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SUPPORTING ENVIRONMENTAL COMPETENCE DEVELOPMENT THROUGH THE GREEN IQ MOBILE APPLICATION

Abstract: The integration of digital technologies into environmental education creates opportunities to link theoretical knowledge with practical activities and environmentally responsible behavior. The aim of this study was to develop and evaluate the Green IQ mobile app as a supplementary educational tool for fostering environmental competencies among students and to determine whether its integration into traditional environmental education is associated with an increase in students' environmental competencies. The study involved a quantitative quasi-experimental pre-test/post-test analysis in a control group. Sixty first-year students participated in the study. Participants were divided into an experimental group ($n = 29$) and a control group ($n = 31$). Both groups received comparable environmental education through lectures, training sessions, and practical assignments, while the experimental group additionally used the Green IQ mobile app. The Eco Index was assessed using a 10-item instrument developed by the author on a five-point Likert scale, covering environmental awareness, attitudes toward the environment, and environmentally responsible behavior. The results of the study showed that the mean Eco Index for the entire sample increased from 2.53 ($SD = 0.769$) on the pre-test to 4.03 ($SD = 0.727$) on the post-test. Both groups demonstrated significant within-group improvement: in the experimental group, it increased from 2.55 to 4.43 (mean change = 1.88), $t(28) = 13.10$, $p < 0.001$, Cohen's $d = 2.42$, while in the control group it increased from 2.52 to 3.65 (mean change = 1.13), $t(30) = 5.35$, $p < 0.001$, Cohen's $d = 0.960$. A mixed-effects analysis of variance revealed a significant time-by-group interaction, $F(1,58) = 8.39$, $p = 0.005$, indicating greater improvement in the experimental group.

Keywords: environmental competencies; environmental education; mobile learning; mobile application; sustainable development; digital learning; higher education.

Introduction (Literary review)

The President of Kazakhstan Kassym-Jomart Tokayev has launched the “Taza Kazakhstan” initiative, which aims to foster an environmental culture amongst the people of country. This initiative is one of the key principles enshrined in the new Constitution of the Republic of Kazakhstan. It reflects a responsible and rational approach to natural resources, the development of environmental literacy, and the cultivation of a culture of environmental awareness within society [1].

Contemporary environmental education for sustainable development is increasingly utilizing digital technologies as one of the key and effective tools for building environmental knowledge and competences, as well as for encouraging environmentally responsible behavior amongst students as a means of motivation. Digital technologies enable educational content to be presented concisely, conveniently and visually. In the interaction between environmental education and digital technologies, educational approaches that can integrate elements of theoretical material into practical activities and increase students’ engagement and motivation play a vital role. The use of digital tools in the development of environmental competences contributes to an effective and accelerated process of fostering a society’s environmental culture. Mobile learning is an integral part of digital technologies and serves as one of the most effective means of training future specialists in various fields, particularly in the context of the Sustainable Development Goals [2-3].

The development of digital technologies has also contributed to the emergence of the concept of ‘green digital literacy’, which combines digital literacy with environmental responsibility. Green digital literacy is regarded as a comprehensive competence encompassing not only the technical skills required to use digital devices, but also the critical evaluation of environmental information, an understanding of the principles of sustainable development, the ethical use of technology, and the development of the social and emotional skills necessary for fostering environmentally responsible behavior. Integrating digital literacy with environmental education enables us to move beyond the mere acquisition of knowledge and towards the formation of values and behavioral patterns geared towards sustainable development [4-5].

Environmental competences are an individual’s ability to apply knowledge in the field of ecology and environmental protection in their everyday and professional activities, with a view to making environmentally sound decisions for the sustainable development of society [6].

In 2017, within the framework of the Sustainable Development Goals (SDGs), UNESCO defined environmental competence as a person’s ability to understand complex environmental issues, make informed decisions and act in ways that promote environmental sustainability at the personal, local and global levels [7].

The development of environmental competences is a complex, sequential, systematic and long-term process. In a previous study, the authors developed a model for the development of environmental competences based on a systems approach, within which environmental competence was conceptualized as a combination of cognitive, affective, and behavioral components. The findings highlighted the need to strengthen the practical focus of environmental education and to expand the use of digital educational tools [8].

Accordingly, the present study aims to empirically examine the potential of a mobile application as a tool for implementing these pedagogical principles in educational practice.

The use of augmented reality (AR) technologies in the development of environmental competencies has attracted considerable research interest. The use of mobile AR applications has been shown to significantly increase learners’ satisfaction with the educational process, contribute to the development of practical knowledge, strengthen interaction among participants in the learning process, and increase their willingness to reuse the application. Combining mobile technologies with learning in real-world environments makes the educational process more visual, practice-oriented, and motivating [9].

