The Impact of a Nanotechnology-Based Training Program on the Development of Digital Competencies among High School Biology Teachers

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Abstract

This study aimed to investigate the impact of a training program based on nanotechnology applications on the development of digital competencies among high school biology teachers. There is a gap between teachers' current digital competencies and the skills needed to effectively leverage nanotechnology in biology education. The study found statistically significant differences between pre-test and post-test scores on a digital competency assessment after teachers completed the nanotechnology training program. The program encompassed fundamental nanoscience knowledge, biology-specific applications, digital skills training, and hands-on activities. Results showed a large effect size, indicating the substantial impact of the intervention on enhancing teachers' digital competencies. Recommendations highlight integrating nanotechnology into science curricula and emphasize biology connections, problem-solving, content creation, and ethical considerations regarding advanced nanomaterials. Promoting teacher motivation and scientific inquiry is vital. The research addresses an urgent need to equip biology educators with digital skills aligned with rapidly evolving science and technology.

Keywords: nanotechnology applications, biology education, digital competencies, teacher training program, educational implications

1. Introduction

In the current era, cognitive and technological growth are accelerating. With this rapid advancement, modern technologies have emerged that enhance educational effectiveness through their unique features, contributing to the development of diverse skills among students. As a result, it is essential to incorporate these technologies into education and train teachers to use them in their teaching practices. This creates a dynamic learning environment that fosters student interaction and active participation in the learning process.

Nanotechnology, a recently introduced advanced technology in education, opens significant opportunities for innovative thinking across various aspects of life. Technological advancements lead to social, political, and economic transformations, underscoring the necessity for students to possess knowledge, understanding, and awareness. These qualities are crucial for utilizing modern applications and optimizing their use to keep pace with scientific and technological developments (Jeffery, 2012).

Countries worldwide have recognized the importance of nanotechnology and made efforts to integrate it into their educational systems. The United States, one of the pioneers, has redesigned its curricula to include nanotechnology applications, preparing and guiding students for the future. Besides emphasizing nanotechnology education in schools and universities, the United States also focuses on training teachers in the science and applications of nanotechnology. Over the past decade, 52 countries have established research and academic programs, research units, institutes, centers, and laboratories, marking nanotechnology as a primary scientific and research interest (Roco, 2011).

In today's dynamic digital landscape, integrating nanotechnology training into high school biology education is transformational. Digital competencies are increasingly essential for educators, and nanotechnology offers a pathway to acquire these skills. This training connects theory with practice, enabling biology teachers to create engaging, hands-on learning experiences that enhance student engagement and critical thinking. Overcoming challenges such as resource scarcity and a lack of teacher expertise is crucial. Strategies for incorporating nanotechnology training include collaboration with experts, utilizing online resources, engaging in hands-on activities, and forming teacher partnerships. These strategies ensure educators can improve their digital competencies and prepare students for a technology-driven future.

Saudi Arabia has emerged as a global leader in nanotechnology, with its interest dating back to 2004. The country is home to four prominent nanotechnology research centers: the King Abdullah Institute for Nanotechnology (KAIN), the Center for Nanotechnology (CNT), the Center of Excellence in Nanotechnology (CENT), and the Research Center at King Abdullah University of Science and Technology (KAUST).

Integrating nanoscience into education is crucial because it focuses on material miniaturization, characterizing their chemical and physical properties, and shrinking material dimensions to the nanometer scale. Nanotechnology involves restructuring atoms and particles to generate and control internal structures, leading to versatile applications that enhance material advantages and address limitations in line with evolving technological demands.

Nanotechnology significantly intersects with various sciences, serving as a common ground for chemistry, physics, biology, and more. This intersection makes it a pioneering area of scientific and technological advancement, highlighting the need to incorporate nanotechnology applications into science education. This integration facilitates the combination of fundamental branches of science, addressing an urgent need in the 21st century.

Studies consistently emphasize the importance of integrating nanotechnology into education, particularly in secondary science education. This integration plays a pivotal role in nurturing scientific knowledge, critical thinking, and creativity in students, which is crucial for progress and the development of 21st-century skills.

Training science teachers in nanotechnology applications is essential, as they often specialize in traditional subjects such as physics, chemistry, and biology but may lack confidence in teaching nanoscience without adequate knowledge. The necessity of staying up to date with the latest scientific advancements and understanding the interconnections among different science disciplines. Moreover, the frequent inquiries from students about nanotechnology highlight the need to equip teachers with the requisite skills in this area to enhance their digital competencies.

Digital competencies are increasingly crucial for both personal and professional growth. Teachers must use information and communication technology (ICT) to facilitate teaching and learning, nurturing students' digital skills. These competencies serve as prerequisites for the effective integration of digital technology into educational processes. Consequently, many countries have incorporated digital competencies into teacher education and training programs, providing digital platforms and open-source courses to bolster teachers' professional development in this critical domain.

