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Teaching Environmental Topics in QR Code-Supported Mobile Learning Environments in Primary School Science: A Mixed-Methods Study[1]

Perihan Köse and Nur Ütkür Güllühan
Istanbul University-Cerrahpaşa, Hasan Ali Yücel Faculty of Education, Department of Primary Education

Abstract

The study examined the effect of teaching primary school science in QR code-supported mobile learning environments on students' academic achievement, knowledge retention and their views on mobile learning. The research was conducted using a mixed-methods design with an experimental group (27 students) and a control group (20 students) attending a public primary school in Istanbul. Quantitative data were collected through an achievement test, while qualitative data were obtained via semi-structured interviews and student journals. The results revealed significantly higher academic achievement of students in the experimental group compared to those in the control group, and that students from the experimental group developed positive perceptions of mobile learning practices. Additionally, students' interest and motivation toward science increased, and improvements were observed in several learning-related skills. These results indicate that QR code-supported mobile learning environments can be an effective instructional approach for teaching environmental topics in primary school science education.

Keywords: *environmental education; mobile learning; primary education; QR codes; science teaching*

[1] This article is based on Perihan KÖSE's master's thesis conducted under the supervision of Assoc. Prof. Dr. Nur Ütkür GÜLLÜHAN at Istanbul University-Cerrahpaşa

Introduction

Educational environments have undergone major transformation with the rapid evolution of digital technologies. As new generations grow up surrounded by technology, traditional teaching methods are becoming increasingly inadequate. Consequently, information and communication technologies—particularly mobile technologies—have reshaped both the tools and methods of education (Koenig, 2011; Prensky, 2012).

The portability and popularity of mobile devices have introduced the concept of mobile learning (m-learning) (Heflin et al., 2017; Omolafe, 2021; Squires, 2017). M-learning enables learning free from time and place constraints, which offers student-centred, interactive environments (Chung et al., 2019; Cin et al., 2022; Kukulska-Hulme & Traxler, 2005; Patten et al., 2006). Portable tools reduce costs, personalise learning and enhance interaction (El-Hussein & Cronje, 2010; Tabuenca et al., 2015). They provide instant information access and allow learners to use e-learning resources independently of computers (Muyinda et al., 2007; Traxler, 2011). Mobile tools and QR codes make learning engaging and allow students to progress at their own pace (Attewell & Savill-Smith, 2004; Daulay et al., 2023; Park et al., 2012). Within this context, QR codes have become a key component of m-learning (Law & So, 2010).

QR codes are two-dimensional barcodes that enable rapid access to digital content when scanned with mobile devices. In education, they link printed materials with online resources, which enriches instructional materials with multimedia content and enables access to learning resources inside and outside the classroom (Law & So, 2010; Rikala & Kankaanranta, 2014; Robertson & Green, 2012). Thus, QR codes are not merely alternatives to traditional web links; they embed digital content in physical learning materials and provide contextual access within learning environments. Research shows that QR code-supported environments can increase curiosity, motivation and classroom participation (Chen et al., 2022; Rikala & Kankaanranta, 2014; Thorne, 2016). They also provide a structure for implementing different learning approaches; however, their effects depend on instructional design and learning content (Lai et al., 2013; Wu et al., 2018). When well designed, QR codes can support personalized and student-centred learning and facilitate access to diverse learning resources (Karia et al., 2019; Rikala & Kankaanranta, 2014). QR code-supported activities may also support learning retention and outcomes (Crompton et al., 2012; Vandenberghe et al., 2021; Lai et al., 2013). QR code-supported environments can also support skills such as communication, collaboration, critical thinking, digital literacy, quantitative reasoning and spatial skills (Mehendale et al., 2017; Mowafi & Abumuhfouz, 2021). In science education, QR code-integrated digital media tools can help concretize abstract scientific concepts and support problem-solving and scientific literacy (Savitri et al., 2021). The use of QR codes and mobile technologies in environmental education is particularly important, as this field aims to develop awareness and responsible behaviour toward the natural environment. Environmental education promotes understanding and action on environmental issues (Rajšp & Fošnarič, 2014; Stapp, 1969), and digital technologies such as m-learning and QR codes provide flexible, interactive access to environmental information, which makes learning more dynamic and raises environmental awareness.

Theoretical framework

Digital technologies not only deliver content but also reshape learning. This study employed a QR code-supported mobile learning (QR m-learning) environment framed by the SAMR (Substitution-Augmentation-Modification-Redefinition) and TPACK (Technological-Pedagogical-Content Knowledge) models. The SAMR model defines technology's pedagogical role through four levels—from substitution and augmentation, which replicate traditional tasks, to modification and redefinition, which transform learning (Hilton, 2016; Puentedura, 2014). The higher levels enable pedagogical transformation and experiences impossible in traditional instruction (Hamilton, et al., 2016; Hilton, 2016).

The TPACK model complements SAMR by explaining how teachers integrate technology (TK), pedagogy (PK) and content (CK) in balanced designs (Chai et al., 2010; Koehler & Mishra, 2009; Mishra & Koehler, 2006). In this study, environmental concepts (CK), group-based strategies (PK) and QR-accessed digital materials (TK) formed the framework. TPACK guided instructional design, while SAMR was used to analyse how technology redefined students' learning experiences, as shown in Figure 1 (Hamilton et al., 2016; Hilton, 2016).

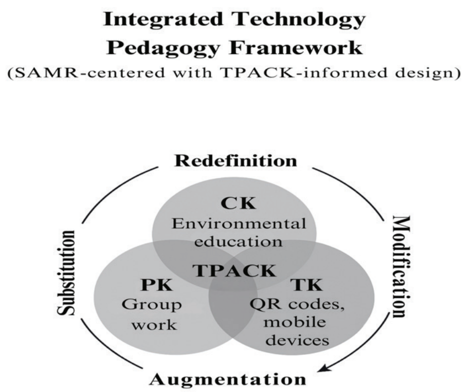

Figure 1. SAMR-Centered Framework with TPACK-Informed Design

Figure 1 illustrates how SAMR operates within a TPACK-informed design to assess the transformative dimension of QR m-learning.

In science education, mobile technologies have been widely applied to enhance learning and engagement (Bressler & Bodzin, 2016; Bjørgen, 2022; Falloon, 2017; McMahon et al., 2016; Ryu et al., 2015; Wang et al., 2023; Zhan et al., 2022; Zhai et al., 2019; Zhai & Shi, 2020). Research on environmental topics in QR m-learning contexts has explored environmental awareness (Uzunboylu et al., 2009), comparisons with traditional instruction (Anderson et al., 2015; Chang et al., 2011; Furió et al., 2015; Ruchter et al., 2010), sustainability education (Bleck et al., 2012) and the effects of early technology use on environmental and technological literacy (Willis et al, 2014). Other studies examined mobile technologies in formal environmental education (Heinonen, 2015), impacts on knowledge and perception (Kalogiannakis & Papadakis, 2017), digital tools that promote environmental learning in primary schools (Bovanova, 2023; Buchanan et al., 2018), mobile devices in teacher training (Sebastián-López & Miguel González, 2020) and gamified programmes that enhance ecological awareness and digital literacy (Ricoy & Sánchez-Martínez, 2022). Figure 2 summarizes these studies.

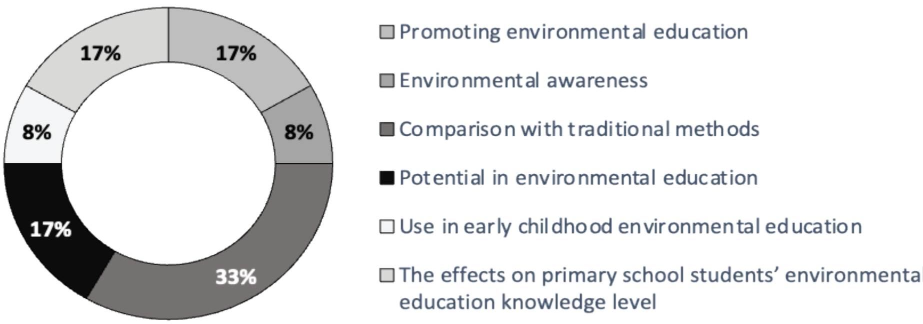

Figure 2. Research on the use of mobile devices in environmental topics.

Figure 2 shows that most studies compared m-learning with traditional methods, while few explored mobile technologies for teaching environmental topics in primary science. This research gap, also identified in international reviews (Yun & Crippen, 2023), highlights the growing importance of mobile-supported learning (Chang et al., 2018). Therefore, the present study was conducted to examine the effect of QR code-supported mobile learning on third-grade students' academic achievement, knowledge retention and their views on m-lerning of the Living Things unit, compared to traditional instruction. The study employed a pretest-post-test control group quasi-experimental design embedded within a mixed-methods framework. The instructional intervention was structured in alignment with the SAMR and TPACK frameworks to ensure pedagogically meaningful technology integration. Based on these aims, the study addressed the following research questions:

RQ1. Is there a significant difference between the experimental and control group in students' academic achievement and knowledge retention over time (pretest, post-test and retention test)?

Hypothesis 1. Students in the experimental group will demonstrate significantly greater improvement in academic achievement from pretest to post-test and achieve higher retention scores than students in the control group.

RQ2. What are the views and experiences of the students in the experimental group regarding the use of QR code-supported mobile learning tools during the science instruction (SI)?

Since this question was addressed through qualitative data, no hypothesis was formulated.

Methodology

The mixed-method approach provides a comprehensive understanding of research problems by integrating quantitative and qualitative data (Creswell, 2021; Teddlie & Tashakkori, 2009). It combines the strengths of both while reducing their limitations (Creswell & Creswell, 2017). Accordingly, this study employed an explanatory sequential mixed-method design (Creswell, 2021).

In the quantitative phase, a quasi-experimental design was adopted, appropriate for educational contexts where full control or randomisation is difficult (Christensen et al., 2020; Cohen et al., 2021; Singh, 2007). The qualitative phase followed a case study approach to explore real-life experiences using multiple data sources (Yin, 2014). Student journals, semi-structured interviews and teacher feedback were analysed to better understand the learning process and assess the implementation's effectiveness.

Sample

The study involved 3rd-grade students aged eight to nine from a public primary school in Istanbul. Criterion sampling considered mobile device access, school internet access, safe learning environments and teacher-parent-student cooperation. Two classes were randomly assigned to the experimental (n = 27; 14 boys, 13 girls) and control group (n = 20; 10 boys, 10 girls). A Mann–Whitney U test examined the differences between the groups' SCAAT pretest scores. The results are presented in Table 1.

Table 1
Groups' SCAAT Pretest Mann-Whitney U Results

Group	n	Mean Ranks	Sum of Ranks	*U*	*p*
Experimental Group	27	27.28	736.50	181.50	.06
Control Group	20	19.58	391.50		

The results showed no statistically significant difference between the groups ($U = 181.50$, $p > .05$), which suggests that the experimental and control group were comparable at the beginning of the study. Using a mixed-method design, an explanatory sequential strategy was employed to examine the experiences and views of students in the experimental group (Creswell, 2021). Based on the quantitative results, maximum variation sampling was used to select participants for the qualitative phase. Students were categorized into low, medium and high achievement levels based on their post-test scores using rank-order grouping. Participants were selected from different points in the score distribution to ensure representation of varying achievement levels. Five students from each category were included, which resulted in a total of 15 participants.

Data collection tools

The Science Course Academic Achievement test (SCAAT)

The Science Course Academic Achievement test (SCAAT), developed by the researchers, was used to collect quantitative data. The test was constructed based on the learning outcomes of the Journey to the World of Living Things unit within the Living Things and Life domain of the 3rd-grade primary school science curriculum. The purpose of the test is to determine students' academic achievement levels regarding the relevant unit and to compare the pre- and post-intervention achievement levels of the experimental and control group.

To ensure content validity, a table of specifications was prepared in accordance with the curriculum outcomes, and test items were developed accordingly. The items were reviewed by a total of 10 experts, including subject matter experts, classroom education specialists, primary school teachers and Turkish language teachers. Based on expert evaluations, content validity ratios were calculated using Lawshe's method, and all items were found to exceed the acceptable threshold ($CVR \geq .62$). The overall content validity index of the test was also high ($CVI = .945$). Item analyses based on classical test theory were conducted. Items that did not meet the required criteria in terms of item difficulty and item discrimination were removed, and the final version of the test consisted of 20 items. The average item difficulty index of the final test was at a moderate level ($\bar{p} = .71$), and the average item discrimination index was at a good level ($\bar{r} = .44$).

The reliability of the test was examined using internal consistency methods, and the Cronbach's alpha coefficient was found to be high ($\alpha = .858$). In addition, split-half reliability analyses were conducted. Cronbach's alpha values were .767 for the first half and .731 for the second half, with a correlation of .755 between the two halves. These results indicate that the test demonstrates adequate reliability when divided into two halves. The Spearman–Brown coefficient was high ($r = .860$), and the Guttman split-half reliability coefficient was similarly high ($r = .859$). Furthermore, the six Guttman reliability coefficients ranged between 0.815 and 0.862, which indicated that the test possessed satisfactory reliability. Overall, these findings demonstrate that the test had adequate reliability.

To examine the structural properties of the test, an exploratory factor analysis was conducted ($n = 100$). The results indicated that the dataset was suitable for factor analysis (KMO = .777; Bartlett's $\chi^2(190) = 544.151$, $p < .001$). The analysis revealed that the test exhibited a multidimensional structure. However, the first factor was dominant, and the scree plot showed a clear break after the first factor. In the literature, it is stated that a certain degree of multidimensionality is expected in achievement tests due to the inclusion of different learning outcomes and cognitive levels, and that the presence of a dominant general factor allows the total score to represent overall achievement (Reckase, 1979; Stout, 1987; Tate, 2012).

Accordingly, considering that the test is an achievement test covering different learning outcomes and cognitive levels, it was deemed appropriate to use the total score as an indicator of students' overall academic achievement. This is also consistent with the classical test theory perspective, which assumes that total test scores can represent individuals' overall level of achievement.