Another rapidly developing area is the use of gamification in mobile applications. The process of gamification can significantly increase student engagement and facilitate the effective integration of environmental education into existing curricula. At the same time, representatives from the education sector emphasize the need for methodological training to ensure the successful implementation of such digital solutions, highlighting the importance of pedagogical support when using mobile technologies [10].

It is also important to note that many existing applications focus predominantly on individual actions and provide limited opportunities for developing collective environmental engagement and interaction [11-12].

Despite the growing body of research on the use of mobile technologies in environmental education, most existing applications and educational interventions are primarily designed for school education, teacher preparation, or the development of specific environmental knowledge and habits. Considerably less attention has been paid to the development of pedagogically grounded mobile applications aimed at the comprehensive development of environmental competencies among higher education students, integrating the cognitive, behavioral, and value-motivational components of environmental competence.

Furthermore, the potential for integrating microlearning, gamification, social interaction mechanisms, and practical environmental tasks into a unified digital learning environment remains insufficiently explored. This research gap provided the rationale for the development of the Green IQ mobile application, designed to foster environmental competencies among university students through a combination of theoretical modules, practical environmental challenges, game-based elements, and social activities. Its concept encompasses not only the individual completion of environmental tasks but also opportunities for social interaction among students.

A previous study conducted by the authors, which introduced the Eco Index as an integrated measure, revealed a substantial gap between environmental knowledge and actual environmentally responsible behavior. The findings indicated that knowledge alone does not necessarily translate into behavior or practical skills without the support of additional educational interventions, such as mobile applications. Accordingly, the present study extends this line of research by experimentally examining a mobile application that integrates theoretical content with practical environmental tasks and challenges [13].

The potential of mobile learning is supported by various meta-analytic findings. A review of 253 articles published between 2013 and 2024, involving 21,323 participants from 45 countries, showed that mobile learning has a significant positive impact on students' learning outcomes. However, the authors also reported substantial heterogeneity across all included studies, indicating that the effect size varied depending on specific learning scenarios and implementation conditions—that is, this does not mean that mobile technologies are inherently effective regardless of the pedagogical context [14].

Although studies on mobile learning generally demonstrate a positive effect of using digital technologies in education—for example, a systematic review of 342 experimental studies showed that the use of relatively small sample sizes is a common characteristic of mobile learning—nearly 40% of the studies included fewer than 30 participants in each group. Consequently, the sample size is comparable to common practice in this field of research; however, it remains a limitation of the present study [15]. Crompton and Burke, based on a systematic review of mobile applications in higher education, demonstrated that there is a gap in the existing literature regarding the pedagogical aspects of mobile learning. Although mobile applications are merely a tool, their educational value depends on how they are used, and the pedagogy underlying the implementation of mobile learning initiatives was addressed in only 20% of the studies reviewed (14 studies). This finding suggests that more attention should be paid not only to the effectiveness of mobile technologies themselves but also to the pedagogical principles underlying their development and integration into the educational process. In the present study, this gap is addressed by examining

a mobile application developed specifically as a pedagogical tool for developing students' environmental competencies [16].

In a systematic review of the use of digital tools for environmental education, 38.1% of the included studies focused on student learning outcomes, another 38.1% examined positive behavioral outcomes related to sustainability awareness, while only 23.8% assessed the effectiveness of the digital tools themselves [17].

These findings suggest that, although digital technologies are increasingly being integrated into environmental education, the evidence base remains fragmented across different outcomes and types of interventions. Based on this, it can be inferred that relatively little attention has been paid to mobile apps specifically designed to support the development of environmental competencies. This study examines Green IQ as a pedagogically designed mobile app that integrates environmental knowledge, hands-on activities, environmentally focused tasks, and motivational elements.

The aim of this study is to investigate the contribution of the Green IQ mobile app to the development of environmental competencies among university students when integrated into traditional environmental education. To achieve this aim, the following objectives were established:

- 1) To develop the Green IQ mobile application;
- 2) To develop and pilot a diagnostic instrument for assessing student's environmental competencies based on indicators of environmental knowledge, behavior, and attitudes;
- 3) To determine the baseline and final levels of environmental competencies among students in the experimental and control groups using the integrated Eco Index;
- 4) To experimentally examine the potential of the Green IQ mobile application in the development of students' environmental competencies and to compare changes in environmental competencies between the experimental and control groups using statistical analysis.

The hypothesis of this study is that students who receive environmental education not only through traditional methods but also with the support of the Green IQ mobile app will demonstrate a greater improvement in environmental competencies from the pre-test to the post-test than students who receive environmental education exclusively through traditional methods. The main result was a change in the Eco Index, a composite measure reflecting environmental knowledge, attitudes toward the environment, and environmentally responsible behavior. The main hypothesis was tested using the time * group interaction in a two-way ANOVA with a mixed design.

