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The Effectiveness of Developing a Geography Study Unit in Light of Nanotechnology in Improving Systemic Thinking and Environmental Intelligence Skills among Students in Jordan

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Research Article

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Abstract

Background/purpose. This study aimed to examine the effectiveness of developing a geography unit on nanotechnology in enhancing students' skills, systemic thinking, and environmental intelligence in Jordan.

Materials/methods. A quasi-experimental approach was followed to achieve the study's objectives. To collect data, the systemic thinking test and the environmental intelligence test were developed. The tools were applied to a group of 60 ninth-grade female students from Al-Karama Secondary Mixed School, affiliated with the Northern Badia Directorate. The participants were divided into two groups: 30 students in the experimental group, who studied according to the developed unit, and 30 students in the control group, who studied according to the usual (non-developed) unit.

Results. Results of the study indicated statistically significant differences between the experimental and control groups in the systemic thinking and environmental intelligence tests, favoring the experimental group. The effect size for the developed unit was 55.6% for systemic thinking and 49% for the environmental intelligence test.

Conclusion. The study recommended introducing nanotechnology concepts into the development processes of social studies curricula.

1. Introduction

Geography is a dynamic field of study that aims to provide students with a deep understanding of the human and natural contexts in which they live. Geography education expands students' knowledge, enabling them to engage with complex situations. It enhances their ability to verify information, apply what they learn in real life, and develop an appreciation for cultural diversity (Abu Maghnam & Ahmed, 2021). A strong geography curriculum is central to social studies because it helps students develop a sense of identity, become proactive in addressing environmental and social challenges, and acquire the knowledge and skills needed to navigate the modern world (Gharaibeh & Bani Khaled, 2021). Geography education is constantly changing and must continue to review new scientific inventions and technological applications. Nanotechnology, the manipulation of matter at the nanoscale, is one such invention with incredible potential applications in almost every aspect of our lives and society, including in renewable/alternative energy sources, water purification, food preservation, health and medicine, and computing (Shahada, 2011; Thaker & Al-Masri, 2020; Ayad, 2017). These applications may directly show what is most relevant to the fundamental goals of geography school subjects, including how they engage critical world issues such as environmental sustainability, the management of natural resources, and social understanding and human development.

Due to the pace of innovation in nanotechnology, educators will need to make explicit connections between nanotechnology and the various areas of academia. Nanotechnology applications and concepts are linked to other human and natural sciences, so they have become part of students' everyday lives (Eid, 2021). Connecting nanotechnology to curricula also reinforces the connection between science and technology to students/society as a whole, as well as science as a viable solution to global challenges. The potential relevance and possibilities for engaging a rich area of knowledge that can be of evident importance and connect with chosen geography studies are substantial, yet have not been fully documented in the emerging literature or addressed in education. Many studies recognize that it is important to update the geography curriculum and related applications, but very few make attempts to engage with and link nanotechnology's possibilities. This study will address this void by determining how to develop nanotechnology-based geography curricula to make learning less rigid and more engaging. This amalgamation creates an opportunity for students to apply what they learn to everyday life and to utilize important skills such as holistic thinking, helping them see nanotechnology as part of the bigger picture. This incorporation will also assist students in understanding the benefits and risks of the technology, thus utilizing students' thinking capabilities.

2. Literature Review

Nanotechnology has garnered the attention of researchers. Mandiracks, Michailidi, and Dimitris (2020) conducted a study to design and implement an educational sequence to assess their ability to think about fundamental issues in nanoscience and nanotechnology. The researchers employed qualitative content analysis methods. The sample consisted of 45 sixth-grade students in Greece for the 2019/2020 school year to achieve the study's objective. The results showed that teaching nanotechnology is an appropriate context for elementary science instruction.