Digital competencies, also known as ICT competencies for teachers, play a pivotal role in enabling the effective use of technology in education and have been integrated into teacher education worldwide.

Numerous studies underscore the importance of developing teachers’ digital competencies, highlighting the need for training in pedagogical applications. In the modern educational landscape, teachers facilitate access to knowledge, necessitating contemporary methods and technology.

Specifically, science teachers, especially those in biology, can significantly benefit from developing digital competencies for integrating nanotechnology into their curriculum. A practical program that equips biology teachers with these competencies is imperative. The impact of nanotechnology-based training on the digital competencies of secondary school biology teachers is being investigated.

In conclusion, the integration of nanotechnology into educational curricula has increasingly captured attention in recent years, given its potential to transform science education. This trend is especially relevant in the context of high school biology instruction, where digital competencies are essential for effective teaching and learning. As contemporary biology research extensively employs advanced technologies and data analysis, high school biology teachers must develop digital competencies to prepare their students adequately for the field's evolving demands. Notably, the literature reveals a gap concerning the impact of nanotechnology-based training programs on the development of critical digital competencies among high school biology teachers. This study seeks to bridge this gap by investigating the effects of a specialized nanotechnology-based training program on enhancing the digital competencies of high school biology educators, thereby contributing to the advancement of science education in the digital era.

1.1 Stamen of the Problem

The Kingdom of Saudi Arabia is dedicated to establishing the most effective methods and training programs to enhance the skills and competencies of science teachers. This initiative is crucial for managing teachers professionally amidst the rapid advancements in science and technology characteristic of an ever-evolving era. Competency-based training emerges as both important and necessary for the sustainable development of educators. Nonetheless, a noticeable deficiency in the digital competencies of teachers within the nation highlights the urgent need to bridge the gap between current digital competencies and modern technological innovations.

Moreover, existing teacher preparation programs fall short of adequately equipping future educators with the necessary skills for teaching in schools. These programs tend to concentrate solely on general teaching skills, thereby creating a disconnect in practical application within real classroom settings. Consequently, there is a significant deficiency in the preparation and training of science teachers concerning innovations in science and its methodologies. Specifically, science teachers in Saudi Arabia require professional support to effectively integrate nanotechnology into their teaching practices. Educational institutions are thus encouraged to revise their programs to accurately reflect the multidisciplinary nature of nanoscience (STEAM Saudi Arabia, 2021).

In addition, science teachers in Saudi Arabia encounter challenges in utilizing nanotechnology applications within secondary science education, which underscores the importance of engaging them in training programs focused on nanotechnology and its applications in science teaching. Furthermore, the adoption of competency-based digital training programs for teachers is recommended, given their beneficial impact on enhancing teachers' performance in the educational process.

To assess the current state of digital competency and the application of nanotechnology in biology teaching among secondary education teachers, the researcher conducted surveys and interviews with several biology teachers. The findings indicated that a significant proportion of teachers possessed a low level of digital competency, and many lacked the necessary background knowledge on nanotechnology applications and how to employ them in biology teaching.

Given these considerations, the current research problem is identified by the low level of digital competencies and the utilization of nanotechnology applications among biology teachers in secondary education. Consequently, this research aims to explore the effects of a training program based on nanotechnology applications on the development of digital competencies among biology teachers in secondary education (Albasalah et al., 2022).

1.2 Research Objectives

Prepare a training program based on nanotechnology applications to enhance the digital competencies of high school biology teachers.

Identify the impact of a training program based on nanotechnology applications on enhancing the digital competencies of high school biology teachers.

1.3 Research Hypothesis

The research aimed to validate the following hypothesis:

- There are statistically significant differences between teachers' mean scores on the digital competencies assessment pre-test and post-test.

The research's significance lies in enhancing biology teachers' skills with the latest educational technologies, improving student outcomes, and nurturing their digital and higher-order thinking abilities. This aligns with 21st-century demands for skills to keep pace with rapid scientific and technological advancements. Biology's centrality and its connections to various scientific fields make mastering its concepts essential for real-world integration. The research offers the following benefits:

- Addressing gaps in biology teacher preparation and draw attention to program development.
- Providing a nanotechnology-based training program for high school biology teachers, applicable across educational levels.
- Introducing a tool to assess science teachers' digital competencies.
- Enhancing high school biology teachers' digital skills for better nanotechnology integration in teaching
- Paving the way for future research on applying nanotechnology in science education and enhancing teachers' digital competencies

1.4 Research Scope

The study will focus on the scopes and boundaries outlined in the provided content.

Objective Scope: The research aims to study the impact of a training program based on nanotechnology applications on the development of digital competencies among high school biology teachers.

Time Scope: The research was implemented during the first semester of the academic year 1444H/2022AD.

Spatial Scope: The research was conducted in Riyadh, Kingdom of Saudi Arabia.

Human Scope: The research was limited to a sample of female biology teachers teaching in government girls' schools in the Riyadh educational region.