Methods and Materials

For the purposes of this study, a structural-functional model for the creation and implementation of the "Green IQ" application was developed, based on the integration of theoretical material into practical activities. The application was developed with the aim of fostering environmental literacy amongst university students. The model consists of a sequence of stages – from defining the initial pedagogical objective through to the design, software development and subsequent testing of the application Figure 1.

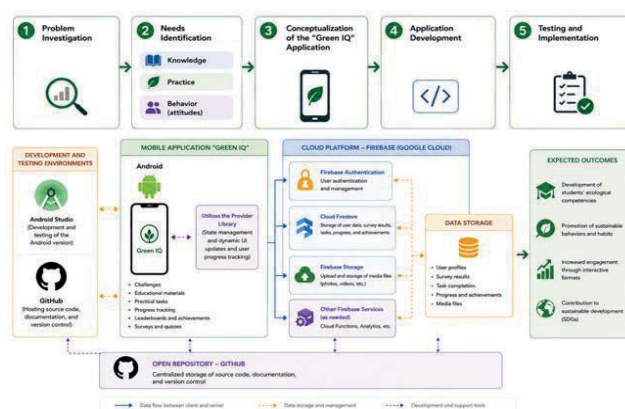


Figure 1. Model for the Development and Implementation of the “Green IQ” Mobile Application.

The application was developed as a cross-platform solution using the Dart programming language and the Flutter framework. The use of these platforms ensures that the application runs on mobile devices running the Android and iOS operating systems. The application’s server-side infrastructure was implemented using the Google Firebase cloud platform, which provides centralised data storage and data exchange between client-side and server-side components. User interface updates and the visualisation of participants’ individual progress were implemented using the Provider library, which enables efficient management of the application’s state and real-time data synchronisation. The mobile application was developed, tested and debugged in the integrated development environments Android Studio for the Android platform and Xcode for the iOS platform.

The content and pedagogical logic of the “Green IQ” app are based on the principles of competency-based, constructivist, activity-based, and person-centered approaches, and also take into account the motivational mechanisms described in self-determination theory [18]. The app’s pedagogical structure involves a gradual transition from accessible information and contextual understanding to independent activity and reflection. The approaches used align with activity-based and constructivist understandings of learning, according to which meaningful knowledge is formed through the active interpretation and application of information, rather than through its passive reception. The app also incorporates elements of authentic learning, as students are provided with concrete examples and practical, action-oriented information. Thematic materials may include links to films and other media resources, information about relevant locations and organizations, as well as specific recommendations and step-by-step instructions for responding to certain environmental situations. This pedagogical logic is particularly important for the competency-based understanding of environmental education adopted in this study. Environmental competence is not limited to the acquisition of factual knowledge but involves the integration of cognitive, value-based, and behavioral components.

Throughout the educational experiment, the Green IQ mobile app was used exclusively by students in the experimental group. The app comprised educational modules on environmental issues and the principles of sustainable development, interactive tasks, a system of environmental challenges and tools for tracking individual progress in Fig. 2.

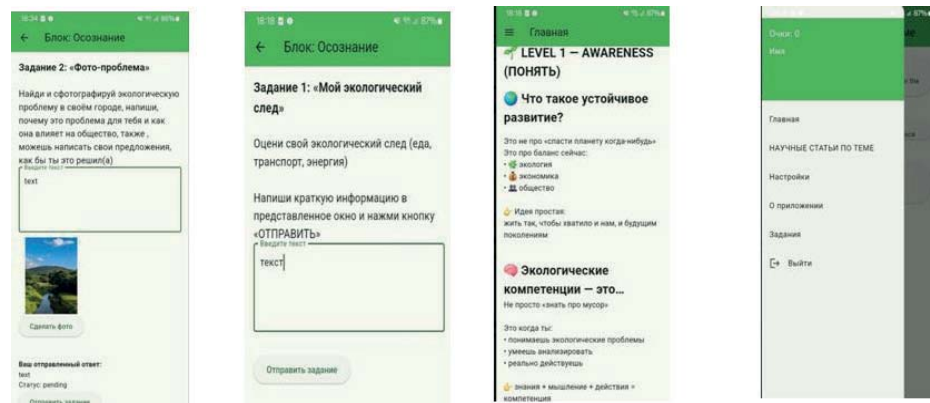


Figure. 2. User screen of the Green IQ app

Completion of practical tasks was accompanied by the awarding of points and the recording of results in the application database, allowing students to monitor their own achievements and contributing to increased motivation to develop environmentally responsible behaviour. To evaluate the effectiveness of the Green IQ mobile application in developing students' environmental competencies, a quantitative quasi-experimental study was conducted. The pre-test and post-test were administered anonymously using Google Forms. Each participant was assigned a sequential identification number from 1 to 60 to enable the tracking of changes before and after the pedagogical experiment.

