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Exploring the awareness and challenges faced by basic stage teachers in integrating nanotechnology into education in Jordan

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Abstract

This study aimed to explore the levels of awareness of nanotechnology among primary school teachers in Jordan and to identify the challenges hindering its integration into educational practices. To achieve this aim, the researcher adopted a descriptive research design and developed a carefully structured questionnaire based on a review of previous studies, which was validated by experts and distributed electronically to the participants. Data were collected from a sample of 100 teachers in Amman. The analysis revealed that teachers possess a relatively high level of awareness and demonstrate strong positive attitudes toward adopting nanotechnology in classroom teaching. This advanced level of awareness can be attributed to the nature of the "digital age," in which rapid technological developments and the abundant flow of information through digital platforms enhance teachers' knowledge of emerging sciences, making them more receptive to technological innovations such as nanotechnology. Despite this theoretical awareness, the study identified a practical implementation gap due to significant challenges, including logistical constraints, limited access to advanced resources and teaching tools, and the lack of specialized training programs that translate theoretical knowledge into tangible classroom practice. Accordingly, the study recommends the development of a national framework incorporating hands-on workshops and the provision of necessary resources. Establishing the infrastructure for practical application could serve as a cornerstone to ensure that primary education aligns with the demands of the Fourth Industrial Revolution, effectively transforming digital awareness into applied, practical learning experiences.

Keywords: Basic education, Educational integration, E-Learning Jordanian teachers, Nanotechnology in education, Teacher awareness, Teaching challenges.

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Contents

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Contribution of this paper to the literature
This study contributes to the existing literature by examining teachers' awareness of nanotechnology and related implementation challenges, distinguishing it from previous research. The paper's primary contribution is offering a framework for curriculum development and teacher training, bridging the gap between scientific knowledge and practical classroom application, while documenting teachers' nanotechnology awareness.

1. Introduction

Nanotechnology has emerged as a leading scientific and technical domain, significantly influencing multiple areas, particularly education. This technology, distinguished by its exceptional precision in nanoscale material analysis one billionth of a meter provides transformative potential to improve instructional tools and processes, making them more interactive and engaging (Schmidt, 2020). Thus, investigating the awareness levels of primary stage educators and the obstacles they face in incorporating nanotechnology has emerged as a vital research area, driven by the rapid progress of nanoscience and its growing societal implications (Villagran-Villegas, Patiño-Ortiz, Patiño Ortiz, & Siordia-Vásquez, 2024).

In the last ten years, nanotechnology has evolved from a specialized scientific field into a multidisciplinary area with applications in medical, electronics, and energy, thus requiring its integration into early education (Gamishidze, 2025; Su, Zhang, & Liu, 2023). This integration corresponds with international educational changes that emphasize STEM skills and digital literacy, crucial foundations for equipping students for future technological environments (Al Husseiny & Saab, 2024). Empirical research indicates that early exposure to nanoscale concepts markedly enhances student engagement and cultivates critical thinking abilities, highlighting the pedagogical importance of this educational transition (Kant, Dhiman, Wang, & Pugalee, 2025; Su et al., 2023).

Recent studies underscore a significant knowledge deficit among elementary stage teachers in Jordan about nanotechnology, as well as considerable obstacles in their efforts to integrate this technology into the educational process (Spyrtou, Manou, & Peikos, 2021). This gap is a significant educational challenge, as the effectiveness of contemporary education relies on teachers' capacity to creatively utilize technology to improve practical learning and foster students' creative and analytical thinking abilities. Reconciling this disparity is essential for harmonizing the conventional curriculum with modern scientific progress.

The integration of Nanoscience and Nanotechnology (NST) into basic education is essential for improving students' comprehension of intricate scientific concepts through practical research (Senocak, Ozdemir, Yilmaz, Tayhan, & McNally, 2021). In current science education, nanotechnology functions as an interdisciplinary domain that enhances scientific literacy and innovation preparedness by linking theoretical knowledge with practical applications (Al Husseiny & Saab, 2024; Gamishidze, 2025; Su et al., 2023). Recent research indicates that early exposure to nanoscale concepts enhances student engagement and offers substantial benefits for future career trajectories and the cultivation of "Nano-literacy," crucial for adjusting to forthcoming technology advancements (Spyrtou et al., 2021). Moreover, instruments like virtual laboratories and multimedia-driven, problem-focused learning techniques augment students' practical application of scientific theories, ensuring educational curricula remain congruent with rapid technological progress (Hussein, 2020; Kumar & Sembiante, 2025).

Educators play a pivotal role in the continuous evolution of education, skillfully reformulating the teaching process into an engaging and inspiring experience. The early stages of education are essential for shaping students' identities and cognitive skills, thereby creating a strong link between the quality of learning and the teachers' expertise, as well as their adeptness in utilizing innovative teaching methods (Mandrikas, Michailidi, & Stavrou, 2020; Muhammad, 2021). Nonetheless, insufficient teacher readiness and limited professional development sometimes hinder effective integration, leading to superficial or fragmented coverage of nanotechnology topics (Milla, Zulkipli, Sahar, Reliubun, & Amri, 2024; Useinov et al., 2024). To succeed in modern educational settings, educators require specialized knowledge and motivational tools to properly connect academic concepts with actual classroom application (Prasetyo & Rosita, 2025).