Eid (2021) aimed to examine the effectiveness of a proposed program in nanoscience and nanotechnology to develop evaluative thinking skills and awareness of nanotechnology issues. In addition to evaluating its biological and environmental applications among science teachers, a quasi-experimental approach was used, including the preparation of a list of topics in nanoscience and nanotechnology, a proposed nanoscience and nanotechnology program, and a teacher's guide for teaching the program. It was applied to 50 male and female students at Assiut University for the academic year 2020/2021. The study's results indicated that the proposed program was effective in

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developing evaluative thinking and awareness of nanotechnology issues and their biological and environmental applications among students. Another study by Abdul Latif (2021) aimed to develop creative thinking skills in chemistry among first-year secondary students using a proposed educational unit based on nanotechnology. The researcher used a quasi-experimental method, and to achieve the study's goal, the following tools were prepared: the proposed unit, a teacher's guide, student worksheets, and a measure of creative thinking skills. Their Validity and reliability were verified. The study was conducted with 30 female students at Al-Shahid Abu Zaid School in Giza Governorate during the 2020/2021 academic year. The study results showed that the designed unit effectively enhanced students' creative thinking skills.

Furthermore, the study by Al-Riyami and Al-Najar (2022) aimed to investigate the effectiveness of an enrichment educational program based on the environmental approach to include nanotechnology applications related to environmental sustainability in the subject of economic geography in terms of academic achievement and attitudes towards nanotechnology, innovation, and decision-making regarding environmental issues among eleventh-grade female students in the Sultanate of Oman. A quasi-experimental design was utilized, including an achievement test in geography, an attitude scale towards nanotechnology, an innovation scale in environmental issues, and a decision-making scale. A study sample consisting of 100 students was divided into an experimental and a control group for the academic year 2021/2022. The study's findings indicated that the educational program was effective in increasing achievement, attitudes towards nanotechnology, and innovation in addressing environmental issues.

Jad (2022) developed a proposed program in environmental nanotechnology and examined its effectiveness in enhancing students' environmental problem-solving skills and strategic thinking. The experimental approach was also used; the study tools have been prepared according to the proposed program in environmental nanotechnology, an environmental problem-solving test, and a strategic thinking test. Sample consisting of (53) male and female students from the education faculty at Assiut University for the academic year 2021/2022. The study found that the proposed program significantly affects students' environmental problem-solving and strategic thinking. Dorouka, Kalogiannakis, and Blonder (2024) used a digital game application to introduce early elementary school students to the concepts and science of nanotechnology, employing an experimental approach; a pre-knowledge assessment test was administered. A sample of 150 second-grade students, divided into experimental and control groups, in a session of 2023/2024. The study's results presented a positive effect of teaching natural sciences, such as nanotechnology, at the elementary level.

The current study is similar to previous ones in its approach to nanotechnology. However, it stands out because it developed a unit from a geography book in light of nanotechnology and measured its impact on the development of systemic thinking and environmental intelligence.

3. Statement of the Problem

The statement of the problem arose from the researcher's long experience teaching social studies, particularly geography. The researcher observed a deficiency in the use of modern technology in social studies and geography curricula. This deficiency prevents growth and leads to stagnation and boredom when teachers and students implement the curricula. An electronic survey was distributed to 51 male and female social studies teachers in the North Badia and Mafraq districts. The results revealed that 8% of teachers knew little about nanotechnology and its role in developing geography curricula. This emphasizes the need to develop social studies curricula, particularly geography curricula, in light of modern technologies, especially nanotechnology. Thus, this study examined the effectiveness of integrating nanotechnology into a geography curriculum to enhance students' systemic thinking skills and environmental intelligence in Jordan.

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4. Significance of the Study

The developed unit is expected to benefit curriculum authors by providing them with the tools to incorporate nanotechnology concepts into geography textbooks in the Hashemite Kingdom of Jordan. Geography teachers may also benefit by learning to use nanotechnology to teach geographical topics. The Training Department of the Jordanian Ministry of Education will benefit from this study by receiving training on how to use nanotechnology to teach social studies, particularly geography.