The study involved 60 first-year students enrolled in the “Physical Education Teacher” program at the Kazakh National University of Sports. The participants belonged to two pre-existing academic groups within the same educational program. One academic group, consisting of 29 students, was assigned to the experimental conditions, while the other group, consisting of 31 students, served as the control group. Individual randomization was not performed, as the intervention was carried out within the framework of the existing organizational structure of the educational process. Participation in the study was voluntary, and written informed consent was obtained from all participants prior to their inclusion in the educational experiment. Participants were informed about the purpose and procedures of the study and that their participation was voluntary. Pre- and post-test questionnaires were completed anonymously, and participants were identified only by sequential identification numbers for the purpose of comparing pre- and post-intervention data. The experimental group participated in environmental education supported by the Green IQ mobile app, while the control group received traditional instruction. The use of full academic classes allowed this intervention to be implemented within a regular educational setting, minimizing disruptions to the established educational process. At the same time, since participants were not individually randomized according to treatment conditions, the possibility of selection bias cannot be completely ruled out. Accordingly, the study was designed and interpreted as a quasi-experimental study rather than a randomized controlled trial.

Prior to the intervention, participants in both groups underwent a baseline assessment. Subsequently, after the intervention was completed, the groups were assessed using the same instrument.

At the first stage, the participants ($n = 60$) completed a pre-test using a questionnaire developed by the authors. The diagnostic questionnaire was designed by the authors to include three aspects of students' environmental competencies: educational experience or a source of knowledge, attitude to environmental issues, and environmentally responsible behavior. The main instrument consisted of 10 points on the Likert scale: four points assessed environmental awareness (Q3-Q6), three points assessed attitudes towards environmental issues (Q7-Q9) and three points assessed environmentally responsible behavior (Q10-Q12). The questionnaire also included open-ended questions for contextual information.; These responses were not included in

the quantitative Eco Index. All 10 key points were evaluated using the same Likert response scale ranging from 1 to 5, where 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree.

The component scores were calculated as the arithmetic mean for the corresponding items. Thus, environmental awareness was the average of Q3-Q6, Attitude was the average of Q7-Q9, and behavior was the average of Q10-Q12. The integral Eco Index was calculated as the arithmetic mean of the three component assessments: $\text{Eco Index} = (\text{Eco awareness} + \text{The relation} + \text{Behavior}) / 3$. Therefore, the theoretical range of the Eco Index was 1-5.

The environmental awareness component included four items assessing awareness and understanding of environmental issues, as well as their previous experience in obtaining environmental information or education.

The equal weight was adopted for conceptual reasons, as the three dimensions were seen as complementary components of environmental competence, and no theoretical framework was established to give greater importance to any one dimension. Since the scores for all components were calculated using the same response rate, direct averaging was considered appropriate. The tool was developed by the authors based on the multidimensional concept of environmental competence used in the previous study. However, the instrument has not passed a comprehensive psychometric check. Cronbach's alpha was used only to evaluate internal consistency.

The pedagogical intervention lasted 10 weeks. Both groups participated in three scheduled training sessions per week, each lasting 50 minutes. Thus, the structured educational component consisted of 30 classes during the entire intervention period.

The experimental and control groups received comparable environmental education through scheduled lectures, training events, and practical educational content. The fundamental difference between the conditions was that the students of the experimental group additionally used the Green IQ mobile application as an additional learning environment.

The Green IQ app contained 10 consecutive practical tasks related to environmental issues and responsible behavior in relation to the environment. The assignments were organized sequentially: students had to complete the previous assignment before they could access the next assignment. This structure was designed to ensure a consistent transition from obtaining environmental information to applying knowledge in practice.

The app included practical and contextually relevant activities aimed at linking environmental concepts to students' daily experiences.

The students of the experimental group ($n = 29$) were also encouraged to use the app on their own in their free time in addition to their scheduled academic activities. The minimum duration of individual use of the application has not been set. The purpose of this flexible approach was to allow students to participate in applied and practical activities without imposing additional strict time requirements.

The lecture programme covered general information on environmental education worldwide and in Kazakhstan, environmental literacy, environmental culture and responsibility, with particular emphasis on the principles of sustainable development and their implementation in various contexts. Training sessions were held immediately after the relevant lecture material had been covered, to facilitate the practical application of the knowledge gained. Topics covered in the training sessions included, for example, "Environmental leadership: how to inspire others to adopt eco-friendly habits", "Environmental solutions in everyday life" and "Sustainable development starts with me".