Student journals

Student journals, developed by the researchers with input from ten experts, were used to collect qualitative data. The journals included reflections on what students learned, found interesting, were curious about and found challenging.

Semi-structured interview form

A semi-structured interview form was designed to explore students' feelings and views about the QR m-learning process, in-class and out-of-class activities, encountered problems and the effects on their skills and attitudes. The form was reviewed by ten experts for content validity, and pre-interviews with two experimental group students ensured clarity and comprehensibility.

Procedure

The study involved the experimental and control group. Quantitative data were collected through a 20-item achievement test administered as pre, post-, and retention test. The retention test, given four months after the post-test, measured recall and long-term knowledge (Bahrick, 1984; Custers, 2010; Frutchey, 1937; Semb & Ellis, 1994; Wodtke, 1967). Each test lasted one school lesson.

Control group procedure

Instruction in the control group followed the national curriculum and textbook, using teacher-guided classroom practices such as direct instruction and question-answer techniques in line with regular classroom implementation. The instructional process was planned in advance, and the control teacher was informed about how the lessons would be carried out to ensure consistency with the experimental group in terms of content, sequence and duration. The lessons were implemented within this planned structure. Both teachers—the control teacher and the researcher—had similar professional experience, and the sessions were conducted simultaneously under comparable classroom conditions. The implementation process was monitored through regular meetings with the control teacher and the use of structured lesson plans, which were followed on a weekly basis.

Experimental group procedure

Instruction was designed within the TPACK framework, while the SAMR model was used to describe the integration of technology into the instructional process. The instructional process was planned in advance and implemented in alignment with the learning objectives, content, sequence and duration used in the control group. QR-supported activities were incorporated into the lessons to support the presentation and exploration of content.

The content covered third-grade environmental topics in science, and technology integrated QR-code digital materials in an m-learning environment. Students used mobile devices to access videos, animations, games and other QR-guided materials. Weekly activities were organised to integrate content, pedagogy and technology within a structured mobile learning environment. Technology was used for the delivery and organisation of instructional tasks, corresponding to different levels of the SAMR model, as shown in Figure 3.

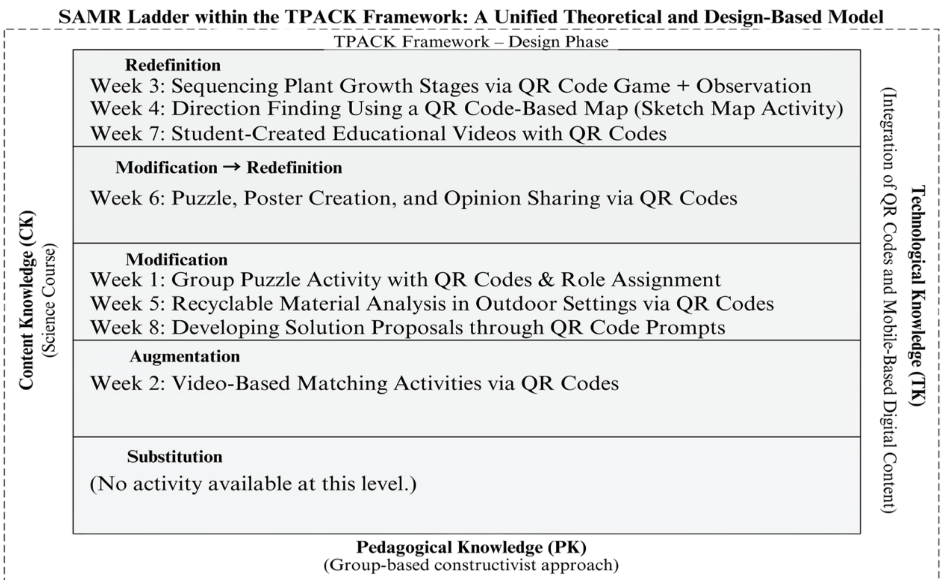

Figure 3. Experimental group procedure

Figure 3 outlines the weekly instructional structure and the SAMR levels associated with each activity. The SAMR model was used to categorise how technology was integrated into instructional tasks, while TPACK ensured coherence among content, pedagogy and digital tools in QR-supported activities. The weekly teaching process of the experimental group is summarized in Figure 4.

Figure 4 shows the progression of activities from substitution and augmentation (e.g., watching videos) to modification and redefinition (e.g., way-finding and student-created videos). Most activities were aligned with the modification or redefinition levels. The in-class mobile learning activities of the experimental group are illustrated in Figure 5.

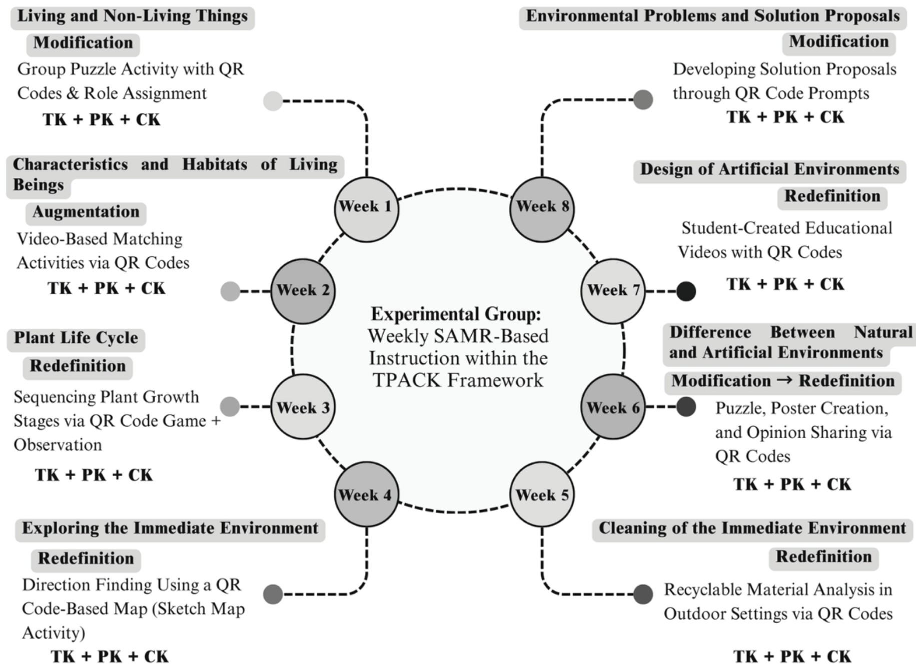

Figure 4. Experimental group weekly teaching process

Figure 5. Experimental group in-class QR supported mobile learning environment activities

Figure 5 presents classroom examples where students engaged with QR-supported materials. Activities such as video creation, digital storytelling, games and treasure hunts were implemented within the instructional process. Overall, these activities illustrate how QR code-supported mobile learning was implemented in line with the SAMR model (Hilton, 2016; Kirkland, 2017; Puentedura, 2014).

Data analysis

Since the sample included less than 30 students (Can, 2020), the Wilcoxon signed-rank test and the Mann–Whitney U test were applied. Given that six non-parametric comparisons were conducted within the 2 × 3 design framework, a Bonferroni correction was applied to control for inflated Type I error, and the adjusted significance level was set at $\alpha = .008$. In addition, a post hoc statistical power analysis was conducted for the six non-parametric comparisons using G*Power 3.1. Effect sizes (r), adjusted significance level ($\alpha = .008$) and sample sizes were used to calculate the achieved power ($1 - \beta$). Power calculations were conducted using the corresponding non-parametric test models in G*Power 3.1. The results of the power analysis are presented in Table 2.

Table 2

Retrospective Statistical Power Analysis for the Six Comparisons

Comparison	Test	n	r	α	Power (1 – β)
Experimental group (pretest vs. post-test)	Wilcoxon signed-rank	27	.88	.008	1.00
Control group (pretest vs. post-test)	Wilcoxon signed-rank	20	.88	.008	1.00
Experimental Group vs. Control Group (Post-test)	Mann–Whitney U	27 / 20	.54	.008	.92
Experimental group (post-test vs. retention)	Wilcoxon signed-rank	27	.10	.008	.04
Control group (post-test vs. retention)	Wilcoxon signed-rank	20	.74	.008	1.00
Experimental Group vs. Control Group (retention)	Mann–Whitney U	27 / 20	.80	.008	1.00

Note. α = .008 (Bonferroni-adjusted). r represents effect size.

For the qualitative data, inductive analysis was conducted using NVivo 14 to analyse the semi-structured interviews. Descriptive statistics from student journals are presented in Table 3. The frequencies represent the number of journal entries submitted each week by students in the experimental group. Variations in weekly totals reflect differences in journal submission and do not indicate changes in the number of participants.

A total of 164 journals were collected during the SC implementation process. The stages of journal analysis are shown in Figure 6.

Figure 6 illustrates the steps followed in analysing qualitative data from student journals: data organisation, coding, theme development and validation through expert review. The steps used for analysing semi-structured interviews are shown in Figure 7.

Figure 7 presents the stages of interview analysis. The interviews were transcribed, organised, coded and thematised in NVivo. Expert review followed, and final revisions were made accordingly.

To ensure reliability, the researcher and an expert independently coded the qualitative data. Inter-coder agreement was calculated using Miles and Huberman's (1994) formula, resulting in 93.06 %, which indicates high reliability (above 80 %).

When reporting qualitative findings, pseudonyms replaced real names in student quotations to ensure ethical standards and coding clarity.

Table 3
Descriptive statistics of student journals in Science

Week	Journal Title (Content Theme)	Female	%	Male	%	Total	%
Week 1	Distinguishing Between Living and Nonliving Things	12	7.32%	12	7.32%	24	14.63%
Week 2	Characteristics and Habitats of Living Beings	10	6.10%	13	7.93%	23	14.02%
Week 3	Observing the Life Cycle of a Plant	7	4.27%	12	7.32%	19	11.59%
Week 4	Exploring One's Surrounding Environment	8	4.88%	11	6.71%	19	11.59%
Week 5	Contributing to the Cleanliness of the Immediate Environment	9	5.49%	10	6.10%	19	11.59%
Week 6	Difference Between Natural and Artificial Environments and the Importance of Nature	7	4.27%	12	7.32%	19	11.59%
Week 7	Designing an Artificial Environment	12	7.32%	12	7.32%	24	14.63%
Week 8	Developing Solutions for Protecting Nature	6	3.66%	11	6.71%	17	10.37%
TOTAL		71	43.29%	93	56.71%	164	100%

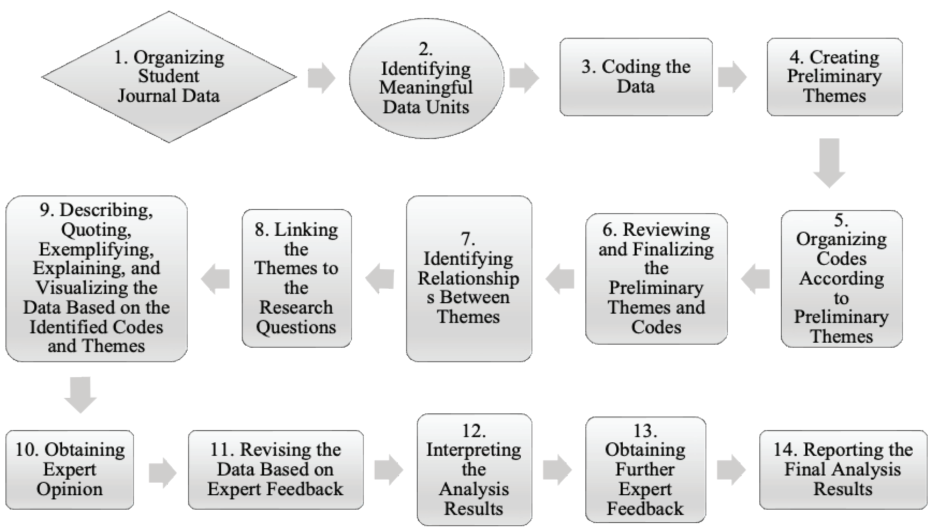

Figure 6. The analysis stages of student journals

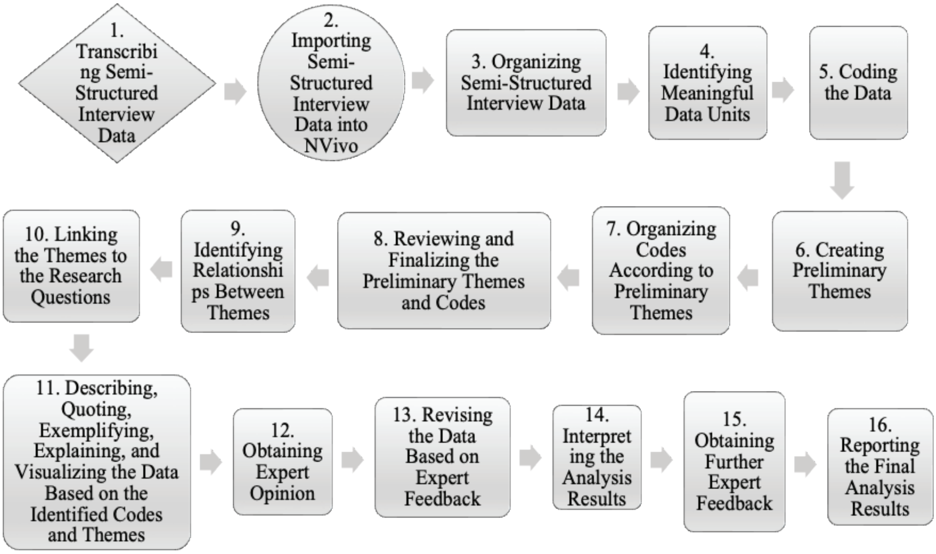

Figure 7. The analysis stage of semi-structured interviews

Ethical Considerations

Ethical approval for the study was obtained from the Social and Human Sciences Research Ethics Committee of the Istanbul University Cerrahpaşa. Official permissions were also granted by the Istanbul Provincial Directorate of National Education. A written informed consent was obtained from the parents of all participating students. To ensure developmental appropriateness, data collection instruments were reviewed by field experts and pilot-tested with students from the same age group. Participation was voluntary, and students were informed about the research process. All data were anonymized, and confidentiality was maintained throughout the study.