Key terms:

• Nanotechnology

Nanotechnology is defined as "the technology of materials at the atomic or molecular scale, or nanotechnology, or the engineering of products at the nanometer scale, derived from the name nanometer as a unit of measurement, which equals one billionth of a meter." Scientists describe nanotechnology's uses as life science applications that consider the sizes of atoms and molecules, simulating their interactions to modify materials and create new properties using equipment, machinery, and robots at the atomic scale. European Commission et al. (2004).

In this study, nanotechnology applications are defined procedurally as "technological applications that examine very small dimensions of atoms and particles, used by biology teachers in teaching biology topics to ensure a deeper understanding among their students and create an educational environment that helps them generate creative ideas for solving practical issues and concerns related to various biology topics."

• Training Program

A training program is a structured and organized educational initiative designed to impart specific knowledge, skills, and competencies to individuals. In the context of this study, it refers to a program focused on providing high school biology teachers with knowledge and skills related to nanotechnology and digital competencies.

1.5 Digital Competencies

Digital competencies encompass the knowledge, skills, and abilities required to effectively use digital tools, technologies, and resources. This study focuses on high school biology teachers' abilities to navigate, utilize, and integrate digital technologies into their teaching practices. Bruckermann et al. (2021).

The researcher formulated a definition for digital competencies, which are procedurally defined as the set of experiences and teaching skills employed by biology teachers for nanoapplications in biology instruction. This encompasses their adherence to digital teaching principles, the use and production of digital content, digital communication, and collaboration, and fostering digital citizenship among their students.

1.6 Literature Review

This literature review examines the development of digital competence among preservice teachers. The studies reveal the importance of targeted interventions to improve skills across information literacy, communication, content creation, safety, and problem-solving. While the studies agree on core competencies, they diverge in methodologies, target populations, frameworks utilized, and specific areas of emphasis, highlighting areas for further research and we will discuss it as the follows:

Gabarda Méndez et al. (2023) investigated the development of digital competence among preservice preschool and primary school teachers through a teaching innovation project at the University of Valencia in Spain. They found significant improvements across all areas of digital competence for the participants, including information/data literacy, communication/collaboration, content creation, safety, and problem solving. Gender differences emerged, with men self-reporting higher competence in communication, safety, and overall digital competence compared to women after the intervention.

Cranmer (2014) compared digital skills frameworks from the UK, Europe, and Australia, finding much overlap between categories like functional skills, creativity, critical thinking, communication, and e-safety. Analysis of a visually impaired student's skills illustrated how creative media enabled by technology aids her transition from secondary school to college. More research is needed on implementing frameworks and supporting major life transitions.

Tudor (2016) described how European and Romanian curriculum reform has prioritized skills and competencies, including digital literacy. A cross-disciplinary, individualized approach is required. Developing students' abilities to judiciously navigate online spaces and assess credibility is now imperative. Tudor advocated curriculum and pedagogies enabling learner self-direction, reflective thinking, and problem solving.

Nowak (2019) reviewed international assessments demonstrating Polish students' progress in functional digital skills but deficits in advanced skills like programming, simulation, and online credibility evaluation. A relational framework sees competencies embedded across life domains. Nowak argued teacher preparation should address students' knowledge gaps while also guiding their safe, ethical online participation.

Martínez-Pérez et al. (2022) evaluated a flipped learning program using a T-MOOC (Transfer Massive Open Online Course) to improve digital competence of 313 preservice primary school teachers in Spain. Results showed improvements in skills like searching for and selecting digital resources, creating original materials, securely sharing content, and perceiving technology's value in enabling innovative pedagogies.

Ciriza-Mendívil et al. (2022) developed a technology-enhanced collaborative learning intervention informed by the TPACK framework for 235 preservice teachers. Students improved technological knowledge and ability to identify ICT tools to teach social sciences, though some confusion persisted between ICT equipment and resources.

Napal Fraile et al. (2018) had 43 secondary preservice teachers in Spain self-assess competence in 21 subareas of digital literacy. Overall proficiency was low, especially in integrating technology into teaching. Students were most skilled at information retrieval reflecting their prior roles as learners. Weakest domains were content creation and using ICT innovatively, underscoring the need for comprehensive technology training.

Alférez-Pastor et al. (2023) systematically reviewed 13 studies of programs to build digital competence of preservice elementary educators. Results verified interventions improved technological knowledge, perceived technology self-efficacy, online communication and collaboration, content creation, and other skills. The authors argue teacher technology training remains imperative for harnessing ICT's pedagogical potential.

Méndez et al. (2022) surveyed 97 Spanish teachers regarding the digital resources and tools used to enable remote instruction during COVID-19 lockdowns. Teachers valued learning management systems and self-created video lessons as most useful but needed more training, highlighting how rapid digitalization accentuates teachers’ support requirements.