The activities were designed to reinforce and integrate the theoretical and practical knowledge gained into the students' everyday lives outside the experimental setting. For example, the social media task "The Zero Waste Principle" was aimed at encouraging environmentally responsible behaviour amongst students through the implementation of 'zero waste' principles. A distinctive feature of the mobile app and the completion of individual tasks was the requirement to provide evidence of task completion in the form of text, photographs or video recordings. For

example, if a student had already incorporated waste sorting into their daily routine based on the theoretical and practical knowledge gained during the programme, they were required to provide evidence of this practice, such as a photograph of a dedicated waste sorting bin, relevant labelling or other appropriate indicators.

The individual time spent using the app was not directly measured. Consequently, although the duration of the overall intervention, the number of scheduled sessions, the duration of the session, and the number of application tasks were standardized, the individual impact of mobile learning could not be measured in minutes.

The control group studied comparable educational material in a traditional format through lectures, training sessions and assignments, without using the mobile app. Upon completion of the educational experiment, both groups undertook a post-test using the same research tool, which made it possible to assess changes in the level of environmental competences and compare the trends in indicators between the groups.

Statistical analysis of the data was carried out using Jamovi software [19]. Firstly, the internal consistency of the questionnaire was assessed using Cronbach's alpha. Descriptive statistics, including the mean and standard deviation, were then calculated, and the normality of the data distribution was assessed using the Shapiro-Wilk test. Subsequently, a t-test for independent samples was performed to assess the comparability of the control and experimental groups prior to the start of the intervention. To examine changes within each group, a t-test for paired samples was used. To assess the effect of the pedagogical intervention, a Repeated Measures ANOVA was conducted to examine the effects of the factors time (pre-test and post-test), group (control and experimental), and their interaction (time $\times$ group). In all analyses, the statistical significance level was set at $p < 0.05$.

Results

As a result of the developed structural-functional model for the creation of the Green IQ application, aimed at developing students' environmental competencies, the first stage involved identifying the need to explore alternative digital tools for fostering environmental competencies. Theoretical analysis and the diagnostic test conducted revealed that the presence of theoretical knowledge alone within the educational environment does not develop environmentally sustainable skills and does not ensure an automatic transition from knowledge and skills to environmentally responsible behavior or habitual practices.

At the second stage, the key components underlying the logic of the application were identified, namely environmentally awareness, behavior, attitudes toward environmental issues. Accordingly, the application was designed not merely as a repository of theoretical environmental awareness, but as a digital learning environment that facilitates the gradual transformation of awareness into skills and subsequently into behavior through specifically designed pedagogical conditions.

The content of the application was organized around interactive tasks, educational materials, practical activities, challenges, surveys, and tests. The application was developed and tested in the Android Studio environment for the Android version.

Thus, the technical architecture of the application enabled the integration of the user interface, educational content, practical tasks, data storage system, and mechanisms for monitoring individual progress. At the final stage-testing and implementation - the developed application was prepared for use in the educational process and piloted as part of the pedagogical experiment.

Following the development and pilot testing of the mobile application structure, the next stage of the study involved assessing the quality of the diagnostic instrument used to evaluate students' environmental competencies.

The reliability analysis yielded Cronbach's alpha values ranging from 0.879 to 0.881, indicating a satisfactory level of internal consistency of the questionnaire.

At the next stage of the analysis, the Eco Index was calculated for each respondent according to the following formula: (Environmental Awareness + Attitude + Behavior) / 3.

Subsequently, descriptive statistical analysis was performed to examine the distribution of the Eco Index. The results are presented in Table 1.

Table 1. Descriptive Statistics

Indicator	Pre-test Eco Index	Post-test Eco Index
N	60	60
Missing	0	0
Mean	2.53	4.03
Median	2.00	4.00
Standard deviation	0.769	0.727
Minimum	1	2.00
Maximum	5	5.00
Shapiro–Wilk W	0.816	0.880
Shapiro–Wilk p	<.001	<.001

A descriptive analysis of the Eco Index showed a significant increase in students' grades after the educational intervention. For the entire sample (N = 60), the average Eco Index increased from 2.53 (SD = 0.769) in the preliminary test to 4.03 (SD = 0.727) in the subsequent test. The average score increased from 2.00 to 4.00, while the observed range changed from 1.00–5.00 in the preliminary test to 2.00–5.00 in the subsequent test. Thus, the descriptive results indicate a positive shift in the practical measurement of environmental competence after the intervention.

The Shapiro-Wilk test revealed statistically significant deviations from the norm both for the distribution of the Eco Index of pre-testing (W = 0.816, $p < 0.001$) and after post-testing (W = 0.880, $p < 0.001$). Thus, normality was not assumed solely on the basis of the Shapiro-Wilk test; the distribution characteristics were further investigated using Q-Q graphs as part of a subsequent assessment of the assumptions underlying the logical analysis.

Before the pedagogical experiment, a t-test with independent samples was performed to find out whether the Eco Index values obtained in the experimental and control groups before the experiment differed significantly. The analysis did not reveal statistically significant differences between the groups.