Results

Descriptive statistics for SCAAT pretest, post-test and retention scores in both groups are presented in Table 4.

Table 4
Descriptive Statistics for SCAAT Scores.

Group	Test	n	*M*	*SD*
Experimental	Pre	27	13.56	3.85
Experimental	Post	27	17.41	2.89
Experimental	Retention	27	17.22	2.06
Control	Pre	20	11.05	4.84
Control	Post	20	13.40	3.97
Control	Retention	20	10.40	3.28

Is there a significant difference between the experimental and control group in students' academic achievement and knowledge retention over time (pretest, post-test and retention test)?

Pretest–Post-test Comparison for the Experimental Group

The Wilcoxon signed-rank test was conducted to determine whether there was a significant difference between the SCAAT pretest and post-test scores of the experimental group. The results are presented in Table 5.

Table 5
Experimental Group SCAAT Wilcoxon Signed-Rank Test Results

SCAAT	n	Mean Rank	Sum of Ranks	*z*	*r*	*p*
Negative Ranks	0[a]	0.00	0.00	-4.56[b]	0.88	< .001
Positive Ranks	27[b]	14.00	378.00			
Ties	0[c]					
Total	27					

a. Experimental Group SCAAT Post-Test < Experimental Group SCAAT Pretest
b. Experimental Group SCAAT Post-Test > Experimental Group SCAAT Pretest
c. Experimental Group SCAAT Post-Test = Experimental Group SCAAT Pretest
p < .008 (Bonferroni-adjusted)

As shown in Table 5, the experimental group demonstrated a statistically significant increase in SCAAT scores from pretest to post-test (z = -4.56, p < .001), which indicates a large effect (r = .878).

Pretest–Post-test Comparison for the Control Group

The Wilcoxon signed-rank test was conducted to determine whether there was a significant difference between the SCAAT pretest and post-test scores of the control group. The results are presented in Table 6.

Table 6
Control Group SCAAT Wilcoxon Signed-Rank Test Results

SCAAT	n	Mean Rank	Sum of Ranks	*z*	*r*	*p*
Negative Ranks	0[a]	0.00	0.00	-3.95[b]	0.88	< .001
Positive Ranks	20[b]	10.50	210.00			
Ties	0[c]					
Total	20					

a. Control Group SCAAT Post-Test < Control Group SCAAT Pre-Test
b. Control Group SCAAT Post-Test > Control Group SCAAT Pre-Test
c. Control Group SCAAT Post-Test = Control Group SCAAT Pre-Test
p < .008 (Bonferroni-adjusted)

As shown in Table 6, SCAAT scores in the control group increased from pretest to post-test. This change was statistically significant (z = -3.95, p < .001) and was associated with a large effect (r = .883).

Although the effect sizes for both groups appear identical when rounded (r = .88), the actual values differ slightly (experimental group: r = .878; control group: r = .883).

This similarity reflects the consistent improvement observed across all participants in both groups, as indicated by the absence of negative ranks in the Wilcoxon signed-rank test. It also suggests that both the intervention and the regular curriculum-based instruction were effective in increasing students' academic achievement, although subsequent between-group comparisons indicate additional benefits associated with the experimental condition.

Post-Test Comparison Between the Experimental and Control Group

The Mann-Whitney U Test was conducted to determine whether there was a significant difference between the SCAAT post-test scores of the experimental and control group. The result s are presented in Table 7.

Table 7

Groups' SCAAT Post-Test Mann–Whitney U Results

Groups	n	Mean Ranks	Sum of Ranks	*U*	*r*	*p*
Experimental Group	27	30.31	818.50	99.50	0.54	< .001
Control Group	20	15.48	309.50			

p < .008 (Bonferroni-adjusted)

As presented in Table 7, post-test scores differed significantly between groups, with the experimental group outperforming the control group ($U = 99.50$, $p < .001$). The magnitude of this difference was moderate to large ($r = .54$).

Retention Test Comparison Between the Experimental and Control Group

After 4 months, the SCAAT was conducted again with both the experimental and control group students to examine the effect of QR code-supported m-learning environments on the retention of environmental topics taught in the SC. For this purpose, the post-test and retention test scores of both groups were analysed using the Wilcoxon signed-rank test. The results for the experimental group are presented in Table 8.

Table 8

Experimental Group SCAAT Retention Wilcoxon Signed-Rank Test Results

SCAAT	n	Mean Rank	Sum of Ranks	*z*	*r*	*p*
Negative Ranks	13[a]	10.00	130.00	-0.51[b]	0.10	0.61
Positive Ranks	8[b]	12.63	101.00			
Ties	6[c]					
Total	27					

a. Experimental Group SCAAT Retention Test < Experimental Group SCAAT Post-Test
b. Experimental Group SCAAT Retention Test > Experimental Group SCAAT Post-Test
c. Experimental Group SCAAT Retention Test = Experimental Group SCAAT Post-Test
p < .008 (Bonferroni-adjusted)

As shown in Table 8, SCAAT scores in the experimental group remained stable from post-test to retention. The difference was not statistically significant ($z = -0.51$, $p = .61$), and the effect size was small ($r = .10$).

The Wilcoxon signed-rank test analysis results for the SCAAT post-test and retention test scores of the control group are presented in Table 9.

Table 9
Control Group SCAAT Retention Wilcoxon Results

SCAAT	n	Mean Rank	Sum of Ranks	*z*	*r*	*p*
Negative Ranks	16[a]	10.09	161.50	-3.32[b]	0.74	< .001
Positive Ranks	2[b]	4.75	9.50			
Ties	2[c]					
Total	20					

a. Control Group SCAAT Retention Test < Control Group SCAAT Post-Test
b. Control Group SCAAT Retention Test > Control Group SCAAT Post-Test
c. Control Group SCAAT Retention Test = Control Group SCAAT Post-Test
p < .008 (Bonferroni-adjusted)

As presented in Table 9, the control group showed a significant decrease from post-test to retention test scores, indicating a decline in retained knowledge over time. This difference was statistically significant ($z = -3.32$, $p < .001$) and associated with a large effect size ($r = .74$).

The Mann-Whitney U test was conducted to determine whether there was a significant difference between the SCAAT retention test scores of the experimental and control group. The results are presented in Table 10.

Table 10
Groups' SCAAT Retention Mann–Whitney U Results

Groups	n	Mean Rank	Sum of Ranks	*U*	*r*	*p*
Experimental Group	27	33.37	901.00	17.00	0.80	< .001
Control Group	20	11.35	227.00			

p < .008 (Bonferroni-adjusted)

As presented in Table 10, the experimental group obtained higher retention scores than the control group, which shows that the knowledge gained through QR code-supported mobile learning was maintained more effectively over time. This difference was statistically significant ($U = 17.00$, $p < .001$) and associated with a large effect size ($r = .80$).

What are the views and experiences of the students in the experimental group regarding the use of QR code-supported mobile learning tools during the science course (SC)?

Opinions of students on the activities during the teaching process

An analysis of the students' opinions on the activities conducted during the teaching process identified seven codes pertaining to the positive aspects of these activities, as shown in Figure 8.

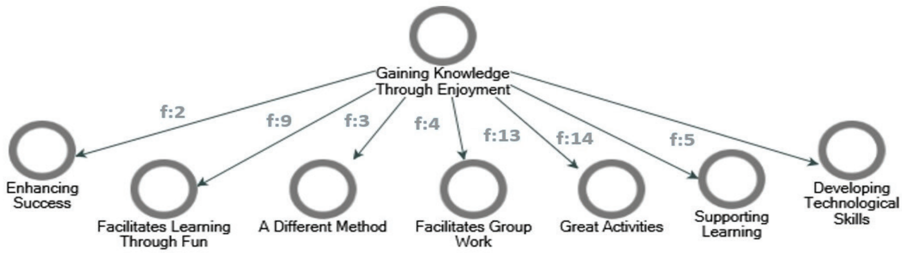

Figure 8. Positive Activity Themes and Codes

Figure 8 illustrates the themes and codes derived from student responses regarding the positive aspects of the instructional activities. Students emphasised gaining knowledge through enjoyment and perceived that the activities enhanced their learning experience. A direct quotation from the students' interviews is as follows.

I think it is good; it is both fun and educational. It not only prevents us from just solving questions and getting bored, but it also facilitates learning through games. We have overcome the harms of technology. In the past, we didn't know what to play, but now we can benefit from and use technology; we have learned how to use music. (Ayşe)

The student also mentioned that the activities contributed to the effective use of technology. An analysis of students' views on the negative aspects of the SC activities conducted during the teaching process identified four codes, as shown in Figure 9.

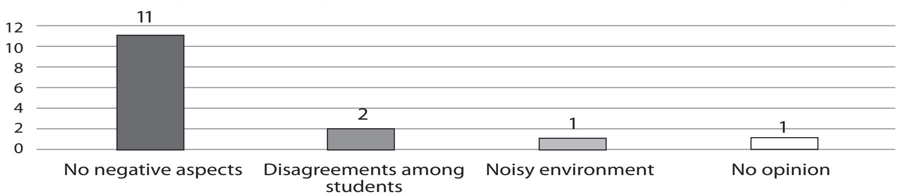

Figure 9. Negative Activity Codes

Figure 9 presents the codes derived from students' responses concerning the negative aspects of the instructional activities. Most students reported no negative experiences; one offered no opinion, and three identified specific issues. Two mentioned disagreements among peers, while one referred to a noisy environment: "The noise made by people in the classroom" (Derya). The student noted that the classroom environment was noisy during the activities.

Opinions of students on emotions experienced during the teaching process

The words most frequently used by students during the interviews to express their emotions regarding the SC activities during the teaching process were "curiosity," "excitement," "great" and "happy." These expressions indicate that students largely associated the learning experience with positive emotions. A direct quotation from the students' interviews is as follows.

Happy, excited, curious. For example, everyone is excited, wondering which question will come up and whether we will be first. Then we encourage each other, saying, 'Come on, friends, let's solve this question.' Later, they wonder what will come out and whether it will be difficult. Finally, when the activity is over, everyone feels happy and rejoices. (Aslı)

Similar results were obtained from the analysis of the journals used in the science instruction.

Table 11
Students' Emotional Responses in the SC

Student Responses	Total
Happy	84
Excited	77
Curious	44
Surprised	19
Fun	17
Interesting	6
Good	5
Great	5
I felt I gained knowledge	5
Peaceful	2
Difficult	1
Like a scientist	1
Energetic	1
Like I know everything	1
Those who did not respond	5

In Table 11, students generally reported feeling happy at the end of the teaching activities. Additionally, excitement and curiosity were frequently mentioned among the emotions experienced. These findings are consistent with the results from student interviews. A direct quotation from the students' journals is as follows: "I felt great; I felt like I knew everything." This indicates that the activities made the students happy and that they felt confident in their learning process.

Upon analysing students' opinions on SC teaching methods, seven codes were identified for the activities they enjoyed. These codes were categorized under two main themes: the type of activity and the location of the activity, as shown in Figure 10.

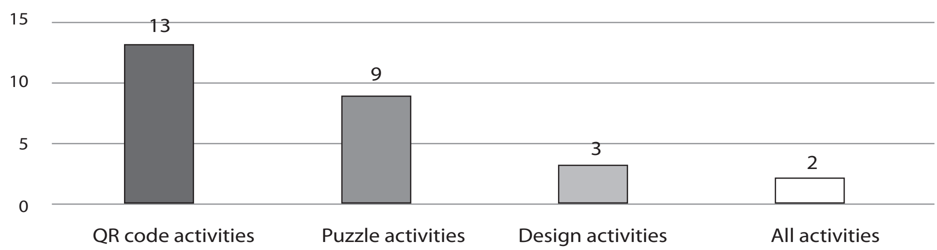

Figure 10. Students' Most Enjoyed Activity Codes

Figure 10 illustrates the types of activities students reported enjoying the most during the instructional process. Among these, QR code-based activities were the most frequently mentioned. Figure 11 presents the activities that students enjoyed, categorized by the location where they were conducted.

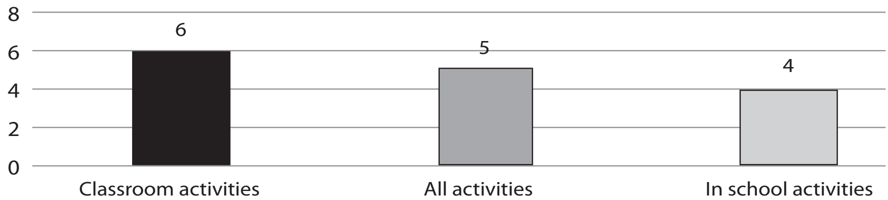

Figure 11. Students' Preferred Activities by Location

Figure 11 presents students' preferences for different types of activities categorized by the setting in which they were conducted. The results indicate that classroom-based activities were the most frequently enjoyed. A direct quotation from the students' interviews is as follows: "The activity we did in the corridor was even more enjoyable because our team came in first. It was more fun to constantly move from one place to another, and solving the codes was enjoyable" (Barış). This indicates that the student found the corridor activity, categorized as in-school activity, more enjoyable.

Only one student did not enjoy the activities. The following direct quotation reflects the student's perspective.

> *There isn't one right now, but if we do it again, maybe there will be. I do have things I don't like, but in QR code games, there is no structured turn-taking; everyone wants to be the first to finish, but some students fall behind. Then, I get annoyed. I'm not saying the games are bad, but my friends play in a way that annoys me*. (Murat)

This indicates that the student's lack of enjoyment is not attributed to the activities themselves but rather to interpersonal disagreements with his friends.

Opinions of students on whether they experienced problems during the activities

An examination of the issues encountered during the activities revealed that 11 students experienced some problems, while 4 students did not encounter any issues. Five codes were identified for the problems experienced, as shown in Figure 12.