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In conclusion and regarding the Points of Agreement: The studies reviewed present a strong consensus on several key points. Firstly, they all emphasize the critical need to develop digital competence in preservice teachers to ensure they can effectively integrate technology into their future classrooms. Secondly, the research shows that well-structured interventions and training programs can lead to measurable improvements in preservice teachers' digital skills across various domains, including information literacy, content creation, and more. Further, there's agreement on the importance of core digital competence areas like information and data literacy, effective and safe communication and collaboration, content creation, and problem-solving with technology. Lastly, the studies consistently stress the need to train teachers on responsible technology use and ethical online behavior.

And with regards to points of difference: Despite the agreement, some differences emerge among the studies. These include variations in the target populations, with some focusing on preservice preschool/primary teachers and others on the secondary level (or more broadly). Additionally, while there's some overlap, studies use distinct digital competency frameworks as the basis for their analysis and interventions. Methodological differences also exist, with studies employing surveys, self-assessments, and program outcome analysis, resulting in slightly varying perspectives on skill levels. Finally, certain studies place a stronger emphasis on aspects, like gender differences in digital competence or the use of specific technologies, such as MOOCs.

Regarding the research gap, the reviewed studies highlight a need for deeper investigation into specific areas. Researchers need to further investigate the long-term effects of digital competence training programs on classroom practice. There is a need to examine potential variations in digital competence requirements based on the specific subject areas that preservice teachers will teach. Studies indicate that while basic competencies are improving, developing advanced skills (programming, simulation) remains a challenge. Additionally, further research should address how best to support teachers using digital tools during crucial transitions—moving from university to the classroom—or rapid shifts like those demanded by the COVID-19 lockdowns.

Also, there are critical points that have not been explored in the current studies. It is critical to gather students' perspectives on how their teachers improved digital competence shapes their learning experiences. Further attention needs to focus on equity, accessibility, and inclusive design in digital competence training to meet the diverse needs of learners and teachers with disabilities. Lastly, with technology and online information evolving at a rapid pace, research must examine how to keep teacher training continuously relevant and up to date.

With reference to the Authors' Academic Contributions: The authors of the reviewed studies contribute significantly to our understanding of digital competence. Their work validates the effectiveness of designed interventions in enhancing preservice teachers' digital skills. They pinpoint specific strengths and weaknesses in competencies, aiding future training design. Their use of various digital competency frameworks demonstrates their utility for assessment and program creation. Most importantly, their findings raise important questions that drive further research into the long-term impact, student perspectives, and challenges faced by teachers during shifts and transitions.

2. Methodology

The research adopted the following methodologies to achieve its objectives:

• The descriptive method for compiling a list of digital competencies required for teaching biology at the secondary level, devising a training program based on nano applications to enhance the digital competencies of secondary school biology teachers, and constructing a digital competency scale.

• The experimental method with a pre-post single-group design was utilized to determine the impact of a training program centered on Nano applications on enhancing the digital competencies of secondary school biology teachers. Figure 1 illustrates the study's experimental design.

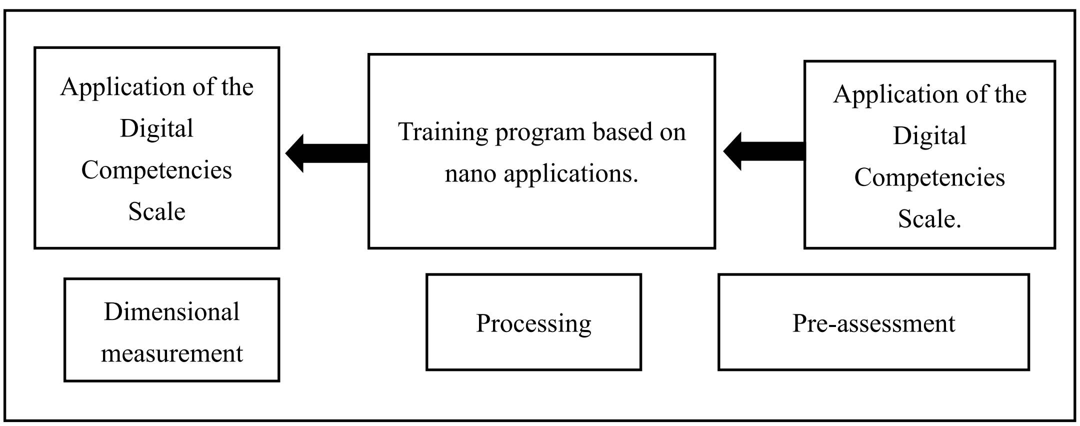

Figure 1. Experimental Approach of the Research

2.1 Research Population

All biology teachers responsible for teaching at the secondary level in the Riyadh region for the academic year 1444H/2022AD.

2.2 Research Sample

Selected using a simple random sampling method, the sample consisted of 32 secondary school biology teachers. They conducted an initial assessment to gauge their level of digital competencies. They implemented the proposed training program for them. At the conclusion of the program, a post-assessment was conducted to evaluate the impact of the training program based on Nano applications on enhancing their digital competencies.

