the use of virtual reality head-mounted displays in education and training," *Education and Information Technologies*, vol. 23, pp. 1515–1529, 2018. doi: 10.1007/s10639-017-9676-0

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

[9] A. G. Abulrub, A. N. Attridge, and M. A. Williams, "Virtual reality in engineering education: The future of creative learning," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 6, no. 4, pp. 4–11, 2011. doi: 10.3991/ijet.v6i4.1766

[10] G. Makransky, N. K. Andreasen, S. Baceviciute, and R. E. Mayer, "Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality," *Journal of Educational Psychology*, vol. 113, no. 4, pp. 719–735, 2021. doi: 10.1037/edu0000473

[11] M. Barnett, "Using virtual reality computer models to support student understanding of astronomical concepts," *Journal of Computers in Mathematics and Science Teaching*, vol. 24, no. 4, pp. 333–356, 2005.

[12] K. T. Sun, C. L. Lin, and S. M. Wang, "A 3D virtual reality model of the solar system," *WSEAS Transactions on Computers*, vol. 9, no. 2, pp. 157–166, 2010.

[13] H. M. Huang, U. Rauch, and S. S. Liaw, "Investigating learners' attitudes toward virtual reality learning environments: A constructivist approach," *Computers & Education*, vol. 55, no. 3, pp. 1171–1182, 2010. doi: 10.1016/j.compedu.2010.05.014

[14] J. Parong and R. E. Mayer, "Learning science in immersive virtual reality," *Journal of Educational Psychology*, vol. 110, no. 6, pp. 785–797, 2018. doi: 10.1037/edu0000241

[15] K. M. Chuah, S. Chen, T. Teo, and T. H. Tan, "Technology acceptance of augmented reality in formal educational settings," *International Journal of Emerging Technologies in Learning*, vol. 14, no. 18, pp. 4–20, 2019.

[16] E. Özeren and E. Top, "The effects of augmented reality applications on the academic achievement and motivation of secondary school students," *Contemporary Educational Technology*, vol. 15, no. 2, ep417, 2023. doi: 10.30935/cedtech/13172

[17] E. Southgate, S. P. Smith, C. Cividino, S. Saxby, J. Kilham, G. Eather, J. Scevak, D. Summerville, R. Buchanan, and C. Bergin, "Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice," *International Journal of Child-Computer Interaction*, vol. 19, pp. 19–29, 2019. doi: 10.1016/j.ijcci.2018.06.001

[18] Y. Astutik, N. F. A. Wahid, R. S. Untari, and F. Wulandari, "Magical World VR: Enhancing English vocabulary acquisition for elementary learners through virtual reality," *International Journal of Information and Education Technology*, vol. 16, no. 1, pp. 27–38, 2026. doi: 10.18178/ijiet.2026.16.1.2480

[19] J. Piaget, *The Psychology of the Child*, Basic Books, 2000.

[20] D. A. Al Shorman, "Examining the role of immersive technologies in preparing preservice elementary teachers: Augmented reality, integrated STEM, teaching self-efficacy, and technology