Figure 12 presents the codes related to the causes of problems experienced by students during the instructional process. The most frequently reported issues were associated with the activities themselves, while internet-related problems were mentioned the least. The following direct quotation illustrates this.

> *I didn't actually have any problems, but the tablet sometimes lagged, which was a bit of an issue. There was no particular difficulty or challenging part. I did experience some difficulty with the cover game. Since the tablet was lagging, I wasn't able to scan the QR codes, so I had some trouble then.* (Mert)

This direct quotation indicates that although the student did not experience long-term problems, he/she did encounter tablet-related problems during some activities.

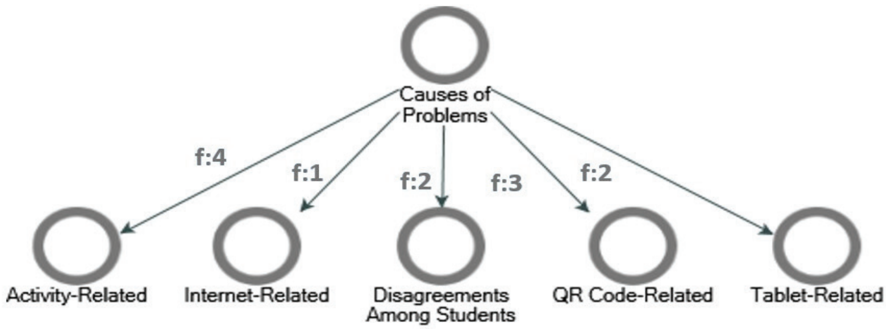

Figure 12. Codes for Causes of Student Problems

Opinions of students on QR code-supported out-of-school activities

Upon analysing students' statements regarding QR code-supported out-of-school activities in SC, 11 codes were identified. These codes were categorized under two main themes: positive aspects and negative aspects, as shown in Figure 13.

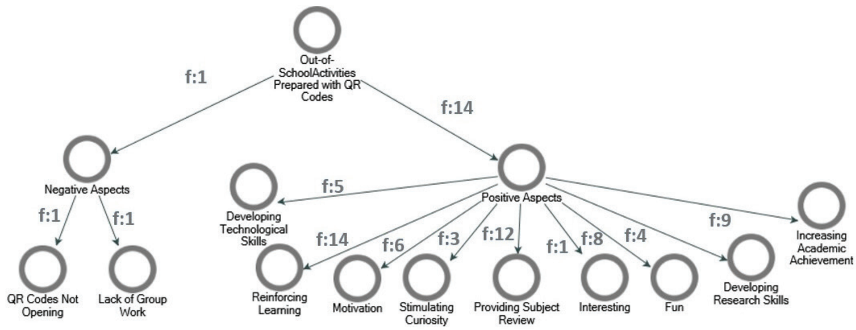

Figure 13. Themes on QR-Supported Out-of-School Activities

Figure 13 presents the themes and codes related to students' perceptions of QR code-supported out-of-school activities. These activities were most frequently reported as effective in reinforcing learning and supporting content review. They are also frequently reported as effective in increasing academic achievement. However, one student expressed negative views due to QR codes not opening and a lack of group work.

Opinions of students on group work in QR code-supported m-learning environments

Upon analysing students' statements regarding group activities conducted in QR code-supported m-learning environments, six codes were identified. These codes were categorized under two main themes: positive aspects and negative aspects, as shown in Figure 14.

Figure 14 illustrates the themes and codes derived from student reflections on group activities within QR code-supported m-learning environments. Collaboration and increased motivation were the most commonly emphasized benefits of group work. However, three students mentioned disagreements within their groups as negative experiences.

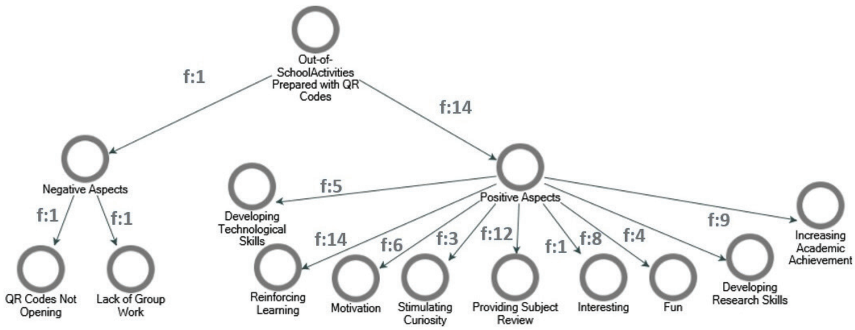

Figure 14. Group Activity Themes in QR m-Learning

Opinions on the effect of activities on students' development, skills and attitudes

Eight codes related to the effect of activities on students' development, skills and attitudes have been identified. These are presented in Figure 15.

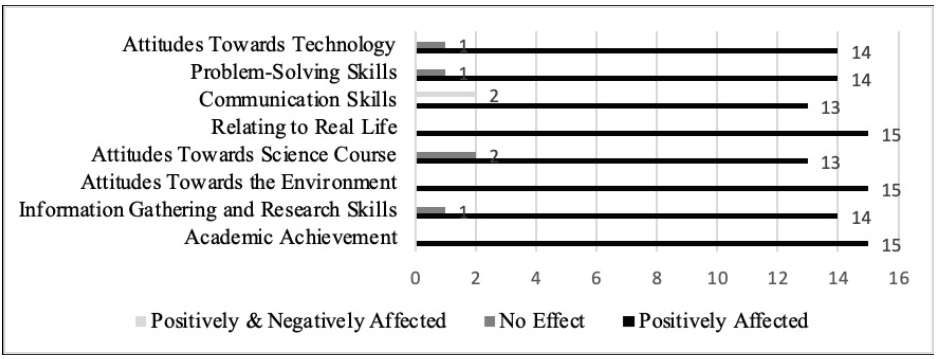

Figure 15. Effects of activities on students' skills and attitudes

Figure 15 summarises students' views on how the instructional activities influenced their skills and attitudes. Most students reported more positive attitudes towards science and the environment, with increased interest and engagement. Although opinions on technology varied, overall confidence improved. Regarding skills, one student reported no change in problem-solving or research, and two mentioned mixed effects on communication. The majority, however, noted gains in communication, real-life application and academic achievement.

Table 12.
Integration of Quantitative and Qualitative Findings

Quantitative Findings	Qualitative Evidence (Themes & Exemplars)	Integrated Interpretation
The experimental group outperformed the control group at post-test (U = 99.50, p < .001, r = .54).	Students emphasized "learning through enjoyment," "facilitates learning," (e.g., "It is both fun and educational… it facilitates learning through games"). QR-based activities were the most preferred.	Convergence: Higher post-test performance in the experimental group is consistent with increased engagement and enjoyment, which suggests that active and interactive learning contributed to improved performance.
Retention remained stable in the experimental group (z = -0.51, p = .61, r = .10), whereas the control group showed a significant decline (z = -3.32, p < .001, r = .74).	Students highlighted reinforcement and review (e.g., "I felt like I knew everything" and references to repeated exposure and practice through QR activities). "Reinforcing learning"; "providing subject review"; effective use of out-of-school QR activities; students noted easier recall and review.	Complementarity: Qualitative data explain the stability of retention in the experimental group by highlighting repeated exposure, reinforcement and opportunities for review beyond the classroom.
The experimental group achieved higher retention scores than the control group (U = 17.00, p < .001, r = .80).	Students reported "increasing academic achievement", "enhancing success" and "confidence" (e.g., "I felt great… I felt like I knew everything") as outcomes of the activities.	Convergence: Students' perceived learning gains align with higher retention performance, supporting the effectiveness of the intervention.
Despite strong quantitative effects, minor issues were reported during implementation.	Some students reported disagreements, noise and technical issues (e.g., "The noise made by people in the classroom" and problems with QR scanning, tablet lag).	Expansion: The intervention was effective overall, but qualitative data reveal practical challenges, which provides a more nuanced and realistic understanding of the implementation process.

The integration of quantitative and qualitative findings provides a comprehensive understanding of the results. The findings demonstrate convergence in terms of improved academic achievement and retention, while qualitative data help explain the underlying mechanisms, such as increased engagement, enjoyment and opportunities for reinforcement. In addition, qualitative findings extend the interpretation by revealing minor implementation challenges, which offers a more nuanced perspective on the intervention.

Discussion

Analysis of within- and between-group comparisons for academic achievement and retention (RQ1), together with qualitative findings, showed that both traditional and QR m-learning environments improved students' SCAAT scores, with stronger effects in the experimental group. This confirms that m-learning is most effective when embedded in pedagogically sound designs. Previous studies similarly report that m-learning enhances retention, motivation and participation in science and environmental education (Kalogiannakis & Papadakis, 2017; Uzunboylu et al., 2009; Zacharia et al., 2016). Interactive, student-centred activities promote engagement and achievement through continuous, accessible and interactive learning (Chang et al., 2011; Demir & Akpınar, 2018; Rikala, 2015).

Consistent with previous research in environmental education contexts, mobile-supported learning activities have been found to improve students' learning performance (Chang et al., 2011). Meta-analyses show that long-term, well-structured m-learning produces stronger outcomes (Chauhan, 2017; Yang & Xiang, 2024). In addition, the effectiveness of such environments is closely related to pedagogical design, learner engagement and contextual interaction (Rikala, 2015). The eight-week design of this study supports these findings, which suggest that technology-integrated instruction can benefit primary science learning. The effectiveness of m-learning depends on pedagogical design, content relevance and learner engagement (Daulay et al., 2023; Tanaka & Ishizaki, 2018; Timotheou et al., 2023). Mobile devices facilitate observation and data collection, which supports learning through visual and experiential processes—an approach suited to young learners (Furió et al., 2015). In contrast, some studies have found that mobile learning does not lead to higher learning outcomes than traditional approaches; rather, similar levels of learning performance and knowledge acquisition have been reported across different instructional media and learning conditions (Nouri et al., 2014; Ruchter et al., 2010). These findings may be related to differences in instructional design, duration of implementation and contextual conditions.

Retention analysis revealed that stable post- and delayed-test scores in the experimental group reflected sustained learning, while the control group's decline suggested short-term effects. However, although no statistically significant difference was found between the post-test and retention scores in the experimental group, this result should be interpreted with caution due to the low statistical power associated with the small effect size. Nevertheless, the observed pattern of stable performance in the experimental group suggests that QR code-supported mobile learning may contribute to sustained engagement over time. Meaningful learning therefore requires sustained engagement and repeated digital reinforcement (Demir & Akpınar, 2018; Najmuldeen, 2017). Designs combining interactivity, repetition and emotional engagement—aligned with SAMR's 'Redefinition' level—yield stronger results. The integrated analysis of quantitative and qualitative findings indicates that the observed improvements in academic achievement and retention are closely associated with students' increased engagement, enjoyment and opportunities for reinforcement provided by the QR-supported mobile learning environment.

Consistent with the quantitative findings on achievement and retention, student feedback confirmed the positive influence of QR m-learning on motivation and attitude. Students described the activities as enjoyable and instructive, consistent with studies showing increased engagement through QR-based applications (Timotheou et al., 2023; Uzunboylu et al., 2009). Younger learners' curiosity and responsiveness to technology enhanced participation, while older students preferred printed materials (Bjørgen, 2022; Vanhöfen et al., 2023). Thus, age and instructional design are key factors that shape motivation and attitude.

Qualitative results also showed that QR m-learning stimulated curiosity and excitement, which strengthened emotional engagement and intrinsic motivation (Heinonen, 2015; Hilton, 2016). Such environments provide experiences unavailable in traditional settings and encourage exploration (Chou et al., 2012). Students reported that revisiting digital content at home reinforced understanding, which extended learning beyond the classroom (Crompton & Burke, 2018). Individualised QR-based tasks reflected SAMR's modification and redefinition levels, which promoted self-regulation and responsibility.

The study effectively integrated technological and pedagogical knowledge within the TPACK framework (Koehler & Mishra, 2009), which supported self-directed learning (Abedi et al., 2023; Ehsanpur & Razavi, 2020). Collaborative group work enhanced communication and problem-solving (Bovanova, 2023; Rikala, 2015), consistent with international findings in science education (Lin et al., 2019; Ryu et al., 2015). Despite occasional conflicts, most students reported higher motivation and accountability, which is in line with sociocultural theory (Vygotsky, 1978).

Students also expressed greater confidence in using technology. Integrating QR m-learning into classroom and home activities increased engagement and performance (Chauhan, 2017). Personalised digital tasks fostered autonomy and satisfaction, which shows that age-appropriate m-learning supports meaningful participation. While communication improved and students showed increased interest in environmental topics, progress in higher-order skills such as problem-solving remained limited, which suggests the need for scaffolding in early education (Timotheou et al., 2023). Linking activities to local environmental issues increased relevance and motivation (Kalogiannakis & Papadakis, 2017).

Some limitations were observed. Technical issues (internet access and device availability) and occasional group tensions caused brief interruptions (Rivers, 2009). Challenges such as cost and maintenance highlight the need for sustainable infrastructure and management (Bleck et al., 2012; Barak et al., 2016). Another limitation of the study relates to the instructional implementation. Although the instructional process was planned in advance and standardised across groups in terms of content, sequence and duration, the experimental group was taught by the researcher, while the control group was taught by a different classroom teacher. This may have introduced a potential teacher-related effect. In addition, the implementation process was monitored through regular meetings with the control teacher and the use of structured lesson plans, which were followed and monitored on a weekly basis. However, no formal classroom observations or independent implementation fidelity measures were employed to verify the consistency of instructional delivery across groups. Therefore, the outcomes may have been influenced, to some extent, by instructor-related factors in addition to the QR-supported mobile learning intervention. Another limitation relates to the potential novelty effect. As students were introduced to QR code-supported mobile learning and the use of mobile devices for instructional purposes, their increased motivation and attention may have been influenced by the novelty of the learning environment rather than the instructional approach itself. Therefore, the observed effects should be interpreted with caution, as they may partially reflect short-term engagement associated with the introduction of new technologies. In addition, the statistical power for the retention comparison within the experimental group was found to be low ($1 - \beta = .04$). Therefore, the non-significant result observed in this analysis should be interpreted with caution, as it may be influenced by insufficient statistical power rather than the absence of a true effect.