Despite the strategic importance of NST, various methodological and pedagogical obstacles hinder its implementation. Globally, there is a significant lack of educational models designed to correspond with the cognitive abilities of young learners, leading to divergent views on the prioritization of multimedia-supported frameworks versus systemic approaches that integrate socio-political contexts (Kumar & Sembiante, 2025; Møller, Petersen, Holler, & Godtliebsen, 2024; Villagran-Villegas et al., 2024). In the realm of Jordanian education, these challenges are exacerbated by inadequate teacher awareness, insufficient educational resources, and the absence of cohesive curricula that connect the theoretical aspects of nanotechnology to everyday experiences (Ipek, Atik, Tan, & Erkoc, 2020; Otar, Al-Momani, & Al-Saedi, 2022). Moreover, the inability to effectively tackle these structural and pedagogical obstacles threatens to sustain educational inequities and compromise the preparation of future professionals in STEM fields (Denga, 2024).

Thus, the current condition of nanotechnology education demonstrates a significant disparity between the recognized pedagogical significance of the field and the actual readiness of the educational system for its execution. Although researchers strive to develop appropriate content frameworks for primary education (Spyrtou et al., 2021), the ongoing existence of knowledge deficiencies and systemic obstacles demands a comprehensive examination of teacher experiences and institutional limitations (Becker, Kreienhop, Otte, & Beeken, 2024; Kant et al., 2025).

The accumulation of these challenges, comprising cognitive deficits and resource accessibility, reveals a significant and deep-rooted systemic issue concerning the educational sector's readiness to implement sophisticated technology scientific integration.

Considering these considerations, it is essential to assess the true level of awareness among educators and the obstacles they encounter. The ongoing absence of a clear integration strategy may impede the development of a generation prepared for innovation and adept at adjusting to scientific progress. Thus, this establishes the primary emphasis of the current investigation, which pertains to the subsequent research inquiry.

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1.1. Statement of the Problem

Nanotechnology markedly improves the educational process by creating novel tools and methodologies that augment students' scientific comprehension, foster creativity, and promote critical thinking, representing a notable technical advancement (Mandrikas et al., 2020). The incorporation of nanotechnology in education encounters obstacles stemming from insufficient understanding among female educators, financial limitations, and the absence of specialized training programs. The restricted curricula and the challenge of simplifying scientific concepts for elementary students impede their utilization. This requires additional work and creativity in pedagogical approaches (Ipek et al., 2020). Al-Qahtani (2022) advocates for the incorporation of nanotechnology principles into educational curricula to enhance awareness among educators and learners. The research by Spyrtou et al. (2021) emphasized the necessity of implementing training programs for educators to familiarize them with the application of nanotechnology to enhance educational outcomes. Despite the established nature of modern nanotechnology, the current cohort of elementary educators generally possesses minimal exposure to nanotechnology and nanoscience (NSNT), with scarce opportunity to grasp the fundamental principles of this technology. In her role as a primary educator, the researcher observed that female teachers have difficulties in implementing current technologies, particularly nanotechnology. She identified that the absence of specialized training constitutes a substantial barrier to attaining the desired benefits, as many female educators depend on conventional teaching methods owing to the lack of technical and advisory support in this domain. This study investigates the awareness level of female basic stage instructors regarding the application of nanotechnology and the obstacles they encounter. It aims to address the following questions:

- What is the level of awareness among basic stage educators regarding the implementation of nanotechnology in private schools in Jordan?
- What problems do primary school teachers have when implementing nanotechnology in private schools in Jordan?

1.2. Significance of the Study

The study seeks to assess the awareness of basic stage instructors in Jordan concerning the application of nanotechnology in private schools, along with the problems encountered in its implementation within these institutions.

This study investigates the significance of nanotechnology in education, emphasizing basic stage teachers' awareness of its relevance. It establishes a foundational knowledge base for educational institutions and researchers engaged in curriculum development and educational technologies. The findings can inform the creation of training programs aimed at enhancing female teachers' understanding of nanotechnology and its educational applications. Additionally, the study supports decision-making regarding the incorporation of nanotechnology into curricula and enhances the learning environment by offering practical recommendations for resources and educational tools related to nanotechnology implementation.

1.3. Terminology of the Study

The study's terms were articulated in a procedural and terminological format as follows.

1.3.1. Level of Awareness

Al-Qahtani (2022) defines the degree of awareness as individuals' understanding of a particular concept and its ramifications. This study serves as a foundational assessment of teachers' awareness of nanotechnology concepts and their comprehension of educational applications, evaluated through a researcher-developed questionnaire.

1.3.2. Utilizing Nanotechnology

Qabati (2022) defines it as the implementation of nanotechnology principles to develop teaching strategies that improve the educational experience. This study describes it as the incorporation of nanotechnology elements, such as interactive experiments or smart materials, into curriculum instruction.

1.3.3. Obstacles in the Utilization of Nanotechnology

Ipek et al. (2020) identify barriers that impede the practical application of nanotechnologies in education, encompassing financial, cognitive, technical, and administrative challenges. This study examines the difficulties faced by primary educators in employing nanotechnology, including resource limitations and insufficient training, assessed via a focused questionnaire to evaluate their effects on education.

2. Review of Literature

Nanotechnology is a modern field that examines and alters materials at the nanoscale. A nanometre is one billionth of a meter. The development of nanotechnology stems from understanding atomic and molecular structures to produce materials and devices with distinctive properties (Gamishidze, 2025). This field enables manipulation of matter at the atomic level, offering vast potential for scientific and industrial progress. It incorporates concepts from physics, chemistry, engineering, and biology (Ge, Wang, & Liu, 2023).