5. Questions

The current study aims to answer the following questions:

1. Are there statistically significant differences at ($0.05 \leq \alpha$) between the means of the control and experimental group in the systemic thinking test based on the non-developed and developed educational units?

2. Are there statistically significant differences at ($0.05 \leq \alpha$) between the means of the control and experimental groups in the environmental intelligence test based on the non-developed and developed educational units?

6. Limitations

The study examined the effectiveness of a geography unit on contemporary environmental issues in developing systemic thinking skills and environmental intelligence during the second semester of the 2024/2025 academic year. The study was conducted at Al-Karama Secondary Mixed School, affiliated with the Northwest Badia District, with a sample of ninth-grade female students. The generalizability of the results is limited by the study itself and the validity and reliability of its tools.

7. Methodology

7.1. Sample

The study sample of 60 female students was randomly selected from Al-Karama Mixed Secondary School in the Northwest Badia District, Directorate of Education, Mafraq Governorate. The sample was selected to include just two sections of ninth graders, and the school's suitability in terms of its educational and technological conditions was considered. The two sections were assigned before the study tools were administered using a random sample. Section (A) was the experimental group of 30 female students who were taught using a developed educational unit from the geography book in light of nanotechnology. The control group (section B) consisted of 30 students who were taught using the non-developed unit from the geography book.

7.2. Tools

To achieve the objectives of the study, the following tools were prepared:

First, a systemic thinking test. A set of procedures and steps was followed to develop the test.

1. Define the objective of the test: to measure systemic thinking skills among female students in the study sample.

2. Review educational literature and previous studies addressing systemic thinking. Examples include the studies by Al-Saadi and Abdul Wahab (2019), Khilawi, Al-Nawajha, and Masri (2022), and Al-Kayyale, Afifi, and Mohamed (2023).

3. Identify the most important systemic thinking skills, including systemic classification, analysis, understanding relationships, evaluation, and taking a holistic view (closing gaps).

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4. Refer to the study unit on contemporary environmental issues from the ninth-grade geography textbook. Analyze it and identify the most important outcomes to be achieved.

5. A total of 26 preliminary multiple-choice questions have been formulated to assess students' systemic thinking skills.

Validity of the Systemic Thinking test

Content Validity

The systemic thinking test was evaluated and checked by a professional teaching the geography subject, curriculum, and methods of teaching social studies. They commented and offered suggestions incorporating terms such as items appropriate to the aim of the study, easy to follow, and open to one interpretation, which were selected based on the aim of the study. In light of their comments, the wording of some items and some phrasing has been adjusted, and the final form of the test becomes (24) questions divided into five systemic thinking skills, as shown in Table 1.

Table 1. Number of Items for Each Skill in the Systemic Thinking Test

Skill	Items	Question No.	Question type	Marks	Mark Relative weight
Systemic Classification	1-7	7	objective	7	29%
Systemic Analysis	8-11	4	objective	4	16.7%
Systemic composition and perception of relationships	12-16	5	objective	5	21%
Systemic evaluation	17-20	4	objective	4	16.7%
The comprehensive vision of the systemic	21-24	4	objective	4	16.7%
Total	1-24	24	objective	24	100%

Test Correction Way

There are 24 questions measuring systemic thinking skills, and each has three options, with only one correct. Each student receives 1 point for a correct answer and 0 for an incorrect answer; thus, the maximum score for systemic thinking is 24, and the minimum is 0.

Construct Validity

The internal consistency validity of the test was verified by administering it to a pilot sample of 30 female students outside the study sample but within its community; also, the correlation coefficients for each skill question with the total score of the skill were calculated. The correlation coefficients ranged between 0.394 and 0.785. They were statistically significant at 0.01 = α / 0.05 = α, indicating that the items of the systemic thinking test and its dimensions demonstrated a high level of construct validity, making it suitable for final application in the study.