In light of these considerations, the results obtained in this study should be interpreted not merely as the effect of QR code usage, but rather as the overall impact of the pedagogical design implemented in a QR code-supported mobile learning environment. Overall, the study confirms that well-designed, developmentally appropriate QR m-learning can transform primary environmental science education. Integration through the SAMR and TPACK frameworks yields measurable gains in achievement and motivation while fostering collaboration and sustained learning.

Conclusion

The study found QR-m-learning more effective than traditional instruction in improving third-grade students' achievement and retention. Students described the process as enjoyable and motivating and as supportive of their learning experiences. The findings indicate that when technology is used through well-designed, age-appropriate, student-centred methods, it contributes to improved academic achievement and is associated with positive learning experiences. Grounded in the SAMR and TPACK frameworks, the research confirms that technology's educational value depends on pedagogical quality rather than its mere presence. Activities promoting collaboration and creativity enhanced student engagement. Although limited to one eight-week science unit in a Turkish primary school, the study highlights QR-m-learning as an accessible, low-cost model for flexible and individualised instruction. Future research should explore its impact on motivation, self-regulation and social interaction across wider age ranges.

Recommendations

This study suggests that innovative teaching practices such as QR code-supported mobile learning can make learning more effective, lasting and enjoyable, while offering a guiding framework for the design of student-centred environments. It is therefore recommended that QR-based mobile learning applications be more widely adopted in environmental education at the primary level.

The study was limited to third-grade students in a Turkish primary school and an eight-week science unit on Living Things. These constraints restrict the generalisability of the findings to other age groups, school types and socio-cultural settings.

Pedagogically, QR-supported mobile learning demonstrates benefits beyond content delivery, which influences instructional design and educational policy. QR codes are inexpensive, accessible and easy for teachers to produce, which supports equity in contexts with limited digital resources. In interdisciplinary fields such as environmental education, QR-based materials can provide microlearning opportunities, adapting to different learning speeds and individual needs to foster flexible, student-centred environments.

At the policy-maker level, integrating QR technology with open-source, teacher-generated content could offer a scalable and cost-effective strategy to reduce digital inequality. Future studies should involve broader samples, varied age levels and longitudinal designs to examine the sustained effects of mobile learning not only on achievement but also on interaction, self-regulation and affective engagement. Theoretically, integrating SAMR and TPACK with sociocultural, motivational and cognitive load perspectives may offer a more comprehensive framework for analysing technology-enhanced learning processes.

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Perihan KÖSE
Istanbul University-Cerrahpaşa, Hasan Ali Yücel Faculty of Education, Department of Primary Education Preparation
Büyükçekmece Campus, Alkent 2000 Neighborhood,
Yiğittürk Street No: 5/9/1
34500 Büyükçekmece, Istanbul, Turkey
perihan0duman@gmail.com

Nur Ütkür GÜLLÜHAN
Istanbul University-Cerrahpaşa, Hasan Ali Yücel Faculty of Education, Department of Primary Education Preparation
Büyükçekmece Campus, Alkent 2000 Neighborhood,
Yiğittürk Street No: 5/9/1
34500 Büyükçekmece, Istanbul, Turkey
nur.utkur@iuc.edu.tr

Poučavanje okolišnih tema u nastavi prirodoslovlja u osnovnoj školi u okružju mobilnoga učenja podržanoga QR kodovima: istraživanje mješovitom metodom

Sažetak

Ovo istraživanje ispitivalo je učinak poučavanja nastavne cjeline „Živa bića" u nastavi prirodoslovlja u osnovnoj školi primjenom mobilnoga učenja podržanoga QR kodovima na učenička postignuća, zadržavanje znanja i stavove učenika. Istraživanje je provedeno primjenom dizajna mješovitih metoda, uz eksperimentalnu skupinu (27 učenika) i kontrolnu skupinu (20 učenika) iz jedne javne osnovne škole u Istanbulu. Kvantitativni podatci prikupljeni su testom akademskoga postignuća, dok su kvalitativni podatci dobiveni polustrukturiranim intervjuima i učeničkim dnevnicima. Rezultati su pokazali da su učenici u eksperimentalnoj skupini postigli statistički značajno viša postignuća u odnosu na kontrolnu skupinu te razvili pozitivne percepcije o primjeni mobilnoga učenja. Nadalje, zabilježen je porast interesa i motivacije za nastavu prirodoslovlja, kao i napredak u različitim vještinama povezanima s učenjem. Dobiveni rezultati upućuju na to da mobilno učenje podržano QR kodovima može predstavljati učinkovit pedagoški pristup poučavanju okolišnih tema u nastavi prirodoslovlja u osnovnoj školi.

Ključne riječi*: odgoj i obrazovanje za okoliš; mobilno učenje; osnovno obrazovanje; QR kodovi; nastava prirodoslovlja*

Uvod

Obrazovna okruženja doživjela su značajne promjene zbog brzoga razvoja digitalnih tehnologija. Kako nove generacije odrastaju okružene tehnologijom, tradicionalne metode poučavanja postaju sve manje učinkovite. Slijedom toga, informacijske i komunikacijske tehnologije, osobito mobilne tehnologije, preoblikovale su i alate i metode obrazovanja (Koenig, 2011; Prensky, 2012).

Prijenosnost i široka dostupnost mobilnih uređaja dovele su do razvoja koncepta mobilnoga učenja (*m-learning*) (Heflin i sur., 2017; Omolafe, 2021; Squires, 2017).

Mobilno učenje omogućuje učenje neovisno o vremenu i mjestu te pruža učenicima usmjerena i interaktivna okružja (Chung i sur., 2019; Cin i sur., 2022; Kukulska-Hulme i Traxler, 2005; Patten i sur., 2006). Prijenosni uređaji smanjuju troškove, omogućuju personalizaciju učenja i potiču interakciju (El-Hussein i Cronje, 2010; Tabuenca i sur., 2015). Također omogućuju trenutačan pristup informacijama te korištenje e-učenja neovisno o računalima (Muyinda i sur., 2007; Traxler, 2011). Mobilni alati i QR kodovi čine učenje zanimljivijim te omogućuju učenicima napredovanje vlastitim tempom (Attewell i Savill-Smith, 2004; Daulay i sur., 2023; Park i sur., 2012). U tom kontekstu QR kodovi postali su važna sastavnica mobilnoga učenja (Law i So, 2010).

QR kodovi su dvodimenzionalni barkodovi koji omogućuju brz pristup digitalnim sadržajima skeniranjem putem mobilnih uređaja. U obrazovanju povezuju tiskane materijale s mrežnim izvorima, obogaćuju nastavne materijale multimedijskim sadržajima te omogućuju pristup izvorima učenja unutar i izvan učionice (Law i So, 2010; Rikala i Kankaanranta, 2014; Robertson i Green, 2012). Stoga QR kodovi nisu samo alternativa tradicionalnim mrežnim poveznicama, već omogućuju integraciju digitalnih sadržaja u fizičke nastavne materijale i pružaju kontekstualizirani pristup u okružjima učenja. Istraživanja pokazuju da okružja podržana QR kodovima mogu povećati znatiželju, motivaciju i sudjelovanje učenika u nastavi (Chen i sur., 2022; Rikala i Kankaanranta, 2014; Thorne, 2016). Također omogućuju implementaciju različitih pristupa učenju, pri čemu njihova učinkovitost ovisi o nastavnom dizajnu i sadržaju učenja (Lai i sur., 2013; Wu i sur., 2018). Kada su dobro osmišljeni, QR kodovi mogu podržati personalizirano i učenje usmjereno na učenika te olakšati pristup raznovrsnim izvorima učenja (Karia i sur., 2019; Rikala i Kankaanranta, 2014). Aktivnosti podržane QR kodovima mogu pridonijeti i zadržavanju znanja te obrazovnim ishodima (Crompton i sur., 2012; Vandenberghe i sur., 2021; Lai i sur., 2013). Takva okružja mogu također poticati razvoj vještina kao što su komunikacija, suradnja, kritičko mišljenje, digitalna pismenost, kvantitativno zaključivanje i prostorne vještine (Mehendale i sur., 2017; Mowafi i Abumuhfouz, 2021). U nastavi prirodoslovlja digitalni alati integrirani s QR kodovima mogu pomoći u konkretizaciji apstraktnih znanstvenih pojmova te podržati rješavanje problema i razvoj znanstvene pismenosti (Savitri i sur., 2021).

Primjena QR kodova i mobilnih tehnologija osobito je važna u odgoju i obrazovanju za okoliš, čiji je cilj razvijanje svijesti i odgovornoga ponašanja prema prirodnom okolišu. Odgoj i obrazovanje za okoliš potiče razumijevanje i djelovanje u vezi s okolišnim problemima (Rajšp i Fošnarič, 2014; Stapp, 1969), dok digitalne tehnologije poput mobilnoga učenja i QR kodova omogućuju fleksibilan i interaktivan pristup informacijama o okolišu, čineći učenje dinamičnijim i pridonoseći razvoju svijesti o okolišu.

Teorijski okvir

Digitalne tehnologije ne služe samo za prijenos sadržaja, već i preoblikuju proces učenja. U ovome istraživanju primijenjeno je mobilno učenje podržano QR kodovima (QR-m-učenje), utemeljeno na modelima SAMR (Substitution–Augmentation–

Modification–Redefinition) i TPACK (Technological–Pedagogical–Content Knowledge). Model SAMR definira pedagošku ulogu tehnologije u četiri razine, od zamjene i nadogradnje koje repliciraju tradicionalne zadatke, do modifikacije i redefinicije koje transformiraju učenje (Hilton, 2016; Puentedura, 2014). Više razine omogućuju pedagošku transformaciju i iskustva koja nisu moguća u tradicionalnoj nastavi (Hamilton i sur., 2016; Hilton, 2016).

Model TPACK nadopunjuje SAMR objašnjavajući kako nastavnici integriraju tehnologiju (TK), pedagogiju (PK) i sadržaj (CK) u uravnoteženim nastavnim dizajnima (Chai i sur., 2010; Koehler i Mishra, 2009; Mishra i Koehler, 2006). U ovome istraživanju koncepti iz područja okoliša (CK), strategije temeljene na radu u skupinama (PK) i digitalni materijali dostupni putem QR kodova (TK) činili su osnovu nastavnoga okvira. TPACK je usmjeravao oblikovanje nastave, dok je SAMR korišten za analizu načina na koji tehnologija redefinira iskustva učenja učenika, kao što je prikazano u Slici 1 (Hamilton i sur., 2016; Hilton, 2016).

Slika 1.

Slika 1 prikazuje kako SAMR djeluje unutar dizajna utemeljenoga na TPACK modelu kako bi se procijenila transformativna dimenzija QR-m-učenja.

U nastavi prirodoslovlja mobilne tehnologije široko se primjenjuju za unaprjeđenje učenja i povećanje angažmana učenika (Bressler i Bodzin, 2016; Bjørgen, 2022; Falloon, 2017; McMahon i sur., 2016; Ryu i sur., 2015; Wang i sur., 2023; Zhan i sur., 2022; Zhai i sur., 2019; Zhai i Shi, 2020). Istraživanja koja se bave okolišnim temama u kontekstu QR-m-učenja obuhvaćaju razvoj svijesti o okolišu (Uzunboylu i sur., 2009), usporedbe s tradicionalnom nastavom (Anderson i sur., 2015; Chang i sur., 2011; Furió i sur., 2015; Ruchter i sur., 2010), obrazovanje za održivost (Bleck i sur., 2012) te učinke rane uporabe tehnologije na okolišnu i tehnološku pismenost (Willis i sur., 2014). Druga istraživanja bavila su se primjenom mobilnih tehnologija u formalnom odgoju i obrazovanju za okoliš (Heinonen, 2015), njihovim utjecajem na znanje i percepciju (Kalogiannakis i Papadakis, 2017), digitalnim alatima za poticanje učenja o okolišu u osnovnim školama (Bovanova, 2023; Buchanan i sur., 2018), uporabom mobilnih uređaja u obrazovanju nastavnika (Sebastián-López i Miguel González, 2020) te gamificiranim programima koji unaprjeđuju ekološku svijest i digitalnu pismenost (Ricoy i Sánchez-Martínez, 2022). Pregled ovih istraživanja prikazan je na Slici 2.

Slika 2.

Slika 2 pokazuje da većina istraživanja uspoređuje mobilno učenje s tradicionalnim metodama, dok se manji broj studija bavi primjenom mobilnih tehnologija u poučavanju okolišnih tema u nastavi prirodoslovlja u osnovnoj školi. Ovaj istraživački jaz, istaknut i u međunarodnim pregledima (Yun i Crippen, 2023), dodatno naglašava važnost mobilno podržanoga učenja (Chang i sur., 2018).

Stoga je ovo istraživanje provedeno s ciljem ispitivanja učinka mobilnoga učenja podržanoga QR kodovima na akademska postignuća učenika trećega razreda, zadržavanje znanja i njihove stavove u nastavnoj cjelini „Živa bića", u usporedbi s tradicionalnom nastavom. Istraživanje je provedeno primjenom kvazieksperimentalnoga dizajna s kontrolnom skupinom i mjerenjima prije i nakon intervencije, u okviru pristupa mješovitih metoda. Nastavna intervencija oblikovana je u skladu s modelima SAMR i TPACK kako bi se osigurala pedagoški utemeljena integracija tehnologije. Na temelju tih ciljeva postavljena su sljedeća istraživačka pitanja:

IP1. Postoji li statistički značajna razlika između eksperimentalne i kontrolne skupine u akademskim postignućima učenika i zadržavanju znanja tijekom vremena (predtest, posttest i test zadržavanja)?

Hipoteza 1. Učenici u eksperimentalnoj skupini pokazat će statistički značajno veće poboljšanje u akademskim postignućima od predtesta do posttesta te ostvariti više rezultate na testu zadržavanja u odnosu na učenike u kontrolnoj skupini.