The interdisciplinary character and significant applications of nanoscience and nanotechnology (NST) have established it as a leading emergent technology of the 21st century. This acknowledgment arises from its capacity to transform diverse sectors, including medicine, electronics, energy, and materials science, through innovations at the atomic and molecular scale. Therefore, NST has emerged as a central focus for global research, investment, and educational initiatives, underscoring its transformative influence on science, industry, and society (Mandrikas et al., 2020). Nanotechnology in education encompasses the application of nanoscience innovations to enhance educational quality and processes. As a rapidly evolving field with immense potential, its incorporation into education is imperative. Effective pedagogical strategies, innovative resources, and international collaboration are vital, while

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familiarizing students with the nanoworld is essential for preparing future professionals and inspiring youth (Gamishidze, 2025).

Nanotechnology is regarded as the impending "industrial revolution" of modern society. To promote effective research, development, and public discourse in this field, educational research is essential to guide standards, curriculum development, and workforce preparedness. Additionally, there is a growing need to enhance awareness among citizens and students about the risks, benefits, and socio-ethical ramifications linked to nanotechnology (Jones et al., 2013).

The incorporation of innovative education into foundational education has gained significant global traction, as educators and policymakers acknowledge its potential to enhance learning outcomes. This methodology seeks to refine educational practices through the utilization of advanced technologies, such as digital platforms, interactive tools, and adaptive learning systems. By integrating these technologies, educational institutions can deliver personalized and engaging learning experiences, fostering critical thinking and problem-solving skills, thereby better preparing students for contemporary digital challenges. Moreover, innovative education enhances communication among teachers, students, and parents, promoting a more interconnected and supportive environment (Firdausi et al., 2024). Nanotechnology enables the presentation of scientific knowledge in a novel manner by elucidating scientific phenomena and the physical and chemical properties of nanoscale materials. This approach emphasizes the incorporation of nanotechnologies and tools in education to improve students' comprehension of intricate scientific concepts via practical experimentation and interactive simulations (Spyrtou et al., 2021).

Recent studies underscore the pedagogical importance of emerging technologies in science education. Educational robots enhance learning by increasing engagement and improving conceptual comprehension (Al-Nawaiseh, Tabieh, Maqableh, Altawalbeh, & Ahmad, 2024). These technologies stimulate innovative thinking and solutions to scientific problems (Mandrikas et al., 2020). Moreover, nanotechnology clarifies complex concepts by offering interactive learning experiences (Darmawansah, Hwang, Chen, & Liang, 2023). Interactive nano-based environments foster creativity and maintain student interest (Lamptey, Owusu, & Antwi, 2021). Additionally, virtual laboratories facilitate safe experimentation and deepen understanding of nanoscale phenomena (Spyrtou et al., 2021).

2.1. Prior Research

The perceptions and understanding of educators concerning nanotechnology and its integration into the educational framework can significantly impact its implementation, as nanotechnology is acknowledged as a principal emerging interdisciplinary field of the twenty-first century. Therefore, numerous studies have been conducted to explore educators' awareness and attitudes towards nanotechnology, and this section reviews the most pertinent prior research that assessed educators' knowledge of nanotechnology within the educational context.

Al-Qahtani (2022) sought to assess the level of awareness among mathematics educators regarding nanotechnology concepts in general education stages and to evaluate the influence of variables such as experience and academic qualifications on this awareness. The study utilized a descriptive analytical methodology and a questionnaire to gauge participants' understanding of nanotechnology concepts and applications. The research population consisted of mathematics teachers in middle schools in Asir City, with a randomly selected sample representing the variables of experience and qualifications. The findings indicated a disparity in awareness levels among teachers, revealing a deficiency in knowledge concerning nanoscale applications and devices, such as anoscopes. Furthermore, no statistically significant differences were observed in teachers' responses related to experience or academic qualifications.

The research conducted by Ipek et al. (2020) sought to assess the levels of awareness, exposure, and knowledge among science educators (physics, chemistry, and biology). An investigation involving 624 secondary school teachers in Turkey revealed variances in their awareness, exposure, and knowledge regarding nanoscience and nanotechnology. While no significant disparities were noted in subject specialization or educational attainment, differences were identified based on gender, duration of teaching, grade level, type of school, and frequency of documentary film viewing.

The research conducted by Spyrtou et al. (2021) seeks to investigate the extent to which primary school teachers are trained in nanoscience within educational settings. Fourteen primary school teachers and ten students were interviewed following their participation in a course on nanoscience and nanotechnology. The findings indicate that many participants acknowledge the educational significance of nanoscience and nanotechnology. The primary arguments pertained to professional opportunities, the relevance of content to everyday life, and the necessity of acquiring knowledge in nanoscience.

Muhammad (2021) sought to assess the efficacy of a proposed program in nanoscience and technology (NST) aimed at enhancing evaluative thinking skills and awareness of biological and environmental nanotechnology issues among science teacher students. The study involved the preparation of a compendium of nanotechnology topics, the proposed program, a teacher's guide, and student working papers, alongside the evaluation of evaluative thinking skills and awareness of nanotechnology issues. The sample comprised 50 students from the Department of Biological, Geological, and Environmental Sciences at the Faculty of Education, Assiut University. The results, following the experimental application and statistical data analysis, indicated the program's effectiveness in improving evaluative thinking skills and increasing awareness of nanotechnology and its applications among science teacher students.