Reliability

The reliability coefficient was calculated by applying the test to the pilot sample using both the internal consistency method of Cronbach's alpha (according to the Kuder-Richardson KR 20 formula, because the nature of the test is either correct or incorrect), and the split-half method, as shown in Table 2:

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Table 2. Reliability Coefficient Using Cronbach's Alpha and Split-Half Methods.

Test	Cronbach's alpha	split-half method
Systemic thinking	0.82	0.74

Table 2 showed that the test has a reasonable degree of reliability, with a value above 0.70, indicating reliability (Cronbach, 1951).

Second, the Environmental Intelligence test

To build the environmental intelligence test, the following steps were followed:

1. The objectives of building the test were defined, which include measuring the level of environmental intelligence in dealing with specific environmental situations based on the experiences of ninth-grade female students in the subject of geography, specifically in the unit of contemporary environmental issues.

2. Previous educational literature and studies addressing the topic of environmental intelligence were reviewed, such as the study by Mainaki, Kastolani, and Setiawani (2018), Al-Qamash and Al-Jawalda (2016), and Akkuzu (2016), which led to the identification of the most important test items.

3. The main components of environmental intelligence were identified. These components include observing elements of living and non-living environments, identifying similarities between different environments, and using those similarities to increase productivity. Other components include observing natural patterns, noticing changes in the environment, and conducting projects to protect wildlife.

4. The items for the environmental intelligence test have been developed, and the items were formulated in their preliminary form, with a total of 23 multiple-choice questions, where the student receives one point for a correct answer and zero points for an incorrect answer.

Validity of the environmental intelligence test

Content Validity

The environmental intelligence test was evaluated and reviewed by a professor at Jordan University and a professional in the Ministry of Education, both specializing in teaching geography, curricula, and methods of teaching social studies and science. They commented and offered suggestions incorporating terms such as items appropriate to the aim of the study, easy to follow, and open to one interpretation, which were selected based on the aim of the study. The examiners approved an agreement rate of 80% to keep the question. In light of their comments, some questions have been rephrased, and the final form of the test consists of 20 questions.

Construct Validity

The internal consistency validity of the test was verified by administering it to a pilot sample of 30 female students outside the study sample but within its community; the person correlation of each skill item with the total skill score was also calculated. The correlation coefficients ranged between 0.427 and 0.787. They were statistically significant at 0.01 = α / 0.05 = α, indicating that the items achieved a high level of construct validity and are suitable for final application in the study.

Reliability

The reliability coefficient was calculated by applying the test to the pilot sample using both the internal consistency method of Cronbach's alpha (according to the Kuder-Richardson KR 20 formula, because the nature of the test is either correct or incorrect), and the split-half method, as shown in Table 3:

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Table 3. Reliability Coefficient Using Cronbach's Alpha and Split-Half Methods.

Test	Cronbach's alpha	split-half method
environmental intelligence	0.91	0.83

Table 2 showed that the test has a reasonable degree of reliability, with a value above 0.70, indicating reliability (Cronbach, 1951).

7.3. Procedure

To achieve the goals of the study, the researchers have followed two steps:

First, developed a unit for a ninth-grade geography textbook, titled "Contemporary Environmental Problems in Light of Nanotechnology." The development process followed these steps:

1. The development aims to incorporate nanotechnology applications from the ninth-grade geography textbook into the unit on contemporary environmental problems.

2. Referring to educational literature on nanotechnology (Shehada, 2011; Al-Iskandarani, 2010).

3. Reviewing previous studies related to nanotechnology, such as (Al-Riyami & Al-Najjar, 2022; Jad, 2022; and Ahmed, 2015).

4. Referring to educational literature and previous studies related to the development of study units, such as: (Al-Sabahin, 2006; Sandougqh, 2019; Abdulrahman, Al-Shawafah, and Al-Qaud, 2020).

