Faculty of Education
Journal of Education

Sohag Universit

The effectiveness of a suggested professional development program in enhancing nano-literacy for secondary school female science teachers

Prepared by

Dr. Aliah Mohamed Karim Al-Atiyat
Tabuk University – College of Education and Arts
Curricula and Instruction Department

Receipt date: 24 August 2024 - Date of acceptance: 15 September 2024

The effectiveness of a suggested professional development program in enhancing nano-literacy for secondary school female science teachers

Abstract

This study aimed at investigating the effectiveness of a suggested professional development program in enhancing nano-literacy for a voluntary sample of secondary school female science teachers in KSA. A quasi-experimental approach based on a one-group pretest-posttest design was used. The population included all female science teachers at secondary schools in KSA. From these, a sample of (33) science teachers were selected voluntarily. Data was collected by the Cognitive Aspect of Nano-Literacy Test (Al-Atiyat , 2016). An online program focusing on six domains of the cognitive aspect of nano-literacy was developed. Results demonstrate the effectiveness of the program in developing nano-literacy as a total degree and sub-domains. The study recommended implementing the professional development program introduced in this study for developing the cognitive aspect of nano-literacy for pre- and in-service science teachers. It was also suggested to conduct a study investigating the effectiveness of a program that integrates the other aspects of nano-literacy (such as the skill dimension, critical thinking, decision-making, and educational applications) in developing science teachers' nano-literacy.

Keywords: Nano-literacy, Professional development, Science education, Nanoscience and Nanotechnology (NST), Online training

عنوان الدراسة : فاعلية برنامج مقترح للتطوير المهني في تنمية التنور النانوي لدى معلمات العلوم بالمرحلة الثانوية

هدفت هذه الدراسة إلى الكشف عن فاعلية برنامج مقترح للتطوير المهني في تنمية التنور النانوي لدى عينة من معلمات العلوم بالمرحلة الثانوية. وتم تنفيذ الدراسة باستخدام منهج شبه تجريبي قائم على تصميم مجموعة الواحدة مع اختبار قبلي واختبار بعدي. واشتمل مجتمع الدراسة على معلمي العلوم بالمرحلة الثانوية بمدارس التعليم العام بالمملكة العربية السعودية ومن بينهم تم اختيار عينة قوامها (٣٣) معلمة بالطريقة الطوعية ممن أبدين الرغبة بالمشاركة في البرنامج. وتم جمع البيانات باستخدام اختبار يقيس الجانب المعرفي للتنور النانوي من اعداد العطيات (٢٠١٦). وتم تصميم برنامج إليكتروني يركز على ست مجالات للبعد المعرفي للتنور النانوي. وقد بينت نتائج الدراسة فاعلية البرنامج المقترح في تنمية التنور النانوي كدرجة إجمالية وكأبعاد فرعية. وفي ضوء هذه النتائج تمت التوصية بتطبيق برنامج التطوير المهني المقدم في هذه الدراسة كبرنامج يعمل على تنمية الجانب المعرفي للتنور النانوي لمعلمات العلوم بمرحلتي ما قبل وأثناء الخدمة لديهم، كما تم اقتراح دراسة لاختبار فاعلية برنامج يستدمج الأبعاد الأخرى للتنور النانوي كالبعد المهاري والتفكير الناقد واتخاذ القرار والتطبيق التربوي واختبار فاعليته في تنمية التنور النانوي لدى معلمي العلوم.

الكلمات الدالة: التنور النانوي, التطوير المهني, تعليم العلوم, علم وتقنية النانو, التدريب عبر الإنترنت.

Introduction

The contemporary world is witnessing massive technological progress which has been leading to enhancing the quality of life. A good example of these progresses is Nanoscience and Nanotechnology (NST) (Spyrtou, Manou, & Peikos, 2021).

NST is deemed to be an immense scientific breakthrough that is almost as important as the industrial revolution and the information technology revolution. NST is currently heavily adopted in many fields and scientific technologies, including medicine, electronics, construction, etc., which means that it is necessary for our educational institutions and universities to get ready to keep pace with this trend (Khalifa, Khalil, Shehata, Abdel Fattah, & Lundy, 2020).