In a research investigation conducted by Enil and Köseoğlu (2016), which sought to examine the degree of awareness, interest, and attitudes of students engaged in science education towards the field of nanotechnology, as well as to ascertain their comprehension of global advancements in nanotechnology and the perceived significance of this domain, and to elevate awareness regarding necessary developments within educational frameworks. To fulfil the aims of the research, the investigators employed a questionnaire crafted in accordance with a comprehensive review of the existing scientific literature pertaining to nanotechnology. The demographic under study comprised 154 students enrolled in pedagogical training programs within faculties of education. The findings indicated that there were no statistically significant discrepancies in the level of nanotechnology awareness among students across various specializations, a phenomenon attributed to their limited foundational knowledge and their dependence on

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preliminary information primarily acquired from television broadcasts rather than scholarly educational resources. The research ultimately posited that the integration of specialized courses on nanotechnology into the curricula of science teacher education programs at higher education institutions is essential to augment their competencies and to adequately prepare prospective educators to disseminate contemporary scientific knowledge to forthcoming generations.

The current study aimed to assess the awareness level of basic stage teachers regarding nanotechnology employment and the challenges they face. Therefore, the study's goal differs from previous research, focusing specifically on teachers' understanding and obstacles related to nanotechnology in education. The study of Al-Qahtani (2022) aimed to measure the level of awareness of mathematics teachers in the stages of general education of the concepts of nanotechnology. The study of Spyrtou et al. (2021) aimed to examine whether each of the primary school teachers trained in nanoscience in school contexts. The study of Muhammad (2021) aimed to measure the effectiveness of a proposed program in nanoscience and technology (NST) to develop evaluative thinking skills and awareness of biological and environmental nanotechnology issues and applications among science teachers' students. The study of Ipek et al. (2020) aimed to determine the levels of awareness, exposure and knowledge of science teachers (physics, chemistry and biology) on nanoscience and nanotechnology.

The present study employed a descriptive methodology, aligning it with most prior research, while diverging from the qualitative approach utilized by Spyrtou et al. (2021) and the semi-experimental method adopted by Muhammad (2021). This study is notable for being the inaugural investigation into "the level of awareness among basic stage teachers regarding the application of nanotechnology and the challenges they encounter" within the Jordanian context, as perceived by the researcher.

Despite the growing interest in integrating Nanoscience and Nanotechnology (NST) into education, a significant gap remains in understanding the awareness and practical challenges faced by primary stage teachers in implementing these technologies, particularly within the Jordanian context. Previous studies have addressed related but distinct aspects of NST awareness and application. For instance, Al-Qahtani (2022) focused on measuring the awareness level of mathematics teachers regarding nanotechnology concepts and examined the influence of experience and academic qualifications. The study revealed generally low awareness of nanoscale applications and devices, with no significant differences based on teacher characteristics. Spyrtou et al. (2021) explored the perceptions of NST-trained primary school teachers and students regarding the inclusion of NST in school curricula, highlighting participants' recognition of its educational significance, career relevance, and importance for everyday life. Muhammad (2021) evaluated the effectiveness of a proposed NST program in developing evaluative thinking skills and awareness of biological and environmental nanotechnology issues among science teacher students, showing positive program outcomes. Similarly, Ipek et al. (2020) investigated awareness, exposure, and knowledge of secondary school science teachers in Turkey, finding variability influenced by factors such as gender, school type, and teaching experience, but not by subject specialization or educational level.

Although these studies offer valuable insights into NST awareness across various educational contexts, they do not specifically address the awareness and challenges faced by primary stage teachers in Jordan concerning the implementation of nanotechnology in classroom practices. Furthermore, the methodological variations ranging from descriptive surveys (Al-Qahtani, 2022) to qualitative interviews (Spyrtou et al., 2021) and semi-experimental designs (Muhammad, 2021) underscore the necessity for a targeted, context-specific investigation. Consequently, the current study is unique in its objective: it aims to evaluate the level of awareness among Jordanian primary stage teachers.

3. Methodology

3.1. Research Methodology

A descriptive methodology was used to assess primary-stage educators' awareness of nanotechnology in education and to identify obstacles they face in its implementation. The study focused on all primary school teachers working in private institutions in Amman during the 2024-2025 academic year, totaling approximately 3,544 teachers. The research also addressed specific challenges encountered by these educators, providing insights into their experiences with nanotechnology integration in the educational context.

The sample was obtained through a simple random sampling method. A total of 100 primary stage teachers from Al-Rowad Private Schools in Amman participated in the study. The research instrument, a questionnaire, was disseminated electronically to participants following the verification of its validity and reliability. Table 1 illustrates the distribution of the study sample based on educational qualifications and years of experience.

Table 1. Distribution of the study sample according to its variables.

Variable	Categories	Frequency	Percentage
Educational Qualification	Bachelor's Degree	46	48.9%
	Postgraduate	54	51.1%
Experience	Less than 10 years	46	42.6%
	10 years or more	54	57.4%
Total		100	100.0%

3.2. Study Instrument

The objective is to assess the level of awareness among primary stage educators regarding the application of nanotechnology and the challenges encountered. A questionnaire was developed, encompassing two primary dimensions: the awareness of female educators concerning nanotechnology and the challenges related to its application. Responses will be categorized using a five-point Likert scale (strongly agree: 5, agree: 4, neutral: 3, disagree: 2, strongly disagree: 1).

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3.3. Questionnaire Validity

The validity of the questionnaire tool was tested by professionals in education and technology, who assessed its relevance, clarity, and precision in measuring the intended variables. The tool was improved and finished based on their observations.

3.4. Questionnaire Stability

The reliability of the questionnaire was evaluated using the Test-Retest method, administered to a survey sample distinct from the primary sample and re-administered after two weeks, resulting in a Pearson's correlation coefficient of 89%.