IP2. Kakvi su stavovi i iskustva učenika u eksperimentalnoj skupini u vezi s primjenom mobilnoga učenja podržanoga QR kodovima tijekom nastave prirodoslovlja?

Budući da je ovo pitanje istraženo kvalitativnim podatcima, nije formulirana hipoteza.

Metodologija

Pristup mješovitih metoda omogućuje sveobuhvatno razumijevanje istraživačkih problema integriranjem kvantitativnih i kvalitativnih podataka (Creswell, 2021; Teddlie i Tashakkori, 2009). Ovaj pristup objedinjuje prednosti obaju metodoloških okvira, istodobno smanjujući njihova ograničenja (Creswell i Creswell, 2017). Sukladno tome, u ovome je istraživanju primijenjen eksplanatorni sekvencijalni dizajn mješovitih metoda (Creswell, 2021).

U kvantitativnoj fazi primijenjen je kvazieksperimentalni istraživački dizajn, prikladan za obrazovne kontekste u kojima je potpuna kontrola ili randomizacija otežana (Christensen i sur., 2020; Cohen i sur., 2021; Singh, 2007). Kvalitativna faza temeljila se na studiji slučaja s ciljem istraživanja stvarnih iskustava iz više izvora podataka (Yin, 2014). Učenički dnevnici, polustrukturirani intervjui i povratne informacije učitelja analizirani su kako bi se bolje razumio proces učenja i procijenila učinkovitost provedene intervencije.

Uzorak

U istraživanju su sudjelovali učenici trećega razreda (u dobi od 8 do 9 godina) iz jedne javne osnovne škole u Istanbulu. Pri odabiru uzorka primijenjeno je kriterijsko uzorkovanje koje je obuhvatilo dostupnost mobilnih uređaja, pristup školskom internetu, sigurnost okružja za učenje te suradnju između učitelja, roditelja i učenika. Dva razredna odjela nasumično su raspoređena u eksperimentalnu skupinu (n = 27; 14 dječaka i 13 djevojčica) i kontrolnu skupinu (n = 20; 10 dječaka i 10 djevojčica). Razlike između skupina u rezultatima predtesta SCAAT-a ispitane su Mann–Whitney U testom. Rezultati su prikazani u Tablici 1.

Tablica 1

Rezultati su pokazali da ne postoji statistički značajna razlika između skupina (U = 181.50, p > ,05), što upućuje na to da su eksperimentalna i kontrolna skupina bile usporedive na početku istraživanja.

Primjenom pristupa mješovitih metoda korištena je eksplanatorna sekvencijalna strategija za ispitivanje iskustava i stavova učenika u eksperimentalnoj skupini (Creswell, 2021). Na temelju kvantitativnih rezultata, za odabir sudionika u kvalitativnoj fazi primijenjeno je uzorkovanje maksimalne varijacije. Učenici su, na temelju rezultata posttesta, kategorizirani u skupine niskog, srednjeg i visokog postignuća primjenom rangiranja. Sudionici su odabrani iz različitih dijelova distribucije rezultata kako bi se osigurala zastupljenost različitih razina postignuća. Iz svake kategorije uključeno je po pet učenika, što ukupno čini 15 sudionika.

Instrumenti prikupljanja podataka

Test akademskoga postignuća iz prirodoslovlja (SCAAT)

Za prikupljanje kvantitativnih podataka korišten je Test akademskoga postignuća iz prirodoslovlja (SCAAT), koji su razvili istraživači. Test je konstruiran na temelju ishoda učenja nastavne cjeline „Putovanje u svijet živih bića" unutar područja „Živa bića i život" u kurikulu prirodoslovlja za treći razred osnovne škole. Svrha testa bila je utvrditi razinu akademskoga postignuća učenika u odnosu na navedenu nastavnu cjelinu te usporediti razine postignuća eksperimentalne i kontrolne skupine prije i nakon intervencije.

Kako bi se osigurala sadržajna valjanost, izrađena je specifikacijska tablica u skladu s ishodima kurikula, a testni zadatci razvijeni su u skladu s njom. Zadatke su evaluirali ukupno 10 stručnjaka, uključujući predmetne stručnjake, stručnjake za razrednu nastavu, učitelje razredne nastave i učitelje materinskog jezika. Na temelju stručnih procjena izračunati su koeficijenti sadržajne valjanosti primjenom Lawsheove metode, pri čemu su svi zadatci premašili prihvatljivi prag ($CVR \geq$,62). Ukupni indeks sadržajne valjanosti testa također je bio visok (CVI = ,945). Provedene su analize zadataka temeljene na klasičnoj teoriji testa. Zadatci koji nisu zadovoljili kriterije u pogledu težine i diskriminativnosti uklonjeni su, a konačna verzija testa sastojala se od 20 zadataka. Prosječni indeks težine zadataka bio je na umjerenoj razini ($\bar{p}$ = ,71), dok je prosječni indeks diskriminativnosti bio na dobroj razini ($\bar{r}$ = ,44).

Pouzdanost testa ispitana je metodama unutarnje konzistentnosti, pri čemu je Cronbachov alfa koeficijent bio visok (α = ,858). Dodatno su provedene analize pouzdanosti metodom podjele testa na polovice. Vrijednosti Cronbachova alfa koeficijenta iznosile su ,767 za prvu polovicu i ,731 za drugu polovicu, uz korelaciju od ,755 između dviju polovica. Ovi rezultati ukazuju na zadovoljavajuću pouzdanost testa pri podjeli na dvije polovice. Spearman–Brownov koeficijent bio je visok (r = ,860), kao i Guttmanov koeficijent pouzdanosti za podijeljeni test (r = ,859). Nadalje, šest Guttmanovih koeficijenata pouzdanosti kretalo se u rasponu od 0,815 do 0,862, što upućuje na zadovoljavajuću pouzdanost testa. Ukupno gledano, ovi rezultati potvrđuju da test posjeduje adekvatnu pouzdanost.

Za ispitivanje strukturnih svojstava testa provedena je eksploratorna faktorska analiza (n = 100). Rezultati su pokazali da su podatci prikladni za faktorsku analizu (KMO = ,777; *Bartlettov* $\chi^2(190) = 544{,}151$, p < ,001). Analiza je pokazala da test ima multidimenzionalnu strukturu. Međutim, prvi faktor bio je dominantan, a *scree* dijagram pokazao je jasan prijelom nakon prvoga faktora. U literaturi se navodi da se određeni stupanj multidimenzionalnosti očekuje u testovima postignuća zbog uključivanja različitih ishoda učenja i kognitivnih razina te da prisutnost dominantnoga općeg faktora omogućuje da ukupni rezultat predstavlja ukupno postignuće (Reckase, 1979; Stout, 1987; Tate, 2012).

Sukladno tome, uzimajući u obzir da se radi o testu postignuća koji obuhvaća različite ishode učenja i kognitivne razine, ocijenjeno je primjerenim koristiti ukupni rezultat kao pokazatelj ukupnoga akademskog postignuća učenika. Ovo je također u skladu s perspektivom klasične teorije testa prema kojoj ukupni rezultati testa mogu predstavljati opću razinu postignuća pojedinaca.

Učenički dnevnici

Učenički dnevnici, koje su istraživači razvili uz doprinos deset stručnjaka, korišteni su za prikupljanje kvalitativnih podataka. Dnevnici su uključivali refleksije učenika o tome što su naučili, što im je bilo zanimljivo, što ih je zanimalo te s kojim su se poteškoćama susreli.

Polustrukturirani intervju

Polustrukturirani intervju osmišljen je kako bi se istražili osjećaji i stavovi učenika o procesu QR-m-učenja, aktivnostima unutar i izvan učionice, uočenim poteškoćama te utjecaju na njihove vještine i stavove. Obrazac intervjua pregledalo je deset stručnjaka radi procjene sadržajne valjanosti, a provedeni su i pokusni intervjui s dva učenika iz eksperimentalne skupine kako bi se osigurala jasnoća i razumljivost pitanja.

Postupak

Istraživanje je uključivalo eksperimentalnu i kontrolnu skupinu. Kvantitativni podatci prikupljeni su testom postignuća od 20 zadataka, primijenjenim kao predtest, posttest i test zadržavanja. Test zadržavanja, proveden četiri mjeseca nakon posttesta, služio je za mjerenje prisjećanja i dugoročnoga znanja (Bahrick, 1984; Custers, 2010; Frutchey, 1937; Semb i Ellis, 1994; Wodtke, 1967). Svaki test trajao je jedan školski sat.

Postupak u kontrolnoj skupini

Nastava u kontrolnoj skupini provodila se u skladu s nacionalnim kurikulom i udžbenikom, uz primjenu uobičajenih nastavnih praksi koju su provodili učitelji, poput izravne nastave i tehnike pitanja i odgovora, u skladu s redovitom nastavnom praksom. Nastavni proces unaprijed je planiran, a učitelj u kontrolnoj skupini bio je informiran o načinu provedbe nastave kako bi se osigurala usklađenost s eksperimentalnom skupinom u pogledu sadržaja, redoslijeda i trajanja. Nastava je provedena u okviru toga planiranog strukturalnoga okvira.

Oba učitelja, učitelj u kontrolnoj skupini i istraživač, imali su slično profesionalno iskustvo, a nastavni sati održavani su istodobno u usporedivim uvjetima u učionici. Provedba nastave praćena je putem redovitih sastanaka s učiteljem kontrolne skupine te korištenjem strukturiranih nastavnih planova koji su se provodili i pratili na tjednoj razini.

Postupak u eksperimentalnoj skupini

Nastava je osmišljena u okviru TPACK modela, dok je model SAMR korišten za opis integracije tehnologije u nastavni proces. Nastavni proces unaprijed je planiran i proveden u skladu s ciljevima učenja, sadržajem, redoslijedom i trajanjem koji su primijenjeni i u kontrolnoj skupini. U nastavu su uključene aktivnosti podržane QR kodovima kako bi se poduprlo predstavljanje i istraživanje sadržaja.

Sadržaj je obuhvaćao okolišne teme iz prirodoslovlja za treći razred, a tehnologija je uključivala digitalne materijale dostupne putem QR kodova u okružju mobilnoga učenja. Učenici su koristili mobilne uređaje za pristup videozapisima, animacijama, igrama i drugim materijalima vođenima QR kodovima. Tjedne aktivnosti bile su organizirane tako da integriraju sadržaj, pedagogiju i tehnologiju unutar strukturiranoga okružja mobilnoga učenja. Tehnologija je korištena za provedbu i organizaciju nastavnih zadataka na način koji odgovara različitim razinama SAMR modela, kao što je prikazano na Slici 3.

Slika 3

Slika 3 prikazuje tjednu strukturu nastave i razine SAMR modela povezane sa svakom aktivnošću. Model SAMR korišten je za kategorizaciju načina na koji je tehnologija integrirana u nastavne zadatke, dok je TPACK osiguravao usklađenost između sadržaja, pedagogije i digitalnih alata u aktivnostima podržanima QR kodovima. Tjedni nastavni proces u eksperimentalnoj skupini sažeto je prikazan na Slici 4.

Slika 4

Slika 4 prikazuje razvoj aktivnosti od razina zamjene i nadogradnje (npr. gledanje videozapisa) do modifikacije i redefinicije (npr. aktivnosti snalaženja u prostoru i videozapisi koje su izradili učenici). Većina aktivnosti bila je usklađena s razinama modifikacije ili redefinicije. Aktivnosti mobilnoga učenja u učionici u eksperimentalnoj skupini prikazane su na Slici 5.

Slika 5

Slika 5 prikazuje primjere iz nastave u kojima su učenici sudjelovali u radu s materijalima podržanima QR kodovima. Aktivnosti poput izrade videozapisa, digitalnoga pripovijedanja, igara i potrage za blagom bile su uključene u nastavni proces. U cjelini gledano, ove aktivnosti pokazuju kako je mobilno učenje podržano QR kodovima provedeno u skladu sa SAMR modelom (Hilton, 2016; Kirkland, 2017; Puentedura, 2014).

Analiza podataka

Budući da je veličina kvantitativnoga uzorka bila manja od 30 (Can, 2020), primijenjeni su Wilcoxonov test rangova s predznakom i Mann–Whitneyjev U test. S obzirom na to da je unutar 2 × 3 istraživačkoga dizajna provedeno šest neparametrijskih usporedbi, primijenjena je Bonferronijeva korekcija kako bi se kontrolirala inflacija pogreške tipa I, a prilagođena razina značajnosti postavljena je na $\alpha = ,008$.

Dodatno je provedena post hoc analiza statističke snage za šest neparametrijskih usporedbi korištenjem programa GPower 3.1. Veličine učinka (r), prilagođena razina značajnosti ($\alpha = ,008$) i veličine uzoraka korištene su za izračun postignute snage testa ($1 - \beta$). Izračuni su provedeni primjenom odgovarajućih neparametrijskih testnih modela u programu GPower 3.1. Rezultati analize statističke snage prikazani su u Tablici 2.

Tablica 2

Za kvalitativne podatke provedena je induktivna analiza korištenjem programa NVivo 14 za obradu polustrukturiranih intervjua. Deskriptivna statistika učeničkih dnevnika prikazana je u Tablici 3. Frekvencije predstavljaju broj dnevničkih zapisa koje su učenici iz eksperimentalne skupine predali tijekom svakog tjedna. Varijacije u tjednim ukupnim vrijednostima odražavaju razlike u predaji dnevnika, a ne promjene u broju sudionika.

Tablica 3

Ukupno je tijekom provedbe nastave prikupljeno 164 učeničkih dnevnika. Faze analize dnevnika prikazane su na Slici 6.

Slika 6

Slika 6 prikazuje korake provedene u analizi kvalitativnih podataka iz učeničkih dnevnika: organizaciju podataka, kodiranje, razvoj tema i validaciju putem stručne procjene. Koraci korišteni u analizi polustrukturiranih intervjua prikazani su na Slici 7.

Slika 7

Slika 7 prikazuje faze analize intervjua. Intervjui su transkribirani, organizirani, kodirani i tematski analizirani u programu NVivo. Nakon toga provedena je stručna evaluacija, a zatim su napravljene završne dorade.