Student's t-test showed $t(58) = -0.178$, $p = 0.860$, while Welch's t-test showed $t(56.8) = -0.179$, $p = 0.859$. Thus, the experimental and control groups did not demonstrate a statistically significant difference in the Eco Index at the initial stage. The results are presented in Table 2.

Table 2. Results of the Baseline Comparison of Eco Index Scores Between the Experimental and Control Groups

		Statistic	df (degrees of freedom)	p
Pre-test Eco Index	Student's t	-0.178	58.0	0.860
	Welch's t	-0.179	56.8	0.859

T-tests with paired samples were conducted separately for the experimental and control groups to determine whether the Eco Index in each group changed significantly from the pre-test to the post-test. This analysis provided information about the direction and statistical significance of the changes occurring in each state. The results are presented in Table 3.

Table 3. Descriptive Statistics of the Pre-Test and Post-Test in the Experimental Group

	N	Mean	Median	SD	SE
Post-test Eco Index	29	4.43	4.50	0.458	0.0850
Pre-test Eco Index	29	2.55	2	0.686	0.1274

A t-test was performed for paired samples to check whether the Eco Index changed significantly from the pre-test to the post-test in the students of the experimental group (n = 29).

The average Eco Index increased from 2.55 (SD = 0.686) in the pre-test to 4.43 (SD = 0.458) in the post-test, representing an average increase of 1.88. This change was statistically significant, $t(28) = 13.1$, $p < 0.001$. The corresponding Cohen coefficient was 2.42, indicating a significant in-group effect. The results are presented in Table 4.

Table 4. Paired-Samples t-Test Results for the Experimental Group

			Statistic	df (degrees of freedom)	p	Mean difference	(SE)		Effect size
Post-test Eco Index	Pre-test Eco Index	Student's t	13.1	28.0	<.001	1.88	0.144	Cohen's d	2.42

These results demonstrate a statistically significant improvement in the Eco Index among students who participated in the formation of environmental competencies using the Green IQ application. However, this result within the group does not in itself prove that the improvement was due specifically to the mobile application, since the experimental group was also involved in a broader program of environmental competence formation through other methods. Thus, the additional contribution of Green IQ was assessed using the time $\times$ group interaction in ANOVA with repeated measurements. As a comparison, the results for the control group were calculated in the same manner. The control group also received environmental education, but without the intervention involving the mobile application. The results are presented in Table 5.

Table 5. Descriptive Statistics of the Pre-Test and Post-Test in the Control Group

	N	Mean	Median	SD	SE
Post-test Eco Index	31	3.65	4.00	0.733	0.132
Pre-test Eco Index	31	2.52	2	0.851	0.153

A t-test was performed for paired samples to check whether the Eco Index changed significantly from pre-test to post-test in the control group of students ($n = 31$). The average Eco Index increased from 2.52 (SD = 0.851) in the pre-test to 3.65 (SD = 0.733) in the post-test, which corresponds to an average increase of 1.13. This change was statistically significant, $t(30) = 5.35$, $p < 0.001$. The corresponding Cohen coefficient was 0.96, indicating a significant in-group effect. The results are presented in Table 6.

Table 6. Results of the T-test for the Control Group

			statistic	df (degrees of freedom)	p	Mean difference	(SE)		Effect size
Post-test Eco Index	Pre-test Eco Index	Student's t	5.35	30.0	<.001	1.13	0.211	Cohen's d	0.960

Thus, the participants in the control group also demonstrated a statistically significant improvement in the Eco Index after completing a 10-week environmental competence development program. However, this improvement within the whole group should not be interpreted as evidence of an effect that can be attributed solely to Green IQ, since the control group did not use the app. Therefore, the comparison of the magnitude of the changes between the experimental and control groups was investigated separately using the Time $\times$ interaction ratio between the groups in ANOVA with repeated measurements. We observe an increase in the results of the control and experimental groups by 1.13 and 1.88 points, respectively.

However, it is necessary to determine whether the experimental group improved statistically more than the control group, in other words, whether the mobile application significantly increases the effectiveness of the effectiveness of the formation of environmental competencies compared with conventional training sessions, lectures, and challenges. For this

purpose, we conducted a Mixed ANOVA (Repeated Measures ANOVA). To study the changes in the Eco Index over time and determine whether the magnitude of the changes differed between the experimental and control groups, ANOVA was performed with repeated measurements according to a mixed scheme, in which time (before and after the experiment) was used as a factor within the subject, and the group (experimental and control) as a factor for comparison. that is, the interdisciplinary factor. The results of the mixed-design repeated-measures ANOVA are presented in Table 7.