3.5. Employed Statistical Methods

The data analysis program (SPSS) was utilized, employing the following statistical methods: arithmetic means and standard deviations, Pearson correlation coefficient for assessing tool reliability, and analysis of variance to investigate the differences among the study variables.

4. Presentation and Analysis of Results

4.1. Results Pertaining to the Initial Inquiry

What is the level of awareness among basic stage teachers regarding the application of nanotechnology in private schools in Jordan?

4.1.1. Initial Domain: Creation of Educational Instruments

To address this inquiry, arithmetic means, standard deviations, relative significance, and rankings of paragraphs pertinent to the development of instructional tools were computed, yielding the following results:

Table 2. Arithmetic means, standard deviations, relative importance, and ranking of paragraphs related to the field of development of educational tools.

No.	Paragraphs	Mean	Standard Deviation	Materiality	Rank
1	Develop nanotechnology interactive whiteboards to improve visual learning experience.	3.95	0.718	79.0%	2
2	Design nanotechnology miniature laboratory instruments that enable the simulation of complex processes.	4.07	0.663	81.5%	1
3	Produce sustainable and long-lived learning materials using cutting-edge nanomaterials.	3.61	0.733	72.2%	9
4	Design nanotechnology-based smart pens and writing devices to provide instant feedback to students.	3.68	0.768	73.7%	8
5	Develop educational applications based on nanotechnology to more accurately analyze student responses.	3.89	0.903	77.8%	3
6	Create interactive learning materials for students using nanoscale hologram techniques.	3.72	0.821	74.4%	6
7	Designing educational programs supported by devices based on nanotechnology to stimulate interaction between students.	3.70	0.701	74.0%	7
8	Develop nano-based smart glasses to enable students to access expanded learning content.	3.73	0.738	74.6%	5
9	Create interactive 3D learning models using nano printing technology.	3.60	0.887	72.0%	10
10	Application of nanotechnology in the development of lightweight and flexible education tablets.	3.77	0.947	75.4%	4
	Total	3.71	0.571	74.3%	

Table 2 shows the arithmetic means, standard deviations and the relative importance of each of the paragraphs related to the field of developing educational tools, where the values of their relative importance ranged between (72.0% - 81.5%). Paragraph (2) states: "Designing miniature nanotechnology laboratory tools that allow the simulation of complex processes."

Ranked top with an arithmetic mean of 4.07 and a significant awareness level of 81.5%, paragraph 9 discusses the creation of interactive 3D instructional models with nano printing technology. In the lowest position, with an arithmetic mean of 3.60. The data indicates that the total number of paragraphs has an arithmetic mean of 3.71 and a significant level of accomplishment.

4.1.2. Second Domain: Enhancing the Classroom Environment

To address this inquiry, arithmetic means, standard deviations, relative significance, and rankings of paragraphs pertaining to the enhancement of the classroom environment were computed, yielding the following results:

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Table 3. Arithmetic means, standard deviations, relative importance and ranking of paragraphs related to the field of improving the classroom environment.

NO.	Paragraphs	Mean	Standard Deviation	Materiality	Rank
1	Use nanomaterials to purify the air in classrooms to ensure a healthy environment.	4.06	0.837	81.2%	1
2	Develop smart windows to control lighting and temperature in classrooms.	3.76	0.713	75.1%	5
3	Use anti-bacterial nano paints to improve hygiene in classrooms.	3.71	0.839	74.1%	6
4	Designing nano floors that reduce noise and increase comfort in the study environment.	3.91	0.711	78.3%	2
5	Installation of nano sensors to measure air quality and ensure proper ventilation.	3.80	0.749	76.0%	4
6	Use nano-based insulation materials to improve thermal and acoustic insulation in classrooms.	3.63	0.753	72.5%	9
7	Providing high-definition displays based on nanotechnology to improve the visibility of educational materials.	3.60	0.783	72.0%	10
8	Integrate light and sturdy school furniture made of innovative nanomaterials.	3.66	0.864	73.2%	8
9	Using nanotechnology to develop smart lighting systems that reduce energy consumption and enhance visibility.	3.68	0.941	73.7%	7
10	Create nanotechnology-based smart digital whiteboards to improve student interaction.	3.83	0.872	76.6%	3
	Total	3.73	0.606	74.6%	

Table 3 presents the arithmetic means, standard deviations, and the relative significance of each paragraph related to the improvement of the classroom environment, with relative significant values ranging from 72.0% to 81.2%.

Paragraph (1) discusses the utilization of nanoparticles for air filtration in educational environments to ensure a healthy atmosphere. Initially, it demonstrates an arithmetic mean of 4.06, accompanied by a substantial level of awareness and a relative significance of 81.2%. In contrast, paragraph 7, which states that high-definition displays based on nanotechnology enhance the visibility of educational materials, ranks lowest, with an arithmetic mean of 3.60, a significant level of awareness, and a relative significance of 72.0%. The table indicates that the total of paragraphs has an arithmetic mean of 3.73 and demonstrates a significant degree of achievement with a relative importance of 74.6%.

4.1.3. Third Dominance: Fostering Practical Comprehension of Concepts

To address this inquiry, arithmetic means, standard deviations, relative significance, and rankings of paragraphs pertinent to the enhancement of practical comprehension of concepts were computed, yielding the following results:

Table 4. Arithmetic averages, standard deviations, relative importance and ordering of paragraphs related to the field of promoting practical understanding of concepts.