2.3 Research Materials

The study incorporated a training program based on Nano applications to foster digital competencies among secondary school biology teachers. The program followed these steps:

• **Program Objective Definition**: The goal of the training program is to enhance the digital competencies of secondary school biology teachers through Nano applications.

• **Sources for Program Preparation**: The program was constructed by referencing previous studies that addressed Nano applications in various scientific branches, including Salama (2017), Mohamed (2018), Al-Otaibi & Sabahi (2021), and ZOR (2018).

• **Preliminary Outline of the Training Program**: Initially, the training program consisted of 5 sessions spread over 5 days, with each day having 3 hours of instruction, including a 15-minute break, a self-assessment for the participants, and a 15-minute daily summary. The program covered various topics related to Nano applications, digital competencies, and their interconnection through hands-on interactive biology activities. Additionally, the program featured an introductory preamble, overarching objectives, target audience, program content, a timeline for implementation, general guidelines for the instructor, session details (session objectives, content, and activities), and the participants' self-assessment with a daily summary.

• **Verifying the program's content validity**: Experts specializing in curricula and teaching methods received the training program. They provided feedback on the program's content alignment with its objectives, presentation, session count, activities, and evaluation methods in relation to Nano applications in biology and the development of digital competencies for secondary school biology teachers. Experts specializing in curricula and teaching methods noted significant amendments in linguistic and scientific phrasing. The majority remarked that the program contained substantial and appropriate scientific content suitable for training secondary school biology teachers, especially in the realm of Nano applications to enhance their digital competencies. We integrated the modifications suggested by the experts, making the final version of the program ready for application to the primary research sample.

2.4 Research Tool

The study relied on the Digital Competencies Scale to gather information. The following steps prepared this scale:

• **The Scale**'s objective is to develop digital competencies for secondary school biology teachers in line with nanotechnology applications.

• **Consulting Prior Research and Studies:** To identify these competencies, we consulted prior research and studies addressing digital competencies, including Al-Rasai (2017) and Asiri (2022). The researchers identified the following digital competency dimensions: digital teaching principles, use and production of digital content, digital communication and collaboration, and digital citizenship.

• **Preliminary Scale Items**: The initial version of the scale consisted of 28 statements divided among the four dimensions: digital teaching principles (6 statements), use and production of content (7 statements), digital communication and collaboration (8 statements), and digital citizenship (7 statements).

• **Experts who assessed the training program also reviewed the scale for validity.** They provided feedback on whether the statements were suitable for the scale's dimensions, the clarity of their formulation, and each statement's effectiveness in measuring its intended dimension. We modified the scale based on their feedback to include 32 statements, with 8 statements dedicated to each dimension.

• **Scoring and Grading System**: Alongside each statement, there was a four-point scale (Strongly Agree, Somewhat Agree, Somewhat Disagree, Strongly Disagree). We assigned scores as follows: 4 points for "strongly agree," 3 points for "somewhat agree," 2 points for "somewhat disagree," and 1 point for "strongly disagree." Consequently, the highest score on the scale was 128, and the lowest was 32. Given that all scale statements were positive, a high score indicated a high level of digital competencies, while a low score indicated a low level.

For the Preliminary Scale Application, we applied the scale to a preliminary sample of 15 teachers—outside the main research sample—to determine the application time and to verify the clarity of its instructions and items. Researchers found the application time to be 20 minutes. We used the Cronbach's alpha coefficient to determine the scale's reliability. Table 1 displays the reliability coefficient for each dimension and the overall scale.

Table 1. Reliability Coefficients for the Digital Competencies Scale

Dimension	Cronbach's Alpha Reliability Coefficient
Digital Teaching Principles	0.89
Use and Production of Content	0.90
Digital Communication and Collaboration	0.94
Digital Citizenship	0.88
Overall Scale	0.89

Table 1 indicates that the reliability coefficients for the Digital Competencies Scale are high, as the reliability coefficient for each dimension ranged between 0.88 and 0.94, and for the scale, it was 0.89. This confirms the scale's stability, making the final form of the Digital Competencies Scale suitable for application to the research sample.

2.5 Research Procedures

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2.6 Statistical Methods of the Research

The SPSS2023 program was used to apply the following statistical methods:

- Cronbach's alpha coefficient to verify the reliability of the Digital Competencies Scale.

- Arithmetic means, standard deviations, and the paired-samples T-test to determine the statistical significance of the differences between the mean scores of biology teachers (research sample) in both pretest and posttest applications of the Digital Competencies Scale.

- The use of Cohen's equation to calculate the effect of the independent variable (the educational program based on nano applications) on the dependent variable (digital competencies) relies on the pre- and post-test of the single group. The effect size is calculated according to the following equation:

$$\text{Effect Size} = \frac{\text{Post-test Mean- Pre-test Mean}}{\text{Standard Deviation}}$$

3. Results

3.1 Results of Addressing the First Research Question

To achieve the research goal of identifying the impact of a training program based on nanotechnology applications on the development of digital competencies among high school biology teachers, the research results were presented by answering its questions and verifying its hypotheses. The findings were discussed, considering previous studies' results, leading to the formulation of recommendations and suggestions based on these results.