Nanotechnology is a technology that relies on shrinking or breaking down a substance into extremely small parts by rearranging the particles of that substance, thus changing its properties to achieve a new product or the same product with different properties (Al-Mafarji, 2023, p. 1736; Al-Douri, 2022, p. 185). In this study, Nanotechnology is defined as a multidisciplinary field that involves the manipulation and engineering of matter at the nanometer scale. This technology enables the creation, observation, and application of materials and devices with unique properties and functions that emerge at this small scale. Nanotechnology encompasses various domains, including physics, chemistry, biology, and engineering, and has applications across a wide range of industries, from medicine and electronics to energy and environmental science.

The accelerated growth of NST applications in everyday life activities and as well as in the industrial sector requires education systems to produce nano-literate citizens who have the skills necessary to handle these technologies and applications (Leonidas, Anna, Euripides & Petros, 2022). It is therefore more essential, within Industry 4.0 era, to integrate and introduce novel concepts in various educational levels, including pre-school and early childhood stages (Lin, Wu, Cho & Chen, 2015); in order to produce graduates who have the skills and knowledge that would empower them to effectively tackle NST products in their daily life in the future (Spirtou, Manou, Peikos & Papadopoulou, 2018).

A close relationship can be observed between science and NST topics based on the various sciences (e.g. physics - chemistry - biology) interference; thus making science serve as a basis for acquiring NST concepts (Al-Taqbi, & Al-Ghuwaij, 2021). Furthermore, NST can be viewed as among the most rapidly evolving trends in science education as a result of the emergence of the interdisciplinary area of Science, Technology, Engineering and Mathematics (STEM) (Gana, Aji, & Gimba, 2020). By including nanotechnology in educational programs, students can gain early exposure to cutting-edge technologies, fostering their ability to think critically about the future of science and technology. This integration helps prepare students to engage with and contribute to emerging scientific fields and equips them with the knowledge to drive future innovations (Al Husseiny & Saab, 2024; Ha, & Lajium, 2022).

NST concepts and topics (also referred to as future sciences) should be introduced in science curriculum, and teacher preparation programs with the purpose of qualifying them to teach these new concepts and integrate them with the other science curriculum domains, along with initiating a thorough development of science curriculum in the coming years to incorporate these concepts and topics (Baghdadi, 2020; Jad, 2022).

A new culture is therefore necessary that would allow individuals to actively engage in the field of nanotechnology in light of the critical importance of its applications in our time (Yawson, 2012). In other words, there is a need to nano-literacy, which despite its importance has not received the substantial amount of attention by science education researchers.Nano-literacy, it is "understanding several basic concepts/ideas of nano-technology" (Dorouka, Papadakis, & Kalogiannakis, 2021, p.4).

An early definition of nano-literacy was stated by a research group at the University of Southern California (as cited in Toumey and Baird, 2006) with the purpose of developing nano-literacy for university students. This definition included identifying nano-literacy as a literacy pointing out that the nano-literate individual would have adequate knowledge of the main concepts and topics of NST, including scientific, human, and societal aspects; be sufficiently sensitized and able to pursue his or her interests in relation to NST and learn from its multiple sources; and to engage meaningfully in the community in terms of NST issues and policies.

Since the role of science teachers is especially critical in improving student learning outcomes in science, it is of utmost importance for learners as well as their teachers to be nano-literate. According to Mandrikas, Michailidi, & Stavrou (2021) teachers need to acquire proper content knowledge and be familiar with the suitable teaching strategies so that they can efficiently deliver NST topics in their instruction.

Teacher professional development courses contribute to integrating content knowledge in science teaching (Feldman-Maggor, Tuvi-Arad & Blonder, 2022); which means that professional development programs have the potential to enhance teachers' nano-literacy. Professional development in nano-literacy and nanotechnology awareness is crucial for supporting teachers in their efforts to integrate these emerging fields into science education. Targeted training programs, access to relevant resources, and collaborative partnerships can all contribute to enhancing teachers' knowledge, confidence, and effectiveness in this area (Spyrtou, et. al, 2021). Providing teachers with opportunities for professional development, such as workshops or online courses, can help empower them to effectively incorporate nanotechnology concepts into their lessons. The following paragraphs discuss research-informed frameworks for nano-literacy with a focus on the aspects1 of interest in this study.