No.	Paragraphs	Mean	Standard Deviation	Materiality	Rank
1	Use nanoscale simulators to illustrate complex scientific concepts.	3.74	0.843	74.9%	5
2	Developing nasoscopes that allow students to see molecules and chemical reactions directly.	3.85	0.862	77.1%	2
3	Designing educational applications in augmented reality and nanotechnology to simplify scientific experiments.	3.74	0.872	74.9%	6
4	Create learning materials whose properties change using nanotechnologies to enhance interactive understanding.	3.80	0.777	76.1%	3
5	Develop nanotechnology-based learning platforms to provide detailed practical examples.	3.94	0.713	78.8%	1
6	The use of nanorobots in student experiments to demonstrate practical applications of technologies.	3.73	0.832	74.6%	7
7	Apply nano-based 3D virtual models to illustrate engineering concepts.	3.56	0.771	71.2%	10
8	Develop mobile nano labs to provide hands-on learning opportunities.	3.59	0.647	71.7%	9
9	Integrate nanotechnology into simulation software to illustrate physical and chemical processes.	3.79	0.984	75.8%	4
10	Produce interactive learning materials that allow students to interact with concepts in real time.	3.72	0.821	74.4%	8
	Total	3.66	**0.578**	73.1%	

Table 4 presents the arithmetic means, standard deviations, and the relative significance of each paragraph according to the enhancement of practical comprehension of the concepts, with relative important values ranging from 71.2% to 78.8%. Paragraph (5) articulates: "Creating educational platforms utilizing nanotechnology to furnish comprehensive practical illustrations." The arithmetic mean is 3.94, with a significant awareness and relative relevance of 78.8%, whereas paragraph 7 mentions the application of three-dimensional virtual models utilizing nanoparticles to elucidate engineering concepts. In the final position, with an arithmetic mean of 3.56 and a significant level of awareness and relative importance of 71.2%.

The table indicates that the total number of paragraphs has an arithmetic mean of 3.66 and a significant level of achievement with a relative importance of 73.1%.

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4.1.4. Fourth Domain: Augmenting Creativity and Exploratory Proficiencies

To address this inquiry, arithmetic means, standard deviations, relative significance, and rankings of paragraphs pertaining to the enhancement of creativity and exploratory skills were computed, yielding the following results:

Table 5. Arithmetic means, standard deviations, relative importance and ranking of paragraphs related to the field of enhancing creativity and exploration skills.

No.	Paragraphs	Mean	Standard Deviation	Materiality	Rank
1	Develop nanotechnology educational games to stimulate creative thinking.	71.0%	0.804	71.0%	8
2	Design nano-educational laboratories to enable students to conduct innovative experiments.	75.4%	0.775	75.4%	2
3	Provide nano-educational tools that allow students to explore scientific theories on their own.	76.8%	0.941	76.8%	1
4	Use nano-based applications to provide diverse exploration scenarios.	73.8%	0.846	73.8%	5
5	Develop nanoscale instructional tools to encourage students to design new models.	72.7%	0.839	72.7%	7
6	Support student competitions with nano-based equipment to stimulate innovation.	70.5%	0.906	70.5%	9
7	Provide nanoscale resources to enable students to carry out their own projects.	74.9%	0.798	74.9%	3
8	Apply nanotechnology in simulation software to provide a safe exploration environment.	70.0%	0.741	70.0%	10
9	Delivering practical nano-based workshops to promote creative thinking.	74.1%	0.824	74.1%	4
10	Create nanoscale learning spaces to encourage collaboration among students.	73.3%	0.837	73.3%	6
	Total	72.5%	0.633	72.5%	

Table 5 shows the arithmetic means, standard deviations and the relative importance of each of the paragraphs related to the field of enhancing creativity and exploration skills, where the values of their relative importance ranged between (70.0% – 76.8%). Paragraph (3) asserts the provision of nano-educational tools that enable pupils to independently investigate scientific notions. The arithmetic mean is 3.84, accompanied by a significant awareness and relative importance of 76.8%, particularly for paragraph 8, which addresses the implementation of nanotechnology in simulation programs to ensure a secure exploration environment. In the final position, with an arithmetic mean of 3.50 and a significant level of awareness and relative importance of 70.0%. The table indicates that the total number of paragraphs has an arithmetic mean of 3.63 and a significant level of achievement with a relative importance of 72.5%.

4.1.5. Fifth Domain: Wearable Technology in Education

To address this inquiry, arithmetic means, standard deviations, relative significance, and rankings of paragraphs pertaining to wearable technology in education were computed, yielding the following results:

Table 6. Arithmetic means, standard deviations, relative importance and ranking of paragraphs related to the field of wearable technology in education.

No.	Paragraphs	Mean	Standard Deviation	Materiality	Rank
1	Develop wearable nanodevices to monitor academic progress and analyze performance.	3.65	0.837	72.90%	8
2	Design nano-based smart glasses to provide instructional content during lessons.	3.89	0.817	77.80%	2
3	Produce smart educational clothing with nano sensors to track physical and mental activity.	3.89	0.861	77.80%	3
4	Provide smart watches based on nanotechnology to alert students to the dates of assignments.	3.79	0.952	75.90%	4
5	Developing nano pods that provide simultaneous translation of multilingual educational content.	3.91	0.938	78.30%	1
6	Create nano-based smart learning bracelets to encourage interactive learning.	3.65	0.924	73.10%	7
7	Providing smart educational shoes with nanodevices to encourage movement and activity during education.	3.66	0.849	73.20%	6
8	Design nano-embedded clothing displays to provide an integrated learning experience.	3.73	0.903	74.60%	5
9	Developing smart hats based on nanotechnology to analyze biological data during learning.	3.61	0.857	72.20%	9
10	Provide nanotechnologies in clothing that allow the presentation of first-hand information on student progress.	3.6	0.89	72.10%	10
	Total	3.7	0.891	74.00%	