Results of Answering the First Research Question: The first research question was, "What is the training program based on nanotechnology applications for developing digital competencies among high school biology teachers?" To answer this question, previous research and studies on nanotechnology applications in biology and digital competencies were reviewed and synthesized. Five sessions were scheduled over five days, each lasting three hours, with a fifteen-minute break included in each session. We included a self-assessment for the trainee and a daily summary lasting 15 minutes. The program was described in detail, as follows:

First, the general objective of the program is to develop digital competencies among high school biology teachers.

Second, the strategies used in the program include the following educational strategies: lectures, open dialogue and discussion, problem-solving, brainstorming, modeling, cooperative learning, and role-playing.

Third: The program's application requirements include an electronic copy of the scientific material it covers, a variety of internet applications for carrying out program tasks, and a computer for both the trainer and each trainee.

Fourth: The educational activities of the program are based on interactive activities (individual and collaborative) during the sessions, as it relies on digital competencies, emphasizing application, experimentation, testing, and investigation to generate creative ideas within each activity.

Fifth: Evaluation methods consist of several assessment methods, namely:

• Formative or diagnostic assessment: pre-program assessment using the digital competency scale, administered before the program starts for the teachers.

• Preparatory assessment: It includes pre-program questions to engage the teachers and retrieve their previous knowledge and experiences.

• Constructive or formative assessment involves the implementation of specific activities based on nanotechnology applications aimed at developing digital competencies among biology teachers.

• Self-assessment: At the end of each session, there is an individual activity based on the trainee's self-learning abilities.

• Summative or final assessment: Consists of the post-program application of the digital competency scale after completing the program.

Table 2 illustrates a structured training program aimed at enhancing the digital competencies of secondary biology teachers. The program focuses on developing teachers' understanding of nanoscience and its applications in biology, promoting skill development in content creation and risk analysis, and fostering higher-order thinking skills among students.

Table 2. Detailed Description of the Nano Applications-Based Training Program for Enhancing Digital Competencies of Secondary Biology Teachers

Session	Session Objective
1	Understand the origin and evolution of nanoscience, secondary materials, their forms, and properties, and acquire fundamental concepts and knowledge in the field of nanoscience.
2	Familiarize with some secondary biological structures, devices, and products and their applications related to biology and the mechanisms of using them in teaching.
3	Employ nano applications in the production of educational content in biology.
4	Present, discuss, and analyze the positive and negative aspects of nano applications and predict some risks associated with nano applications in biology. Use skills to deal with these risks and mitigate them.
5	Utilize nano applications to enhance higher-order thinking skills, improve educational outcomes, and assess them among female students in biology.

3.2 Results of Answering the Second Question and Validating the Research Hypothesis

The second research question for the study is: "What is the nano-applications-based training program for enhancing digital competencies among high school biology teachers?" To answer this question and validate the research hypothesis, which posited that "there are no statistically significant differences between the mean scores of teachers in the pre-application and post-application of the digital competencies scale," arithmetic means, standard deviations, and a paired-samples T-test were calculated. Table (3) illustrates the results.

Table 3. Teacher Competency Scores - Pre vs. Post Digital Literacy (n=32)

Dimension	Pre-Application	Post-Application	t-Value	Degrees of Freedom	Statistical Significance
Teaching Digital Fundamentals	14.47	6.32	31.34	1.00	0.001
Content Creation and Usage	14.72	6.88	31.28	0.96	0.001
Digital Communication	16.31	6.17	31.66	0.55	0.001
Digital Citizenship	16.13	5.02	31.06	1.27	0.001
Overall Scale	61.63	21.85	162.34	2.52	0.001

According to Table 3, the differences between the mean scores of biology teachers in the pre-application and post-application phases of the digital competency scale are statistically significant at the 0.01 significance level for each dimension and the overall scale, in favor of the post-application phase. The research hypothesis was rejected based on these results, and the alternative hypothesis indicating statistically significant differences at the 0.01 level between the mean scores of biology teachers (the research sample) in both the pre-application and post-application phases of the digital competency scale in favor of the post-application phase was accepted.

We used Cohen's equation to determine the impact of the independent variable "nano-based educational program" on the dependent variable "digital competencies," and the results of this analysis are illustrated in Table 4.

Table 4. Effect Size - Nano-Based Educational Program on Digital Competencies (n=32)

Dimension	Pre-Application Mean	Post-Application Mean	Standard Deviation	Effect Size Value	Effect Size
Teaching Digital Fundamentals	14.47	31.34	6.50	2.60	Large
Content Creation and Usage	14.72	31.28	6.85	2.42	Large
Digital Communication	16.31	31.66	6.15	2.50	Large
Digital Citizenship	16.13	31.06	5.38	2.78	Large
Overall Scale	61.63	126.34	22.01	2.94	Large

It is evident from Table 4 that all effect size values are greater than 0.8. Cohen (1988) proposed three levels of effect size: small (ranging from 0.2 to 0.49), medium (ranging from 0.5 to 0.79), and large (0.8 and above). This indicates that the nano-based educational program has a large impact on the development of digital competencies among high school biology teachers.