5. Reaching concepts and applications of nanotechnology that set the standards for development.

6. Referring to the study unit represented by contemporary environmental issues in the ninth-grade geography book.

7. Developing the study unit in light of the concept of nanotechnology applications by adding information and concepts related to nanotechnology that fit with the study unit, including activities, videos through QR codes, additional information, and homework related to nanotechnology applications in topics related to the study unit, as well as creating drawings, knowledge quests (WebQuest), and proposing several solutions on how to utilize nanotechnology in the topics within the unit, and writing innovative proposals that contribute to solving the environmental problems present in the study unit.

The developed unit was evaluated and reviewed by six social studies curriculum professionals and several educational professionals involved in authoring school curricula. Their suggestions and comments were based on the study's aim. They included feedback that the content should be easy to follow, open to only one interpretation, and appropriate for measuring the study's aim.

Second, Geography teachers were trained to teach the developed unit. They were provided with an overview of nanotechnology, trained to use educational barcode technology, and shown how to obtain Arabic translations of videos. The experimental and control groups were selected using simple random sampling. Then, a systemic thinking test and an environmental intelligence test were administered to both groups before the instructional unit began. The experimental treatment was applied to the study sample: the experimental group was taught using the developed unit, while the control group was taught using the conventional unit. The selected content was taught over 12 classroom lectures. Then, a post-test for systemic thinking and environmental intelligence was administered to both groups. The researcher and teacher then corrected the two study instruments to ensure inter-rater reliability and obtain the necessary data for analysis.

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7.4. Data Analysis

SPSS version 25 was used to analyze the results of the study. Means and standard deviations, adjusted means and standard errors, Pearson's correlation coefficient, Cronbach's alpha, analysis of covariance (ANCOVA), and multivariate analysis of covariance (MANCOVA) have been calculated.

8. Results

This nanotechnology section presents the study's results on measuring the effectiveness of developing a unit in the geography subject, in light of fostering systemic thinking skills and environmental intelligence among students in Jordan.

First Question: Are there statistically significant differences at (0.05≤α) between the means of the control and experimental group in the systemic thinking test based on the non-developed and developed educational units?

Table 4. Means and SDs (Pre and Post test) for Systemic Thinking Test Scores by Educational Unit.

Test	Group	Pre-test		Post-test	
		Means	SD	Means	SD
systemic thinking	Experimental (Developed unit)	12.8	3.44	17.2	2.92
	Control (non-developed unit)	12.5	3.13	14.25	2.81

Total score 24

Table 4 shows apparent differences in the mean scores of the study participants on the thinking test between the pre-test and post-test, by educational unit. To determine whether the differences are statistically significant, a one-way ANCOVA was used to analyze post-test scores on the systemic thinking test by educational unit, controlling for the pre-test. As presented in Table 5.

Table 5. Results of One-way ANCOVA

variation Source	Sum of squares	df	mean square	F	Sig	Eta Squared η^2
Pre-test	0.332	1	0.332	0.040	0.843	0.001
Educational unit	595.305	1	595.305	71.296	0.000	0.556
Erro	475.934	57	8.350			
Total	12894.000	60				
Corrected Total	1077.933	59				

Table (5) indicated statistically significant differences at (α=0.05) in participants' scores on the systemic thinking test across the educational units, "F" = 71.296, sig = 0.00. Furthermore, the effect size of the developed unit was enormous; the eta squared (η^2) value (55.6%) of the explained variance in the systemic thinking test. To determine the Favor, the differences were attributed; the adjusted means and their standard errors were extracted for each group, as shown in Table 6.

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Table 6. Results of the Adjusted Means and Standard Errors

Teaching method	adjusted means	standard errors
Developed unit	17.21	0.53
Non-developed unit	14.25	0.53

Table 6 showed differences in Favor of the experimental group, which taught the developed unit on contemporary environmental issues, compared to the control group, which studied the undeveloped unit. According to Table 5, the developed unit has a statistically significant effect on improving the experimental group's performance in developing systemic thinking.

The means and standard deviations of the pre-test and post-test performance of the study participants were calculated for the systemic thinking test dimensions, by group, as shown in Table 7.