Table 6 presents the arithmetic means, standard deviations, and the relative significance of each paragraph related to wearable technology in educational environments, with relative significant values ranging from 72.1% to 78.3%. Paragraph (5), which delineates the concept of nanoscale headphones enabling the concurrent translation of multilingual educational materials, holds the primary position, with an arithmetic mean of (3.91) and a notable level of awareness and relative significance of (78.3%). In contrast, paragraph (10), which proposes the integration of nanotechnologies into clothing for the real-time display of information about a student's academic performance, is

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assigned the lowest rank, with an arithmetic mean of (3.39) and a significant awareness level of (72.1%). Moreover, the chart demonstrates that the total of paragraphs attains an arithmetic mean of 3.70, accompanied by a notable level of awareness and relative significance of 74.0%. The subsequent table presents the arithmetic means, standard deviations, relative significance, and ranking for each domain, facilitating the nanotechnology domains.

Table 7. Arithmetic averages, standard deviations, relative importance and order for each nanotechnology domain.

Area	Mean	Standard Deviation	Materiality	Rank
Educational Tools Development Area	3.71	0.571	74.3%	2
Area of improvement of the classroom environment	3.73	0.606	74.6%	1
Area to promote practical understanding of concepts	3.66	0.578	73.1%	4
Field of Enhancing Creativity and Exploration Skills	3.63	0.633	72.5%	5
Wearable Technology in Education	3.70	0.703	74.0%	3
Total	3.68	0.585	73.7%	

Table 7 demonstrates that all domains of nanotechnology achieved high awareness scores. The enhancement of the classroom environment ranked first with an arithmetic mean of 3.73 and a relative importance of 74.6%. The development of educational tools followed in second place with an arithmetic mean of 3.71 and a relative importance of 74.3%. The application of wearable technology in education secured third place with an arithmetic mean of 3.70 and a relative importance of 74.0%. The improvement of practical understanding of concepts ranked fourth with an arithmetic mean of 3.66 and a relative importance of 73.1%. Lastly, the promotion of creativity and exploration skills ranked fifth with an arithmetic mean of 3.63 and relative importance of 72.5%. This table also showed that the general arithmetic means of the fields obtained an arithmetic mean of (3.68) and a high degree of awareness and relative importance of (73.7%).

The research findings indicate that primary educators at private institutions in Jordan possess a significant awareness of the application of nanotechnology in educational contexts across the examined disciplines. Female educators predominantly focus on improving the classroom environment, recognizing its direct impact on student comfort and the overall quality of education, including the application of nanomaterials to enhance air quality, sound attenuation, and thermal insulation. The advancement of educational tools has gained significant importance, as the integration of nanotechnology in creating sophisticated and interactive educational instruments is essential for enhancing the learning experience of students and making it more effective. This includes the development of laboratory instruments that enable the simulation of complex processes, as well as the introduction of innovative methods to improve teaching resources. The realm of wearable technology in education has shown notable awareness, as educators favor practical technological solutions that facilitate the monitoring of student performance and provide immediate support through intelligent nanotechnology devices, including headsets and interactive eyewear.

Conversely, it was shown that domains such as improving practical comprehension of concepts and fostering creativity and exploratory skills ranked somewhat lower than other areas. This may be because these areas require greater training and advanced technical resources to effectively apply nanotechnologies in educational experiments and projects. Nonetheless, the outcomes in these domains remain favorable, signifying a distinct recognition among female educators of the importance of nano stimulation in fostering pupils' scientific and creative cognition.

The outcome aligned with the findings of the study by Spyrtou et al. (2021), which indicated that teachers possess awareness of nanotechnology. The outcome contrasted with Al-Qahtani (2022) findings, which indicated a low level of awareness of nanotechnology. The research underscores the necessity of incorporating nanotechnology into education, focusing on equipping educators with the requisite knowledge and skills to effectively employ this technology, considering advancements in the nanotechnology sector and enhancing student motivation for learning. Properly equipped educators are essential for the effective incorporation of nanotechnology into the educational curriculum, enhancing pedagogical approaches and broadening students' intellectual perspectives (Fidan & Winter, 2025).

4.2. Findings Related to the Second Question

What problems do primary school teachers have when implementing nanotechnology in private schools in Jordan?

To answer this question, arithmetic averages, standard deviations, relative importance and ranking of paragraphs related to the challenges facing the employment of nanotechnology were calculated, and the results were as follows:

Table 8. Arithmetic averages, standard deviations, relative importance and ranking of paragraphs. Challenges to the employment of nanotechnology.