Kako bi se osigurala pouzdanost, istraživač i jedan stručnjak neovisno su kodirali kvalitativne podatke. Podudarnost kodiranja izračunata je primjenom formule Milesa i Hubermana (1994), pri čemu je dobivena vrijednost od 93,06 %, što ukazuje na visoku pouzdanost (iznad 80 %). Prilikom prikaza kvalitativnih nalaza korišteni su pseudonimi umjesto stvarnih imena učenika kako bi se osigurali etički standardi i jasnoća kodiranja.

Rezultati

Deskriptivna statistika rezultata na SCAAT predtestu, posttestu i testu zadržavanja u obje skupine prikazana je u Tablici 4.

Tablica 4

Postoji li statistički značajna razlika između eksperimentalne i kontrolne skupine u akademskim postignućima učenika i zadržavanju znanja tijekom vremena (predtest, posttest i test zadržavanja)?

Usporedba predtesta i posttesta u eksperimentalnoj skupini

Kako bi se utvrdilo postoji li statistički značajna razlika između rezultata eksperimentalne skupine na SCAAT predtestu i posttestu, primijenjen je Wilcoxonov test rangova s predznakom. Rezultati su prikazani u Tablici 5.

Tablica 5

Kao što je prikazano u Tablici 5, u eksperimentalnoj skupini zabilježen je statistički značajan porast rezultata na SCAAT-u od predtesta do posttesta (z = -4,56, p < ,001), uz veliku veličinu učinka (r = ,878).

Usporedba predtesta i posttesta u kontrolnoj skupini

Kako bi se utvrdilo postoji li statistički značajna razlika između rezultata kontrolne skupine na SCAAT predtestu i posttestu, primijenjen je Wilcoxonov test rangova s predznakom. Rezultati su prikazani u Tablici 6.

Tablica 6

Kao što je prikazano u Tablici 6, rezultati na SCAAT-u u kontrolnoj skupini porasli su od predtesta do posttesta. Ta je promjena bila statistički značajna (z = -3,95, p < ,001) i povezana s velikom veličinom učinka (r = ,883). Iako veličine učinka za obje skupine pri zaokruživanju izgledaju jednako (r = ,88), stvarne se vrijednosti neznatno razlikuju (eksperimentalna skupina: r = ,878; kontrolna skupina: r = ,883). Ova sličnost odražava dosljedno poboljšanje zabilježeno kod svih sudionika u objema skupinama, što pokazuje izostanak negativnih rangova u Wilcoxonovu testu rangova s predznakom. Ujedno upućuje na to da su i intervencija i redovita nastava temeljena na kurikulu bile učinkovite u povećanju akademskoga postignuća učenika, iako naknadne usporedbe između skupina pokazuju dodatne prednosti povezane s eksperimentalnim uvjetom.

Usporedba posttesta između eksperimentalne i kontrolne skupine

Kako bi se utvrdilo postoji li statistički značajna razlika između rezultata eksperimentalne i kontrolne skupine na SCAAT posttestu, primijenjen je Mann–Whitneyjev U test. Rezultati su prikazani u Tablici 7.

Tablica 7

Kao što je prikazano u Tablici 7, rezultati posttesta statistički su se značajno razlikovali između skupina, pri čemu je eksperimentalna skupina ostvarila bolje rezultate od kontrolne skupine (U = 99,50, p < ,001). Veličina te razlike bila je umjerena do velika (r = ,54).

Usporedba rezultata testa zadržavanja između eksperimentalne i kontrolne skupine

Nakon četiri mjeseca ponovno je proveden SCAAT test među učenicima eksperimentalne i kontrolne skupine kako bi se ispitao učinak mobilnoga učenja podržanoga QR kodovima na zadržavanje znanja o okolišnim temama obrađenima u nastavi prirodoslovlja. U tu svrhu analizirani su rezultati posttesta i testa zadržavanja u obje skupine primjenom Wilcoxonova testa rangova s predznakom. Rezultati za eksperimentalnu skupinu prikazani su u Tablici 8.

Tablica 8

Kao što je prikazano u Tablici 8, rezultati na SCAAT-u u eksperimentalnoj skupini ostali su stabilni od posttesta do testa zadržavanja. Razlika nije bila statistički značajna (z = -0,51, p = ,61), a veličina učinka bila je mala (r = ,10).

Rezultati analize Wilcoxonova testa rangova s predznakom za rezultate posttesta i testa zadržavanja u kontrolnoj skupini prikazani su u Tablici 9.

Tablica 9

Kao što je prikazano u Tablici 9, u kontrolnoj skupini zabilježen je značajan pad rezultata od posttesta do testa zadržavanja, što ukazuje na smanjenje zadržanoga znanja tijekom vremena. Ta je razlika bila statistički značajna (z = -3,32, p < ,001) i povezana s velikom veličinom učinka (r = ,74).

Kako bi se utvrdilo postoji li statistički značajna razlika između rezultata testa zadržavanja eksperimentalne i kontrolne skupine, primijenjen je Mann–Whitneyjev U test. Rezultati su prikazani u Tablici 10.

Tablica 10

Kao što je prikazano u Tablici 10, eksperimentalna skupina ostvarila je više rezultate na testu zadržavanja u odnosu na kontrolnu skupinu, što upućuje na to da je znanje stečeno putem mobilnoga učenja podržanoga QR kodovima učinkovitije zadržano tijekom vremena. Ta je razlika bila statistički značajna (U = 17,00, p < ,001) i povezana s velikom veličinom učinka (r = ,80).

Kakvi su stavovi i iskustva učenika u eksperimentalnoj skupini u vezi s primjenom mobilnoga učenja podržanoga QR kodovima tijekom nastave prirodoslovlja?

Stavovi učenika o aktivnostima tijekom nastavnoga procesa

Analizom stavova učenika o aktivnostima provedenima tijekom nastavnoga procesa utvrđeno je sedam kodova koji se odnose na pozitivne aspekte tih aktivnosti, kao što je prikazano na Slici 8.

Slika 8

Slika 8 prikazuje teme i kodove proizašle iz odgovora učenika o pozitivnim aspektima nastavnih aktivnosti. Učenici su isticali stjecanje znanja putem zabave te su smatrali da su aktivnosti unaprijedile njihovo iskustvo učenja. Izravan navod iz intervjua s učenicima glasi:

Mislim da je to dobro, i zabavno je i poučno. Ne samo da nas sprječava da samo rješavamo zadatke i dosađujemo se, nego i olakšava učenje igrom. Prevladali smo negativne strane tehnologije. Prije nismo znali što igrati, a sada možemo imati koristi od tehnologije i koristiti je, naučili smo kako koristiti glazbu (Ayşe).

Učenica je također istaknula da su aktivnosti pridonijele učinkovitijoj uporabi tehnologije. Analizom stavova učenika o negativnim aspektima aktivnosti u nastavi prirodoslovlja tijekom nastavnoga procesa identificirana su četiri koda, kao što je prikazano na Slici 9.

Slika 9

Slika 9 prikazuje kodove proizašle iz odgovora učenika o negativnim aspektima nastavnih aktivnosti. Većina učenika nije navela negativna iskustva, jedan učenik nije iznio mišljenje, a troje je učenika identificiralo određene poteškoće. Dvoje učenika spomenulo je nesuglasice među vršnjacima, dok je jedan učenik naveo buku u učionici: „Buka koju stvaraju ljudi u učionici."(Derya). Učenik je istaknuo da je tijekom aktivnosti u učionici bila prisutna buka.

Stavovi učenika o emocijama doživljenima tijekom nastavnoga procesa

Riječi koje su učenici najčešće koristili tijekom intervjua kako bi izrazili svoje emocije u vezi s aktivnostima u nastavi prirodoslovlja bile su „znatiželja", „uzbuđenje", „odlično" i „sretan". Ovi izrazi upućuju na to da su učenici iskustvo učenja u velikoj mjeri povezivali s pozitivnim emocijama. Izravan citat iz intervjua s učenicima glasi:

„Sretan, uzbuđen, znatiželjan. Na primjer, svi su uzbuđeni, pitaju se koje će se pitanje pojaviti i hoćemo li biti prvi. Zatim bodre prijatelje govoreći: „Hajde, prijatelji, riješimo ovo pitanje". Kasnije se pitaju što će se pojaviti i hoće li biti teško. Na kraju, kada je aktivnost završena, svi su sretni i raduju se". (Aslı).

Slični rezultati dobiveni su analizom učeničkih dnevnika korištenih u nastavi prirodoslovlja.

Tablica 11

Kao što je prikazano u Tablici 11, učenici su na kraju nastavnih aktivnosti najčešće navodili osjećaj sreće. Uz to, često su spominjani i uzbuđenje te znatiželja. Ovi su nalazi u skladu s rezultatima dobivenima iz intervjua s učenicima. Izravan citat iz učeničkih dnevnika glasi: „Osjećao sam se odlično, imao sam osjećaj da sve znam." To upućuje na to da su aktivnosti učenike činile sretnima te da su se osjećali sigurnima u vlastiti proces učenja.

Analizom stavova učenika o metodama poučavanja u nastavi prirodoslovlja identificirano je sedam kodova koji se odnose na aktivnosti u kojima su najviše uživali. Ti su kodovi grupirani u dvije glavne teme: vrsta aktivnosti i mjesto provedbe aktivnosti, kao što je prikazano na Slici 10.

Slika 10

Slika 10 prikazuje vrste aktivnosti u kojima su učenici tijekom nastavnoga procesa najviše uživali. Među njima su najčešće isticane aktivnosti temeljene na QR kodovima. Na Slici 11 prikazane su aktivnosti u kojima su učenici uživali, razvrstane prema mjestu njihove provedbe.

Slika 11

Slika 11 pokazuje da su učenici najčešće uživali u aktivnostima provedenima u učionici. Izravan navod iz intervjua glasi: „Aktivnost koju smo radili u hodniku bila je još zabavnija jer je naš tim bio prvi. Bilo je zabavnije, stalno kretanje s jednog mjesta na drugo i rješavanje kodova bilo je zanimljivo." (Barış). Ovaj iskaz pokazuje da je učenik aktivnost provedenu u hodniku, kategoriziranu kao školsku aktivnost, doživio posebno zabavnom.

Utvrđeno je da samo jedan učenik nije uživao u aktivnostima. Sljedeći navod odražava njegovo stajalište:

„Trenutačno nema takve aktivnosti, ali ako to ponovno budemo radili, možda će biti. Imam stvari koje mi se ne sviđaju, ali u igrama s QR kodovima nema reda na poteze, žele biti prvi pa zaostanu. Tada se naljutim. Ne kažem da su igre loše, ali moji prijatelji igraju na način koji me nervira." (Murat)

Ovaj iskaz upućuje na to da nezadovoljstvo nije povezano s aktivnostima samima po sebi, već s interpersonalnim nesuglasicama među učenicima.

Stavovi učenika o tome jesu li tijekom aktivnosti imali poteškoća

Analizom poteškoća s kojima su se učenici susretali tijekom aktivnosti utvrđeno je da je 11 učenika imalo određene poteškoće, dok 4 učenika nisu prijavila nikakve probleme. Za uočene poteškoće identificirano je pet kodova, kao što je prikazano na Slici 12.

Slika 12

Slika 12 prikazuje kodove povezane s uzrocima poteškoća koje su učenici doživjeli tijekom nastavnoga procesa u nastavi prirodoslovlja. Najčešće prijavljeni problemi odnosili su se na same aktivnosti, dok su poteškoće povezane s internetskom vezom bile najmanje zastupljene. Sljedeći izravan navod to ilustrira:

„Zapravo nisam imao nikakvih problema, ali tablet je ponekad zastajkivao, što je predstavljalo manji problem. Nije bilo posebnih poteškoća ni zahtjevnih dijelova. Imao sam poteškoća s igrom pokrivanja. Budući da je tablet zastajkivao, nisam mogao skenirati QR kodove, pa sam tada imao problema". (Mert)

Ovaj navod pokazuje da učenik nije imao dugotrajne poteškoće, ali je tijekom pojedinih aktivnosti iskusio tehničke probleme povezane s uređajem.

Stavovi učenika o izvannastavnim aktivnostima podržanima QR kodovima

Analizom izjava učenika o izvannastavnim aktivnostima podržanima QR kodovima u nastavi prirodoslovlja identificirano je 11 kodova. Ti su kodovi svrstani u dvije glavne tematske kategorije: pozitivni aspekti i negativni aspekti, kao što je prikazano na Slici 13.

Slika 13

Slika 13 prikazuje teme i kodove koji se odnose na percepcije učenika o izvannastavnim aktivnostima podržanima QR kodovima. Učenici su ove aktivnosti najčešće opisivali kao učinkovite u ponavljanju i utvrđivanju gradiva. Također su često navodili da takve aktivnosti pridonose povećanju akademskoga postignuća. Međutim, jedan je učenik iznio negativno mišljenje zbog nemogućnosti otvaranja QR kodova te izostanka grupnoga rada.

Stavovi učenika o grupnom radu u okružju mobilnoga učenja podržanom QR kodovima

Analizom izjava učenika o grupnim aktivnostima provedenima u okružju mobilnoga učenja podržanom QR kodovima identificirano je šest kodova. Ti su kodovi svrstani u dvije glavne tematske kategorije: pozitivni aspekti i negativni aspekti, kao što je prikazano na Slici 14.

Slika14

Slika 14 prikazuje teme i kodove proizašle iz učeničkih refleksija o grupnim aktivnostima u okružju mobilnoga učenja podržanom QR kodovima u nastavi prirodoslovlja. Suradnja i povećana motivacija bili su najčešće istaknuti pozitivni aspekti grupnoga rada. Međutim, troje učenika navelo je nesuglasice unutar svojih skupina kao negativno iskustvo.

Stavovi o učinku aktivnosti na razvoj, vještine i stavove učenika

Identificirano je osam kodova povezanih s učinkom aktivnosti na razvoj, vještine i stavove učenika. Oni su prikazani na Slici 15.