self-efficacy," Ph.D. dissertation, University of Nebraska–Lincoln, 2024.
[21] G. Makransky and G. B. Petersen, "Investigating the process of learning with desktop virtual reality: A structural equation modeling approach," *Computers & Education*, vol. 134, pp. 15–30, 2019. doi: 10.1016/j.compedu.2019.02.002
[22] E. L. Deci and R. M. Ryan, "The 'what' and 'why' of goal pursuits: Human needs and self-determination of behavior," *Psychological Inquiry*, vol. 11, no. 4, pp. 227–268, 2000. doi: 10.1207/S15327965PLI1104_01
[23] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda," *Computers & Education*, vol. 147, 103778, 2020. doi: 10.1016/j.compedu.2019.103778
[24] E. J. Blown and T. G. K. Bryce, "Theoretical frameworks for conceptual change research in astronomy education," *International Journal of Science Education*, vol. 35, no. 8, pp. 1299–1341, 2013. doi: 10.1080/09500693.2012.730456
[25] J. D. Plummer, "Spatial thinking as the dimension of progress in an astronomy learning progression," *Studies in Science Education*, vol. 50, no. 1, pp. 1–45, 2014. doi: 10.1080/03057267.2013.869039
[26] N. S. Newcombe and T. F. Shipley, "Thinking about spatial thinking: New typology, new assessments," in *Studying Visual and Spatial Reasoning for Design Creativity*, J. S. Gero, Ed., Springer, 2015, pp. 179–192. doi: 10.1007/978-94-017-9297-4_10
[27] W. R. Borg and M. D. Gall, *Educational Research: A Guide for Preparing a Thesis or Dissertation Proposal in Education*, Longman, 1989.
[28] J. W. Creswell and J. D. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 5th ed. SAGE Publications, 2018.
[29] J. R. Fraenkel and N. E. Wallen, *How to Design and Evaluate Research in Education*, 7th ed. McGraw-Hill, 2009.
[30] British Educational Research Association, *Ethical Guidelines for Educational Research*, 4th ed., 2018.
[31] L. Cohen, L. Manion, and K. Morrison, *Research Methods in Education*, 8th ed. Routledge, 2018. doi: 10.4324/9781315456539
[32] Y. Dede and S. Yaman, "A questionnaire for motivation toward science learning: A validity and reliability study," *Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education*, vol. 2, no. 1, pp. 19–37, 2008.
[33] G. Makransky and G. B. Petersen, "The Cognitive-Affective Model of Immersive Learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality," *Educational Psychology Review*, vol. 33, pp. 937–958, 2021. doi: 10.1007/s10648-020-09573-1
[34] C. Erbas and V. Demirer, "The effects of augmented reality on students' achievement and motivation in science education," *Journal of Science Education and Technology*, vol. 28, pp. 353–364, 2019. doi: 10.1007/s10956-019-09783-0
[35] S. Cai, X. Wang, and F. K. Chiang, "A case study of augmented reality simulation system application in a chemistry course," *Computers in Human Behavior*, vol. 37, pp. 31–40, 2014. doi: 10.1016/j.chb.2014.04.018
[36] H. K. Wu, S. W. Y. Lee, H. Y. Chang, and J. C. Liang, "Current status, opportunities and challenges of augmented reality in education," *Computers & Education*, vol. 62, pp. 41–49, 2013. doi: 10.1016/j.compedu.2012.10.024
[37] J. A. Delello, "Insights from pre-service teachers using science-based augmented reality," *Journal of Computers in Education*, vol. 1, no. 4, pp. 295–311, 2014. doi: 10.1007/s40692-014-0013-8
[38] S. S. Jamali, M. F. Shiratuddin, K. W. Wong, and C. L. Oskam, "Utilizing mobile-augmented reality for learning human anatomy," *Procedia – Social and Behavioral Sciences*, vol. 197, pp. 659–668, 2015. doi: 10.1016/j.sbspro.2015.07.054
[39] A. Taşkıran, S. Koralp, and A. Kuzu, "Usability of mobile augmented reality applications in education: A systematic review," *Mersin University Journal of the Faculty of Education*, vol. 11, no. 2, pp. 418–436, 2015.
[40] Yulkifli, D. Hariyanto, N. Suprapto, S. R. Hakim, F. Mufit, M. Dhanil, and F. Novitra, "The impact of virtual reality on creative thinking skills and self-efficacy in learning rotational dynamics," *International Journal of Information and Education Technology*, vol. 15, no. 6, 2025. doi: 10.18178/ijiet.2025.15.6.2332
[41] S. A. Yoon, E. Anderson, M. Park, K. Elinich, and J. Lin, "How augmented reality, textual, and collaborative scaffolds work synergistically to improve learning in a science museum," *Research in Science & Technological Education*, vol. 36, no. 3, pp. 261–281, 2018. doi: 10.1080/02635143.2017.1386645
[42] T. A. Mikropoulos and A. Natsis, "Educational virtual environments: A ten-year review of empirical research," *Computers & Education*, vol. 56, no. 3, pp. 769–780, 2011. doi: 10.1016/j.compedu.2010.10.020
[43] K. H. Cheng and C. C. Tsai, "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*, vol. 51, no. 6, pp. 2140–2159, 2020. doi: 10.1111/bjet.12956

Copyright © 2026 by the authors. This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (CC BY 4.0).