Table 7. Results of the Mixed-Design Repeated-Measures ANOVA for the Eco Index

	Sum of Squares	df (degrees of freedom)	Mean Square	F	p	η^2_G	η^2
RM 1 Factor	67.80	1	67.801	134.88	<.001	0.544	0.506
RM 1 Factor * Group	4.22	1	4.217	8.39	0.005	0.069	0.031
Residual	29.16	58	0.503				

The analysis revealed a statistically significant main effect of time, $F(1.58) = 134.88$, $p < 0.001$, $n_2G = 0.544$, $n_2p = 0.506$. The data indicate that the Eco Index indicators changed positively from pre-test to post-test throughout the sample. The relatively large size of the effect indicates that the change over time accounted for a significant proportion of the variability in the results.

It is important to note that there was also a statistically significant interaction between time and the group: $F(1.58) = 8.39$, $p = 0.005$, $n_2G = 0.069$, $n_2p = 0.031$. This interaction indicates that the magnitude of the Eco Index change was significantly different between the experimental and control groups. Considering that the experimental group demonstrated a more significant increase in the Eco Index (from 2.55 to 4.43; +1.88 points) than the control group (from 2.52 to 3.65; +1.13 points), a significant interaction indicates a greater improvement in the experimental conditions compared to the control conditions.

A statistically significant main effect of the group was also revealed: $F(1.58) = 10.6$, $p = 0.002$, $n_2G = 0.082$, $n_2p = 0.038$. This indicates that when averaged over two measurement points, the experimental and control groups differed in their overall Eco Index values. However, since the main research question was whether the groups differed in their changes over time, the "Time $\times$ group" ratio is the most appropriate test to assess the additional effect of the intervention supported by Green IQ. The results are presented in Table 8.

Table 8. Effect Sizes for the Mixed-Design Repeated-Measures ANOVA

	Sum of Squares	df (degrees of freedom)	Mean Square	F	p	η^2_G	η^2
Group	5.06	1	5.055	10.6	0.002	0.082	0.038
Residual	27.72	58	0.478				

After significant interaction over time and in the group, paired comparisons were conducted to clarify the nature of the differences in four conditions (the pre-test control group, the post-test control group, as well as the pre-test experimental group and the post-test experimental group). During preliminary testing, no significant difference was found between the experimental and control groups (the average difference = -0.0356, $p = 0.998$), which confirms the close correspondence of their baseline values according to the Eco Index. On the contrary, both groups showed a significant increase in indicators from the pre-test to the post-test period: in the control group, the average difference was -1.1290 ($p < 0.001$), while in the experimental group, the average difference was -1.8793 ($p < 0.001$). After the experiment, the experimental group had a significantly higher Eco Index than the control group (average difference = -0.7859, $p < 0.001$). The results are presented in Table 9.

Table 9. Pairwise Comparisons of Eco Index Scores Between Time Points and Groups

Comparison									
RM 1 Factor	Group		RM 1 Factor	Group	Mean difference.	SE	df (degrees of freedom)	t	p
Time	C	-	Time	Э	-0.0356	0.200	58.0	-0.178	0.998
		-	Time (2)	K	-1.1290	0.180	58.0	-6.269	<.001
		-	Time (2)	Э	-1.9149	0.180	58.0	-	<.001
	E	-	Time (2)	K	-1.0934	0.182	58.0	-6.022	<.001
		-	Time (2)	Э	-1.8793	0.186	58.0	-	<.001
Time (2)	C	-	Time (2)	Э	-0.7859	0.159	58.0	-4.944	<.001

Discussion

Mobile applications aimed at developing students' environmental competencies should be considered as an additional pedagogical tool integrated into the educational process, rather than as an independent substitute for traditional education. In addition, one of the sections of the post-test administered to the experimental group included an evaluation of the "Green IQ" application, in which participants could assess its technical aspects, educational content, and motivational effect. The results of this analysis are presented in Table 10.

Table 10. Descriptive Statistics of the Application Evaluation Results

Descriptive Statistics	M	SD
The mobile application helped me better understand environmental issues.	4.50	0.826
The application increased my motivation to engage in environmentally friendly behaviors.	4.59	0.783
The application was easy to use.	4.79	0.479

The results demonstrate a positive level of assessment by the participants of the technical aspects of the application, including its intuitive and user-friendly interface, logical organization of information, and visual effects. Comments regarding the educational and motivational effects were also viewed positively; however, it should be noted that higher standard deviation values may be linked to differences in the perception of information depending on age or other physiological, social or personal characteristics, whilst factors influencing motivation are individual in nature.

These results reflect the subjective assessment of the application by the participants and should not be interpreted as direct evidence of learning achievements or behavioral changes. The variability of the participants' responses indicates individual differences in their perception of the application; however, the factors underlying these differences were not considered in this study. However, despite this positive assessment, respondents also highlighted areas for improvement, including expanding the types and formats of practical environmental tasks, increasing the variety of multimedia, animated and video content, introducing additional game-based elements, and providing more specific examples of well-known people who apply environmental competences in their everyday lives. It is worth noting that the development of artificial intelligence technologies opens new opportunities for environmental education.