4. Discussion

The study revealed statistically significant enhancements in the digital competencies of high school biology teachers after they participated in a nano-based educational program, as indicated by the increased average scores on the digital competency scale in the post-application phase compared to the pre-application phase, with these differences being statistically significant at the 0.01 level and demonstrating a large effect size. The success of this training program can be attributed to several pivotal factors: foundational knowledge about nanotechnology, including its definition, history, scientific underpinnings, and practical applications, was imparted, enriching teachers' comprehension of the subject. The emphasis on Nano applications pertinent to biology showcased the utility of nanodevices in cell detection, diagnosis, and treatment. The program's activities, which employed nano applications to solve scientific problems, heightened awareness of the technology's applicability in biology education. By presenting both the advantages and disadvantages, along with the risks associated with Nano applications, the program equipped teachers with the necessary insight to navigate these challenges effectively. Practical exercises in creating educational content utilizing Nano applications bolstered digital content production skills. The emphasis on generating sensory educational materials, such as models featuring unique nanomaterial properties, was underscored. Additionally, the program utilized specific nanomaterials to enhance educational tools, including televisions, microscopes, and projectors, thereby improving teachers' proficiency with these technologies. Cooperative activities encouraged scientific inquiry into the applications of nanoscience in biology, fostering a deeper interest among teachers. Moreover, dialogue sessions deepened understanding, facilitated critical judgment on scientific and ethical issues, and supported the development of strategies for effectively integrating nanotechnology into biology education, minimizing potential problems or challenges.

This research is in accord with several prior studies that underscore the significance of incorporating nanotechnology applications in education. For example, Baghdad's study (2020) highlighted the necessity of bolstering science teachers' understanding of nanotechnology, their attitudes towards its instruction, and the provision of requisite technologies and support for both learning and teaching this science, along with its integration into science curricula at various educational levels. Eid's study (2021) advocated for the enrichment of science teaching with nanotechnology, tailored to the age-specific characteristics of students and promoting integration across various science disciplines. The traditional demarcations between science fields such as chemistry, physics, and biology become blurred when materials are described at the nanoscale, given that nature adheres to a uniform set of laws applicable to both living and non-living entities. Thus, integrating nanotechnology into science education facilitates the exploration of interdisciplinary connections across different science curricula. Manou et al. (2021) emphasized the critical importance of science teachers being conversant with nanotechnology applications, considering their novelty. Mastery in utilizing these applications in science teaching is requisite. Michailidi and Stavrou (2022) confirmed the significance of training educators in nanotechnology to expand their knowledge base regarding nanotechnology issues. The provision of a training program aimed at enhancing digital competencies among teachers, as delineated by this research, resonates with recommendations from various scholars, including Babaer (2020), Al-Mulhi (2021), Aseeri (2022), and Al-Smadi (2019). These studies have illuminated the evolving role of teachers amidst technological advancements in education; teachers have transitioned from being the primary sources of knowledge to becoming designers and managers of the educational environment, advisors, connectors, and developers. In this era of educational technology, possessing the requisite digital competencies is imperative for teachers to fulfill their multifaceted roles effectively and competently in teaching.

5. Conclusion

In recent years, the integration of nanotechnology into educational curricula has garnered increasing attention due to its potential to revolutionize science education. This trend is particularly relevant in the context of high school biology instruction, where digital competencies have become essential for effective teaching and learning. As modern biology research relies heavily on advanced technologies and data analysis, high school biology teachers must possess digital competencies to adequately prepare their students for the evolving demands of the field. However, there is a notable gap in the literature regarding the impact of nanotechnology-based training programs on the development of these crucial digital competencies among high school biology teachers. This study aims to address this gap by exploring the effects of a specialized nanotechnology-based training program on the digital competency enhancement of high school biology educators, ultimately contributing to the advancement of science education in the digital age.

The results of this research have significant implications for both the field of science education and teacher professional development. First and foremost, the findings underscore the effectiveness of a nanotechnology-based training program in enhancing the digital competencies of high school biology teachers. This suggests that similar programs could be implemented to empower educators with the necessary skills to navigate the digital landscape of modern classrooms. As scientific and technological transformations continue to accelerate, equipping teachers with aligned competencies becomes increasingly urgent to promote student readiness.

Furthermore, the study provides an initial model for constructing professional development initiatives aimed at capability-building in a rapidly progressing domain. As emerging fields like nanoscience continue to evolve, consistent teacher training is vital for translating cutting-edge advances into impactful learning experiences. This research offers a template for fostering aligned teacher competencies.