Yawson (2012) introduced a conceptual framework for nano-literacy based on technology literacy which refers to the ability to use, manage, understand, and evaluate technology, with attention paid to the various dimensions of knowledge, ways of thinking, behaviors, and capabilities. In this framework, Yawson (2012) links nano-literacy to science, technology and society (STS- literacy), environmental literacy and scientific literacy. He argued for the integration of these cultures in order to produce nano-literate teachers. According to this framework, nano-literacy comprises three main aspects; the first one is the cognitive aspect which entails that nano-literate teachers should have sufficient knowledge of nano-products and services that can be used in specific situations, along with realizing their benefits and risks. The second aspect is concerned with the skills or capabilities an individual needs within the design process to solve a specific problem using nanotechnologies. The final aspect focuses on critical thinking and decision-making informed by the benefits and hazards of nanotechnology.

In addition, the researcher believes that science teacher nano-literacy should include a fourth aspect which concerns how to integrate NST concepts into the content of the curriculum, and how to identify appropriate learning strategies and activities to develop these concepts for students. It bears repeating that there is a dearth of appropriate teaching methods and materials for NST concepts available to date in the curriculum (Dorouka, Papadakis & Kalogiannakis, 2020). In this study, however, the focus is primarily on the cognitive aspect of nano-literacy included in this framework.

Feldman-Maggor, et al. (2022) tried to apply the "SOLO" taxonomy with the purpose of identifying the complexity levels of learning outcomes related to science teacher nano-literacy. This taxonomy aligns with progressive layers of nano-literacy for teachers, including five levels, namely Pre-structural, uni-structural, multi-structural, relational, and extended abstract. The bottom layer involves introducing the main concepts of NST without establishing any connection to the science curriculum. At the second, third, and fourth layers, some connections are made between the learning content of nano-literacy development courses and the curriculum being taught, however specific concepts of NST are still absent. At the most elaborated sophisticated layer, well-defined applications of nano concepts are included in specific topics and contexts of the curriculum, which goes beyond the teaching content. In this study, the focus is on the first and second layers to introduce basic knowledge of NST in addition to some of its general applications in the current science curriculum.

With regard to the cognitive aspect of nano-literacy, teachers need to be acquainted with a number of NST concepts and topics. Based on a Delphi method study by Sakhnini & Blonder (2015), the Feldman-Maggor, et al. (2022) identified the main concepts of nanotechnology and nanoscience that teachers and students need to master, namely: size-dependent properties, size and scale, characterization methods, functionality, classification of nanomaterials, the fabrication approach of nanomaterials, innovations and applications of nanotechnology & the making of nanomaterials.

Leonidas, et al. (2022) identified (13) of the main (NST) concepts that must be taught in all stages of education, elementary, intermediate, secondary, or university, namely: Size and scale, size-dependent properties, surface area to volume, science-technology-society, tools and instrumentation, models and simulations, quantum effects, self-assembly, classification of nanomaterials, the making of nanotechnology, forces and interactions, structure of matter & functionality (Leonidas, et al., 2022).

By referring to the literature focused on professional development related to nanoscience and nanotechnology for science teachers (Feldman-Maggor, et. al, 2022; Eid, 2021; Mandrikas, et. al, 2021; Friedersdorf, 2020; Sgouros & Stavrou, 2019; Menon & Devadas, 2019; Açıkel, 2018; Abu-Much & Hugerat, 2017), the key considerations to focus on when building professional development programs aimed at enhancing teachers' nanotechnology awareness and literacy can be summarized as follows:

1. Educating teachers about different types of nanomaterials, such as nanoparticles, nanotubes, and nanowires, and their unique properties.
2. Providing insights into nanoscale structures and devices, including quantum dots, nanorobots, and nanosensors, and their applications in various fields.
3. Providing insights into nanoscale structures and devices, including quantum dots, nanorobots, and nanosensors, and their applications in various fields.
4. Incorporating real-world examples and case studies demonstrating the successful application of nanotechnology in various industries.
5. Introducing educational software and online platforms that provide interactive lessons and exercises on nanotechnology.
6. Developing activities and exercises that promote critical thinking about the potential benefits and risks of nanotechnology.
7. Offering self-paced, asynchronous modules that allow teachers to engage with the content on their own schedule, accommodating varying commitments and personal preferences.
8. Conducting regular surveys to gather feedback from participants about their experiences with the online program and identify areas for improvement.
9. Conducting regular surveys to gather feedback from participants about their experiences with the online program and identify areas for improvement.
10. Developing modules that align with current science curricula to seamlessly integrate nanotechnology concepts, and providing practical examples and applications of nanotechnology relevant to existing subject areas.