Table 7. Means and Standard Deviations of the Pre-Test and Post-Test Performance

Dimension	Questions No.	Group	Pre-test		Post-test	
			Means	SD	Means	SD
Systemic Classification	4	Experimental	3.83	1.53	4.67	1.29
		Control	3.82	1.70	3.93	1.13
Systemic Analysis	4	Experimental	2.20	0.96	3.07	0.64
		Control	2.21	0.85	2.53	1.14
Systemic composition and perception of relationships	4	Experimental	3.07	1.11	4.10	0.71
		Control	3.23	0.82	3.44	1.21
Systemic evaluation	4	Experimental	1.73	0.94	2.53	1.04
		Control	1.87	1.28	1.98	1.19
The comprehensive vision of the systemic	4	Experimental	1.97	1.16	2.87	0.89
		Control	2.20	0.89	2.37	0.96

Table 7 indicates apparent differences in the pre- and post-test means for the systemic thinking test domains. To verify the significance of the apparent differences, a MANCOVA was applied, as shown in Table 8.

Table 8. Results of MANCOVA Analysis

Effect	Type of multiple test	Value of multiple tests	F total	Hypothetical df	df error	Sig	Effect size η^2
Group	Hotelling's Trace	1.856	19.674	5	53	0.000	0.656

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Table 8 showed a statistically significant effect of the teaching unit variable on systemic thinking skills; the Eta-squared indicates that the group variable explains approximately 65.5% of the variance in performance across five dimensions of systemic thinking. To examine the statistical significance of post-performance differences in the dimensions of systemic thinking, after adjusting for pre-performance effects by group, a MANCOVA was conducted, as illustrated in Table 9.

Table 9. Results of MANCOVA After Adjusting for the Impact of the Pre-Test Performance According to the Group.

Source of variation	dimension	Sum of squares	df	mean square	F	Sig	Eta Squared η^2
The accompanying pre-variable	Systemic Classification	3.509	1	3.509	2.429	0.125	0.041
	Systemic Analysis	0.161	1	0.161	0.187	0.667	0.003
	Systemic composition and perception of relationships	0.161	1	0.161	0.162	0.689	0.003
	Systemic evaluation	0.488	1	0.488	0.384	0.538	0.007
	The comprehensive vision of the systemic	0.277	1	0.277	0.316	0.576	0.006
Educational unit	Systemic Classification	15.710	1	15.710	10.873	0.002	0.160
	Systemic Analysis	4.375	1	4.375	5.071	0.028	0.082
	Systemic composition and perception of relationships	55.199	1	55.199	55.485	0.000	0.493
	Systemic evaluation	17.427	1	17.427	13.712	0.000	0.194
	The comprehensive vision of the systemic	47.092	1	47.092	53.804	0.000	0.486
Erro	Systemic Classification	82.357	57	1.445			
	Systemic Analysis	49.172	57	0.863			
	Systemic composition and perception of relationships	56.706	57	0.995			
	Systemic evaluation	72.445	57	1.271			
	The comprehensive vision of the systemic						
Total	Systemic Classification	49.890	57	0.875			
	Systemic Analysis	1128.00	60				

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Source of variation	dimension	Sum of squares	df	mean square	F	Sig	Eta Squared η^2
	Systemic composition and perception of relationships	524.000	60				
	Systemic evaluation	702.000	60				
	The comprehensive vision of the systemic	330.000	60				
Corrected total	Systemic Classification	333.000	60				
	Systemic Analysis	102.933	59				
	Systemic composition and perception of relationships	53.600	59				
	Systemic evaluation	112.933	59				
	The comprehensive vision of the systemic	90.000	59				

Table 9 indicates a statistically significant difference at (α=0.05) according to the effect of the group (the developed unit, non-development unit) in all dimensions. To investigate which study groups showed significant differences, adjusted means and standard errors for the five dimensions within each group were calculated, as shown in Table 10.