No.	Paragraphs	Mean	Standard deviation	Materiality	Rank
Educational Tools Development Area					
1	The high cost of nanotechnologies: The difficulty of providing the necessary budget for the development or purchase of advanced nanotechnological tools.	3.95	0.718	79.0%	4
2	Complexity of techniques: The need for intensive teacher training to understand how to use nanoscale instructional tools.	4.08	0.663	82.5%	1
3	Curriculum Alignment: The challenge of integrating nanotools with traditional curricula.	3.61	0.733	72.2%	14
Area of improvement of the classroom environment					
4	Construction and Maintenance Costs: The high cost of installing nanomaterials in improving the classroom environment.	3.68	0.768	73.7%	12

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No.	Paragraphs	Mean	Standard deviation	Materiality	Rank
5	Inadequate infrastructure: Lack of classroom equipment supporting nanotechnologies in some schools.	3.89	0.903	77.8%	6
6	Lack of awareness of modern technologies: Lack of knowledge among teachers about how to improve the environment using nanotechnology.	3.72	0.821	74.4%	9
Area to promote practical understanding of concepts					
7	High costs of fittings: Difficulty in procuring devices such as nano scopes or simulation tools.	3.70	0.701	74.0%	10
8	Complexity of using tools: The need for advanced technical skills is difficult for some teachers to acquire.	3.73	0.738	74.6%	11
9	Potential risks: Teachers are afraid to use techniques that may be sensitive or need special attention.	3.60	0.887	72.0%	15
Field of Enhancing Creativity and Exploration Skills					
10	Lack of available resources: Limited educational materials that support innovation using nano.	3.77	0.947	75.4%	8
11	Poor student interaction: Difficulty involving students in the use of creative techniques due to their inexperience.	4.07	0.663	81.5%	2
12	Lack of time: Compressing the school schedule does not allow enough time for creative activities.	3.95	0.718	79.0%	5
Wearable Technology in Education					
13	Providing wearable devices: The high cost of buying devices such as glasses or smartwatches.	3.89	0.903	77.8%	7
14	Maintaining privacy: Concern about the use of wearable technology and its impact on student data.	3.68	0.768	73.7%	13
15	Distraction while learning: The likelihood that wearable devices will become a distraction rather than an aid.	4.07	0.663	81.5%	3
	Total	3.71	0.571	74.3%	

Table 8 clearly indicates that the predominant challenges in all areas of nanotechnology stem chiefly from the development of educational tools, highlighting the complexity of technologies and the requisite for comprehensive training for educators to understand the application of nanotechnological educational resources. This domain attained the greatest challenge scores, with the related field achieving the top ranking, as demonstrated by an arithmetic mean of 4.08 and a relative significance of 82.5%. Conversely, the same table indicates that the least significant challenges across all sectors of nanotechnology pertain to the promotion of practical understanding of concepts, suggesting potential risks related to educators' apprehension about employing techniques that may be sensitive or necessitate specialized attention. The problems in this area were ranked lowest, with an arithmetic mean of 3.60 and a relative importance of 72.0%.

The results revealed that the primary challenge is the complexity of nanotechnologies and the requirement for female educators to have extensive training to understand the use and implementation of these technologies in the educational context. This highlights a significant gap between the rapid advancement of these technologies and the current qualifications and training provided to educators. Nanotechnology is a complex and evolving field that requires specialized technical and scientific knowledge, posing further challenges for educational institutions that may not have training programs to adequately prepare educators for effective use of these tools. Furthermore, there may be deficiencies in coordination between technical developers and educational practitioners, which obstructs the seamless integration of these technologies.

The findings indicate that students' lack of experience and insufficient engagement with new technologies significantly hinder their creativity and exploratory skills, likely due to the fact that integrating nanotechnology into the educational framework requires skills and exploration capabilities that are not adequately developed at their current educational level. One of the most salient challenges identified is the substantial financial burden associated with the implementation of nanotechnology, whether pertaining to the development of educational instruments, enhancement of the classroom milieu, or provision of wearable devices. The dependence of nanotechnology on sophisticated materials and precise instruments makes it excessively costly, both for procurement and upkeep, posing a considerable obstacle for private educational institutions that may find it challenging to allocate sufficient funds for such technological investments.

The findings further indicated that inadequately equipped infrastructure in certain schools presents a significant challenge, particularly in enhancing the classroom environment. The implementation of nanomaterials requires a teaching environment specifically tailored to support the use of sophisticated tools and techniques. In the pursuit of enhancing practical understanding of concepts, the issue of "potential risks" was identified as the least significant challenge, as educators expressed concerns about the use of nanotechnologies that may require specialized oversight due to their sensitivity or precision. This issue may stem from a lack of awareness regarding safety requirements relevant to the use of these technologies in an educational setting.

5. Recommendations & Suggestions

The results indicate many approaches for incorporating nanotechnology into teaching. Professional development opportunities, particularly for female educators, are essential due to their lower self-efficacy in using nanotechnology

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tools. Such initiatives will equip teachers for effective pedagogical adaptations. Furthermore, schools must allocate resources for the procurement and maintenance of nanotechnology resources, as their functionality is vital for successful classroom integration. Establishing contemporary educational laboratories in private institutions would facilitate active engagement with novel technologies for both students and teachers.

Nanotechnology can improve e-learning by promoting interactive digital resources and virtual simulations that clarify intricate ideas. It can also promote technology-enhanced pedagogical methods by integrating nanotechnology into digital learning frameworks. These modifications augment the manuscript's relevance to the journal's focus on educational innovation and technological integration.

Additionally, curriculum redesign is necessary to incorporate practical nanotechnology applications. Such initiatives are anticipated to shift student perceptions of nanotechnology and promote understanding of its real-world applications, thereby equipping them with relevant knowledge for future scientific developments.

5.1. Prospective Endeavors

The study findings suggest multiple avenues for future research. One important area involves examining the effect of training programs on teachers' competency and efficiency in using nanotechnology within educational settings, as professional development may influence their adoption of new technologies in classrooms. Additionally, future studies should explore the psychological and technical challenges teachers face when employing nanotechnology tools. Addressing these challenges can alleviate potential obstacles and facilitate the successful and sustainable incorporation of nanotechnology in education.

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