Additionally, the recognition of nanotechnology's multidisciplinary nature supports its incorporation into science education standards by policymakers. As traditional scientific boundaries disappear at the nanoscale, integrating nanoscience promotes vital interdisciplinary connections across subjects. This implication aligns with the evolving, cross-cutting view of science education.

While this study features certain limitations, it meaningfully addresses a critical gap around empowering educators to navigate the digital era. The findings offer an actionable blueprint for enhancing teacher competencies in line with accelerating scientific progression. Further research into specialized applications, customized training, and diverse educational contexts would powerfully build upon this initial effort. With rapid evolution as the only constant, equipping teachers with agile competencies is key to activating student potential. This work strives to move that vision forward.

6. Recommendations

Considering the results obtained, the research recommends the following:

- Reviewing the preparation of training programs for high school biology teachers to ensure their alignment with rapid scientific developments, especially those specialized in the application of nanotechnology in biology instruction.

- Incorporating topics, activities, and educational materials in high school biology curricula that require the use of nanotechnology applications in biology This is crucial for developing higher-order thinking skills among students and making them more capable of creatively generating innovative ideas to solve scientific problems related to biology.

- Utilizing the training program developed in this research to train high school biology teachers in the use of nanotechnology applications in biology instruction. Such training will contribute to enhancing their digital competencies.

- Conducting training courses to train biology teachers and teachers in various science disciplines at different educational levels on the use of nanotechnology applications in educational settings to achieve their objectives.

- Integration of Nanotechnology: Curriculum developers should consider integrating topics related to nanotechnology applications in biology into the high school biology curriculum. This integration can help develop higher-order thinking skills among students and enhance their ability to creatively solve scientific problems related to biology.

7. Study Limitations

While this study has limitations, it's important to emphasize that it provides valuable insights into the impact of a nanotechnology-based training program on high school biology teachers' digital competencies. The sample size, while not fully representative, still offers meaningful findings. While findings are context-specific, they are relevant for similar educational contexts. The relatively short study duration provides initial insights into short-term effects, and the absence of a control group doesn't diminish the observed improvements. Self-reported data, while having potential biases, still offers valuable self-perception insights. External factors and resource requirements, though not fully explored, don't negate the study's contributions. Ethical considerations, while briefly addressed, highlight a relevant aspect of nanotechnology education. Long-term impacts and external validity, although needing further investigation, don't diminish the immediate significance of the study. While acknowledging these limitations, this study remains a valuable step towards understanding the potential benefits of nanotechnology-based training programs for educators, with implications for science education.

8. Study Implications

The results of this research have significant implications for both the field of science education and teacher professional development. First and foremost, the findings underscore the effectiveness of a nanotechnology-based training program in enhancing the digital competencies of high school biology teachers. This suggests that similar programs could be implemented to empower educators with the necessary skills to navigate the digital landscape of modern classrooms.

Furthermore, the specific strategies employed in the training program, such as lectures, open dialogue, problem-solving, and cooperative learning, provide a valuable blueprint for designing future teacher development initiatives. Educators and curriculum designers can draw inspiration from these methods to create engaging and interactive learning experiences that foster digital competency growth among teachers.

The emphasis on ethical considerations and risk assessment related to nanotechnology applications in biology education highlights the importance of addressing these issues in science classrooms. This implies a need for teacher education programs to incorporate modules on ethical and responsible use of emerging technologies, ensuring that educators are well-prepared to guide their students in these areas.

Additionally, the research findings support the integration of nanotechnology into science curricula at various educational stages, as it promotes interdisciplinary learning and aligns with the evolving nature of scientific boundaries. This suggests that educational policymakers and curriculum developers should consider the inclusion of nanotechnology concepts in science education standards.

Finally, the study's recognition of teachers' changing roles in the digital age underscores the importance of equipping educators with digital competencies. As teachers transition from knowledge providers to educational facilitators and technology integrators, professional development programs should prioritize digital skill development to meet the demands of contemporary education.

9. Suggestions for Further Research

- The impact of a proposed strategy based on nanotechnology applications on the development of higher-order thinking skills among biology students.
- The effect of a teaching program based on nanotechnology on biology instruction is to enhance the digital skills of high school students.
- Assessing the inclusion of educational content based on nanotechnology applications in high school biology curricula.
- Replication and Validation: Researchers are encouraged to replicate this study in different educational settings to validate the effectiveness of nanotechnology-based training programs in enhancing digital competencies among biology teachers.
- Teacher Preparedness: Further research should focus on assessing the preparedness of science teachers, especially biology teachers, to adopt nanotechnology applications in their teaching.
- To improve how nanotechnology is used in biology education, future research should include longitudinal studies, diverse samples of participants, comparative approaches, customization, advanced nanotechnology applications, digital skills in online learning, specialized assessment tools, ethical considerations, and teacher collaboration.

• These research directions will contribute to equipping biology teachers with the necessary digital skills and ensuring effective teaching in the digital era.

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