Table 10. Adjusted Means and Standard Errors for the Post-Application of the Fields According to the Group (Developed Unit – Non-Developed Unit).

Dimension	Group	Adjust mean	standard errors
Systemic Classification	Experimental (developed unit	4.647	0.220
	Control (non-developed unit)	3.951	0.220
Systemic Analysis	Experimental (developed unit	3.071	0.170
	Control (non-developed unit)	2.542	0.170
Systemic composition and perception of relationships	Experimental (developed unit	4.096	0.182
	Control (non-developed unit)		
Systemic evaluation	Experimental (developed unit	3.461	0.182
	Control (non-developed unit)	2.541	0.206
The comprehensive vision of the systemic	Experimental (developed unit	1.992	0.206
	Control (non-developed unit)	2.872	0.171

Table 10 indicates statistically significant differences in the dimensions of the systemic thinking assessment in Favor of the experimental group. According to the MANCOVA results in Table 9, the

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developed unit had a statistically significant effect on improving the experimental group's performance in the dimension of systemic thinking. The most improvement was systemic composition, understanding of relationships, and effect size (49.3%). The second dimension was the comprehensive view of the systemic effect size (48.6%). Finally, the effect sizes across the five dimensions ranged from 8.2% to 49.3%.

Second question: Are there statistically significant differences at (0.05≤α) between the means of the control and experimental groups in the environmental intelligence test based on the non-developed and developed educational units?

To answer this question, the means and standard deviations of the ninth-grade female students on the environmental intelligence test were calculated for both the pre-test and post-test measurements, by group (the experimental group that studied according to the developed unit and the control group that studied according to the non-developed unit).

Table 11. Means and SDs (Pre and Post test) for Environmental Intelligence Test Scores by Educational Unit.

Test	Group	Pre-test		Post-test	
		Means	SD	Means	SD
environmental intelligence	Experimental (Developed unit)	12.4	2.64	17.37	2.01
	Control (non-developed unit)	12.2	2.50	13.41	3.68

Total score 20

Table 11 showed apparent differences in the means of the study participants on the environmental intelligence test between the pre-test and post-test, according to educational unit. To examine whether the differences are statistically significant, a one-way ANCOVA was used to analyze post-test scores on the environmental intelligence test by educational unit, controlling for the pre-test. As presented in Table 12.

Table 12. Results of One-way ANCOVA

variation Source	Sum of squares	df	mean square	F	Sig	Eta Squared η^2
Pre-test	0.861	1	0.861	0.096	0.758	0.002
Educational unit	486.657	1	486.657	54.065	0.000	0.49
Erro	513.072	57	9.001			
Total	13622.000	60				
Corrected Total	1007.000	59				

Table 12 presented statistically significant differences at (α=0.05) in participants' scores at the environmental intelligence test according to the educational unit "F" =54.065, sig = 0.00. Furthermore, the effect size of the developed unit was large (0.49); the eta squared (η^2) value (49%) of the explained variance in the environmental intelligence test. To know the Favor, the differences are Favor? The adjusted means and their standard errors were extracted for each group, as shown in Table 13.

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Table 13. Results of the Adjusted Means and Standard Errors

Group	adjusted means	standard errors
Experimental (Developed unit)	17.386	0.551
Control (non-developed unit)	13.431	0.551

Table 13 indicated that the differences favored the experimental group, which was exposed to educational experiences based on nanotechnology, compared to the control group (non-developed unit), which was subjected to traditional educational experiences in a unit on contemporary environmental issues. According to Table 12 of the accompanying one-way ANOVA, the developed unit has a statistically significant effect on improving the experimental group's performance in enhancing environmental intelligence skills.