Slika 15

Slika 15 sažima stavove učenika o tome kako su nastavne aktivnosti utjecale na njihove vještine i stavove. Većina učenika izvijestila je o pozitivnijim stavovima prema prirodoslovlju i okolišu, uz povećan interes i angažman. Iako su se mišljenja o tehnologiji razlikovala, općenito je zabilježen porast samopouzdanja. Što se tiče vještina, jedan učenik nije primijetio promjene u rješavanju problema ili istraživanju, dok su dva učenika navela mješovite učinke na komunikaciju. Većina je, međutim, istaknula napredak u komunikaciji, primjeni znanja u stvarnome životu i akademskome postignuću.

Integracija kvantitativnih i kvalitativnih nalaza pruža sveobuhvatno razumijevanje rezultata. Nalazi ukazuju na konvergenciju u pogledu poboljšanja akademskoga postignuća i zadržavanja znanja, dok kvalitativni podatci objašnjavaju temeljne mehanizme, poput povećanoga angažmana, uživanja i mogućnosti za ponavljanje i utvrđivanje gradiva. Nadalje, kvalitativni nalazi proširuju interpretaciju otkrivajući manje poteškoće u provedbi, čime se pruža nijansiranija i realističnija slika procesa implementacije.

Diskusija

Analiza unutargrupnih i međugrupnih usporedbi u pogledu akademskoga postignuća i zadržavanja znanja (RQ1), zajedno s kvalitativnim nalazima, pokazala je da su i tradicionalna nastava i QR–mobilno učenje doveli do povećanja SCAAT rezultata učenika, pri čemu su učinci bili izraženiji u eksperimentalnoj skupini. Ovi rezultati potvrđuju da je mobilno učenje najučinkovitije kada je integrirano u pedagoški utemeljene nastavne dizajne. Prethodna istraživanja također pokazuju da mobilno učenje poboljšava zadržavanje znanja, motivaciju i sudjelovanje u nastavi prirodoslovlja i okolišnoga odgoja i obrazovanja (Kalogiannakis i Papadakis, 2017; Uzunboylu i sur., 2009; Zacharia i sur., 2016). Interaktivne aktivnosti usmjerene na učenika potiču angažman i postignuće kontinuiranim, dostupnim i interaktivnim učenjem (Chang i sur., 2011; Demir i Akpınar, 2018; Rikala, 2015).

U skladu s prethodnim istraživanjima u području okolišnoga obrazovanja, mobilno podržane aktivnosti pokazale su se učinkovitima u poboljšanju učenikovih obrazovnih postignuća (Chang i sur., 2011). Metaanalize pokazuju da dugoročno i dobro strukturirano mobilno učenje daje snažnije rezultate (Chauhan, 2017; Yang i Xiang, 2024). Osim toga, učinkovitost takvih okružea usko je povezana s pedagoškim dizajnom, angažmanom učenika i kontekstualnom interakcijom (Rikala, 2015). Osmerotjedni dizajn ovoga istraživanja podupire navedene nalaze, sugerirajući da nastava integrirana s tehnologijom može unaprijediti učenje prirodoslovlja u osnovnoj školi. Učinkovitost mobilnoga učenja ovisi o pedagoškom dizajnu, relevantnosti sadržaja i angažmanu učenika (Daulay i sur., 2023; Tanaka i Ishizaki, 2018; Timotheou i sur., 2023). Mobilni uređaji omogućuju promatranje i prikupljanje podataka te podržavaju učenje putem vizualnih i iskustvenih procesa, a to je pristup prikladan za mlađe učenike (Furió i sur., 2015). Suprotno tome, neka istraživanja pokazala su da mobilno učenje ne dovodi do viših ishoda učenja u odnosu na tradicionalne pristupe, umjesto toga zabilježene su slične razine obrazovnoga postignuća i usvajanja znanja u različitim nastavnim medijima i uvjetima učenja (Nouri i sur., 2014; Ruchter i sur., 2010). Ovi nalazi mogu biti povezani s razlikama u nastavnom dizajnu, trajanju provedbe i kontekstualnim uvjetima.

Analiza zadržavanja znanja pokazala je da stabilni rezultati između posttesta i odgođenoga testa u eksperimentalnoj skupini odražavaju održivo učenje, dok pad u kontrolnoj skupini upućuje na kratkoročne učinke. Međutim, iako nije utvrđena statistički značajna razlika između posttesta i testa zadržavanja u eksperimentalnoj skupini, ovaj rezultat treba tumačiti s oprezom zbog niske statističke snage povezane s malom veličinom učinka. Ipak, uočeni obrazac stabilnoga postignuća u eksperimentalnoj skupini sugerira da mobilno učenje podržano QR kodovima može pridonijeti dugoročnom angažmanu učenika. Smisleno učenje stoga zahtijeva kontinuirani angažman i ponavljano digitalno utvrđivanje gradiva (Demir i Akpınar, 2018; Najmuldeen, 2017). Nastavni dizajni koji kombiniraju interaktivnost, ponavljanje i emocionalni angažman, u skladu s razinom „Redefinition" u SAMR modelu, daju snažnije rezultate. Integrirana analiza kvantitativnih i kvalitativnih nalaza pokazuje da su uočena poboljšanja u akademskom postignuću i zadržavanju znanja usko povezana s povećanim angažmanom učenika, osjećajem zadovoljstva i mogućnostima za ponavljanje koje pruža QR-mobilno okružje učenja.

U skladu s kvantitativnim nalazima o postignuću i zadržavanju znanja, povratne informacije učenika potvrdile su pozitivan utjecaj QR-mobilnoga učenja na motivaciju i stavove. Učenici su aktivnosti opisivali kao zabavne i poučne, što je u skladu s istraživanjima koja pokazuju povećani angažman putem QR-temeljene primjene (Timotheou i sur., 2023; Uzunboylu i sur., 2009). Znatiželja i osjetljivost mlađih učenika na tehnologiju povećale su njihovo sudjelovanje, dok su stariji učenici preferirali tiskane materijale (Bjørgen, 2022; Vanhöfen i sur., 2023). Stoga su dob i nastavna struktura ključni čimbenici koji oblikuju motivaciju i stavove.

Kvalitativni rezultati također su pokazali da QR-mobilno učenje potiče znatiželju i uzbuđenje, čime se jača emocionalna uključenost i intrinzična motivacija (Heinonen, 2015; Hilton, 2016). Takva okružja pružaju iskustva koja nisu dostupna u tradicionalnim nastavnim okružjima i potiču istraživanje (Chou i sur., 2012). Učenici su izvijestili da ponovno pregledavanje digitalnih sadržaja kod kuće učvršćuje njihovo razumijevanje, čime se učenje proširuje izvan učionice (Crompton i Burke, 2018). Individualizirani zadatci temeljeni na QR kodovima odražavaju razine „Modification" i „Redefinition" u SAMR modelu, potičući samoregulaciju i odgovornost.

Istraživanje je učinkovito integriralo tehnološko, pedagoško i sadržajno znanje unutar TPACK okvira (Koehler i Mishra, 2009), podržavajući samostalno učenje (Abedi i sur., 2023; Ehsanpur i Razavi, 2020). Suradnički rad u skupinama unaprijedio je komunikaciju i rješavanje problema (Bovanova, 2023; Rikala, 2015), što je u skladu s međunarodnim nalazima u prirodoslovnom obrazovanju (Lin i sur., 2019; Ryu i sur., 2015). Unatoč povremenim sukobima, većina učenika izvijestila je o povećanoj motivaciji i odgovornosti, što je u skladu sa sociokulturnom teorijom (Vygotsky, 1978).

Učenici su također izrazili veće samopouzdanje u korištenju tehnologije. Integracija QR–mobilnoga učenja u aktivnosti u učionici i izvan nje povećala je angažman i postignuće (Chauhan, 2017). Personalizirani digitalni zadatci potaknuli su autonomiju i zadovoljstvo, pokazujući da dobno prilagođeno mobilno učenje podržava smisleno sudjelovanje. Iako je zabilježen napredak u komunikaciji i povećan interes za okolišne teme, napredak u višim kognitivnim vještinama, poput rješavanja problema, ostao je ograničen, što ukazuje na potrebu za dodatnim pedagoškim potporama u ranom obrazovanju (Timotheou i sur., 2023). Povezivanje aktivnosti s lokalnim okolišnim problemima povećalo je relevantnost i motivaciju (Kalogiannakis i Papadakis, 2017).

Uočena su određena ograničenja. Tehnički problemi (pristup internetu i dostupnost uređaja) te povremene napetosti u skupinama uzrokovale su kratkotrajne prekide (Rivers, 2009). Izazovi poput troškova i održavanja ukazuju na potrebu za održivom infrastrukturom i upravljanjem (Bleck i sur., 2012; Barak i sur., 2016). Drugo ograničenje odnosi se na provedbu nastave. Iako je nastavna provedba unaprijed planirana i standardizirana između skupina u pogledu sadržaja, redoslijeda i trajanja, eksperimentalnu skupinu poučavao je istraživač, dok je kontrolnu skupinu poučavao drugi učitelj. To je moglo dovesti do mogućega učinka nastavnika. Nadalje, provedba je praćena redovitim sastancima s učiteljem kontrolne skupine i korištenjem strukturiranih nastavnih planova koji su se pratili na tjednoj razini. Međutim, nisu provedene formalne učioničke opservacije ni neovisne mjere provjere dosljednosti provedbe. Stoga su rezultati mogli biti djelomično pod utjecajem čimbenika povezanih s nastavnikom, uz učinak QR–mobilnoga učenja. Dodatno ograničenje odnosi se na mogući učinak novosti. Budući da su učenici prvi put bili izloženi mobilnom učenju podržanom QR kodovima, njihova povećana motivacija i pažnja mogli su biti posljedica novosti učenja, a ne same nastavne metode. Stoga rezultate treba tumačiti s oprezom jer mogu djelomično odražavati kratkoročni angažman povezan s uvođenjem novih tehnologija. Nadalje, statistička snaga za usporedbu zadržavanja znanja u eksperimentalnoj skupini bila je niska ($1 - \beta = ,04$). Stoga neznačajni rezultat treba tumačiti s oprezom jer može biti posljedica nedovoljne statističke snage, a ne stvarnog izostanka učinka.

Uzimajući u obzir navedeno, dobiveni rezultati ne bi se trebali tumačiti isključivo kao učinak uporabe QR kodova, već kao ukupni učinak pedagoškog dizajna primijenjenoga u QR–mobilnom okružju učenja. Općenito, istraživanje potvrđuje da dobro osmišljeno, razvojno primjereno QR–mobilno učenje može unaprijediti poučavanje prirodoslovlja u osnovnoj školi. Integracija putem SAMR i TPACK okvira donosi mjerljive dobitke u postignuću i motivaciji te potiče suradnju i održivo učenje.

Zaključak

Istraživanje je pokazalo da je QR–mobilno učenje učinkovitije od tradicionalne nastave u poboljšanju postignuća i zadržavanja znanja učenika trećih razreda. Učenici su proces opisali kao zabavan i motivirajući te kao podršku njihovim iskustvima učenja. Rezultati pokazuju da, kada se tehnologija koristi primjenom dobro osmišljenih, dobno prilagođenih i učeniku usmjerenih metoda, doprinosi poboljšanju akademskoga postignuća i povezana je s pozitivnim iskustvima učenja. Utemeljeno na SAMR i TPACK okvirima, istraživanje potvrđuje da obrazovna vrijednost tehnologije ovisi o pedagoškoj kvaliteti, a ne o njezinoj samoj prisutnosti. Aktivnosti koje potiču suradnju i kreativnost povećale su angažman učenika. Iako je istraživanje ograničeno na jednu osmotjednu nastavnu cjelinu iz prirodoslovlja u jednoj turskoj osnovnoj školi, ono ističe QR–mobilno učenje kao pristupačan i troškovno učinkovit model za fleksibilno i individualizirano poučavanje. Buduća istraživanja trebala bi ispitati njegov utjecaj na motivaciju, samoregulaciju i socijalnu interakciju u širim dobnim skupinama.

Preporuke

Ovo istraživanje ukazuje na to da inovativne nastavne prakse, poput mobilnoga učenja podržanoga QR kodovima, mogu učiniti učenje učinkovitijim, trajnijim i zanimljivijim, istodobno pružajući okvir za oblikovanje okružja usmjerenih na učenika. Stoga se preporučuje šira primjena QR–mobilnoga učenja u okolišnom obrazovanju na osnovnoškolskoj razini.

Istraživanje je ograničeno na učenike trećega razreda u jednoj turskoj osnovnoj školi te na osmotjednu nastavnu cjelinu „Živa bića". Ta ograničenja smanjuju mogućnost generalizacije nalaza na druge dobne skupine, tipove škola i sociokulturne kontekste.

S pedagoškoga aspekta, mobilno učenje podržano QR kodovima pokazuje prednosti koje nadilaze prijenos sadržaja, utječući na dizajn nastave i obrazovne politike. QR kodovi su jeftini, dostupni i jednostavni za izradu, čime podržavaju jednakost u okružjima s ograničenim digitalnim resursima. U interdisciplinarnim područjima poput okolišnoga obrazovanja, QR materijali mogu pružiti mikroučenje, prilagođeno različitim brzinama učenja i individualnim potrebama, čime se potiču fleksibilna i učeniku usmjerena okružja.

Na razini obrazovne politike, integracija QR tehnologije s otvorenim, učiteljski generiranim sadržajem može predstavljati skalabilnu i troškovno učinkovitu strategiju za smanjenje digitalne nejednakosti. Buduća istraživanja trebala bi uključivati veće uzorke, različite dobne skupine i longitudinalne dizajne kako bi se ispitali dugoročni učinci mobilnoga učenja ne samo na postignuće, već i na interakciju, samoregulaciju i afektivni angažman. Teorijski, integracija SAMR i TPACK okvira sa sociokulturnim, motivacijskim i kognitivnim perspektivama može pružiti sveobuhvatniji okvir za analizu procesa učenja potpomognutih tehnologijom.