The effectiveness of mobile applications is largely determined by the way educational content is organized. Users interact significantly more frequently with short learning materials and brief quizzes than with extensive texts. Microlearning makes environmental education more flexible, convenient, and aligned with the characteristics of mobile device use [20-21].

Conclusion

The conducted research demonstrated the potential of the Green IQ mobile application as an additional pedagogical tool for the development of students' environmental competencies. The application has been developed based on competence-based, constructivist, activity-oriented, and

student-centered approaches, with an emphasis on a gradual transition from environmental awareness and understanding to practical activities, reflection, and environmentally responsible behavior. The results of the quasi-experimental study showed a significant positive change in the Eco Index during the 10-week intervention period in the general sample. Both the experimental and control groups demonstrated significant improvements in both the pre-test and post-test, which indicates that structured environmental education itself contributed to the development of students' environmental competencies. At the same time, the experimental group showed a greater increase in the Eco Index than the control group (1.88 versus 1.13 points). The statistically significant time $\times$ group interaction, $F(1.58) = 8.39$, $p = 0.005$, indicates that the magnitude of the changes differed significantly between the two learning conditions.

These results confirm the assumption that the integration of Green IQ has made an additional contribution to the development of environmental competencies beyond just traditional environmental education. Positive ratings of the app by students also indicate that Green IQ has been recognized as useful for understanding environmental issues, stimulating engagement, and user-friendly. However, these assessments reflect the subjective perception of the participants, and they should be distinguished from the actual learning outcomes. The Eco Index served as the main indicator of changes in environmental competence, while the results of the post-intervention application assessment were used to characterize students' perception of the digital learning environment.

Overall, the results indicate that the educational value of Green IQ is not to replace traditional environmental education, but to complement it with a structured digital environment that connects environmental information with practical tasks, challenges, and opportunities for reflection and application. Thus, the integration of such mobile learning tools into the higher education system may represent a promising approach to strengthen the practical and behavioral aspects of environmental competence and support education for sustainable development.

This conclusion is consistent with the findings of recent studies, which highlight the potential of mobile technologies to enhance environmental awareness, motivation and student engagement in environmentally responsible activities. Similar conclusions have been presented by Fernandez and Ceacero-Moreno [22].

Taking into account the results of the application evaluation of the “Green IQ” app in terms of technical usability, educational content and motivational impact, a number of application design suggestions can be put forward for the further improvement of such apps:

1. An intuitive user interface using calm pastel colors and free from visual clutter caused by animations and other distracting effects.
2. Expanded educational content without convoluted phrasing; the material should be presented in short, clear sentences with attention-grabbing introductory words to enhance users' concentration.
3. The development of motivational mechanisms based on users' needs, not only through material incentives such as points for completed tasks, but also with an emphasis on values, for example, compelling real-life examples or demonstrations of how environmentally responsible practices can be meaningfully integrated into everyday life, as well as into personal and professional development.
4. The use of such applications as a supplementary means of achieving educational objectives alongside traditional formats, ensuring consistent learning and a clear understanding of processes through interaction, not only in a virtual environment but also in real-world settings.

At the same time, the findings open up avenues for further research. It would be worthwhile to investigate the effectiveness of mobile applications in developing environmental competences among learners of different age groups, including school pupils, students on various educational programs and training courses, as well as adults enrolled in postgraduate programs. Of particular interest is an analysis of which digital mechanisms-such as gamification, personalized tasks, environmental challenges, social interaction and feedback systems-have the greatest influence on

the development of environmentally responsible behavior among different age groups. Such studies would make it possible to identify the pedagogical conditions under which mobile technologies can most effectively complement traditional forms of environmental education and contribute to the achievement of the Sustainable Development Goals.

Limitations

The present study did not perform exploratory/confirmatory factor analysis, as well as criterion, convergent, and discriminant validity analysis. These limitations are recognized, and further psychometric validation of this tool is planned in future studies.

The results should be interpreted in the light of a number of methodological limitations. The study used two pre-existing academic groups and did not conduct individual randomization, so the possibility of bias against the sample cannot be completely excluded. In addition, the individual time spent using the app was not measured.

Behavioral outcomes were assessed using self-reported indicators that were not independently verified. In addition, although the diagnostic tool has demonstrated satisfactory internal consistency, it was developed by the author and has not yet undergone comprehensive psychometric validation, including factor analysis and criteria-related validation. These limitations limit the degree of generalization of the results obtained and emphasize the need for further research using larger and more diverse samples, more advanced experimental schemes, objective indicators of environmentally responsible behavior, and comprehensive validation of the assessment tool.

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