9. Discussion

The current study was designed to explore whether developing a geography study unit on nanotechnology would improve students' systemic thinking and environmental intelligence skills in Jordan. The study's findings revealed statistically significant differences in favor of the experimental group on the systemic thinking and environmental intelligence tests. The effect size of the developed unit explained 55.6% of the variance in systemic thinking and 49% of the variance in environmental intelligence. This result can be attributed to the unit's focus on nanotechnology applications in students' environments. This deepened their understanding of the structures that make up their environments and helped them perceive relationships between components. Nanotechnology provides multiple solutions to environmental problems, enabling students to identify gaps and weaknesses in ecosystems and connect them with innovative solutions offered by this technology. This aligns with Ausubel's theory of meaningful learning. These results can also be attributed to nanotechnology's ability to develop students' cognitive skills and to enhance the principle of self-learning, helping them keep up with the latest scientific developments, thereby reinforcing the idea of lifelong learning.

Additionally, nanotechnology has facilitated the integration of geography and science, enhancing students' understanding of environmental issues. Geography alone cannot provide a complete picture of environmental issues, so linking it to other sciences aligns with the STEM approach of connecting different sciences. The unit was developed based on a set of videos and questions that stimulate students' thinking. Many of the videos included practical experiments demonstrating the role of nanotechnology in addressing environmental problems. This practical application of knowledge enhanced students' systemic synthesis skills and comprehensive systemic vision. The result can be attributed to the fact that the developed unit provided environmental education focused on recycling and offered new ways to address pollution. It emphasized sustainable resource use and reliance on alternative energy sources. It usually led to improved environmental behavior, as it considered environmentally friendly practices, including rationalizing consumption and using technology to develop new solutions to environmental problems. The unit also engaged in systemic thinking, which could benefit environmental intelligence, as systemic thinking is about ecosystemic problems, awareness of the environmental problems students may wish to address, and the creation of environmental intelligence. The current unit would also follow Gardner's multiple intelligences theory, which holds that intelligence can be developed through experiences provided to students.

These findings corroborate earlier studies that recognized the potential usefulness of a nanotechnology-based curriculum to promote higher-order thinking and problem-solving. For example, Mandiracks, Michailidi, and Dimitris (2019) found that learning that included nanotechnology could promote critical thinking of their pre-service teachers in the B.A. of Education

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in their first semester. Eid (2021) also found that nanoscience educational programs fostered evaluative thinking and knowledge of environmental constructs and their applications. Abdul Latif (2021) found that secondary school students who completed a nanotechnology-based unit achieved higher levels of creative thinking. Support for the present study comes from significant improvements in systemic thinking and composing among Jordanian students. Moreover, there is congruence with the conclusions derived from other studies. For instance, Al-Riyami and Al-Najar (2022) demonstrated that addressing nanotechnology from an environmental perspective fosters achievement and positive attitudes toward sustainable environmental issues. This is evident in the growth of environmental intelligence observed in phase two of this research. Regarding the congruence of improvements in authoritative authors' research outcomes, Jad (2022) found that environmental nanotechnology programs can enhance environmental problem-solving and strategic thinking. The work of Dorouka, Kalogiannakis, and Blonder (2024) showed that young students can learn nanotechnology through new approaches. The results of this study enhance the body of evidence by showing that incorporating nanotechnology into geography education can develop systems thinking and environmental intelligence in students while introducing new scientific contexts to the discipline.

10. Suggestion

- Introducing nanotechnology concepts during the development of geography textbooks.
- Holding training courses by the Ministry of Education to train teachers on incorporating nanotechnology concepts into social studies curricula.
- Conducting a study that connects nanotechnology with other types of intelligence, such as emotional intelligence, and other types of thinking, such as critical and creative thinking.

Declarations

Author Contributions. Alkaldi, PhD candidate, designed the study, collected and analyzed the data, and drafted the initial manuscript. Also, contributed to the interpretation of the findings and the refinement of the final version of the article. Dr. Obeidat, the research supervisor, guided throughout all stages of the study, also contributed to developing the research design, reviewing data analysis procedures, offering critical revisions to the manuscript, and ensuring the academic rigor and quality of the final article.

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