11. Offering interactive workshops that include hands-on activities and experiments to familiarize teachers with nanotechnology tools and techniques.
12. Creating and distributing comprehensive teaching resources, including lesson plans, instructional materials, and multimedia content focused on nanotechnology.
13. Aligning nanotechnology training with broader STEM (Science, Technology, Engineering, and Mathematics) education initiatives to enhance interdisciplinary teaching.

The following paragraphs review some studies that tried to improve the awareness, knowledge, and understanding of science teachers of NST.

Feldman-Maggor, et al., (2022) focused in their study on the development and investigation of the effects of a professional development electronic course for (95) chemistry teachers in the occupied Palestinian territories. A mixed research design, that included a semi-experimental approach based on a pre-test post-test control-group design along with qualitative data collected through semi-structured interviews, was used. The results revealed that the implemented professional development course contributed to increasing teachers' understanding of NST concepts as well as their ability to integrate them into the content of the secondary school chemistry curriculum.

In their qualitative study, Michailidi and Stavrou (2022) employed on post-induction mentoring in training Greek science teachers to deliver nanotechnology-based instruction. The intervention was implemented on 20 teachers (15 trainees and 5 mentors) for nine months. Analyzing the content of the recorded sessions revealed that nanotechnology teaching strategies were the major theme discussed by the participants, followed by the organizational concerns. It was found that the mentors provided advice, modeled the lessons, and exchanged experiences and resources with the trainees to help them. the study concluded that mentoring can be a powerful tool in broadening the teaching repertoire of teachers on nanotechnology.

Jad (2022) developed a suggested program in environmental nanotechnology to enhance environmental problem-solving skills and strategic thinking for student teachers majoring in science. In this one-group experimental study, data was collected from a total number of (53) students at the Faculty of Education, Assiut

University by the environmental problem-solving test and the strategic thinking test. The results demonstrated the effectiveness of the suggested program in fostering environmental problem-solving skills and strategic thinking.

Similarly, Eid (2021) investigated the effectiveness of a suggested program in NST in developing student teachers' evaluative thinking skills and awareness of nanotechnology issues and its biological and environmental applications. Data was collected from a sample of (50) third-year students majoring in Biology, Geology and Environmental Sciences at the Faculty of Education, Assiut University. Analyzing the data collected by an NST topics checklist, an evaluative thinking skills test, and an awareness motivation of nanotechnology issues and its biological and environmental applications scale demonstrated the effectiveness of the suggested program in enhancing the participants' evaluative thinking skills and awareness of nanotechnology issues and its biological and environmental applications.

In similar vein, Al-Salwi, Al-Suwaidi, and Al-Hakimi (2020) developed a suggested course in nanotechnology to enhance student teachers' concepts of and attitudes towards NST. Data was collected by a nanotechnology concepts test the attitudes towards NST scale from a sample of (34) randomly chosen senior students majoring in science at the Faculty of Education, Taiz University. The results revealed statistically significant differences in favor of the post-administration to the test as a total degree and each of its sub-levels (remember, understand, apply, analyze, synthesize, and evaluate). Similar results were also found for the attitudes towards NST scale as a total degree and each of its sub-domains in favor of the post-administration.

Sgouros and Stavrou (2019) explored the effect of a learning community as a professional development context about NST for science teachers. The model adopted in this case study was based on integrating science exhibits and social issues which relate to science with NST topics. Data was collected by interviews and video recordings. The results revealed that the challenges emerging during the implementation of the module affected how participating teachers interacted with each other, as well as the processes involved in their professional learning. The findings reached can be drawn on in examining how teachers may apply the newly learnt NST topics in their instructional practice.

Zor and Aslan (2018) investigated the effect of activity-based NST instruction on the conceptual understanding of student teachers majoring in science education at a university in Turkey. Data for this mixed methods research study was collected from 32 students participating in a seven-week NST intervention within a physics course by an NST Concept test and an assessment form for evaluating activity-based NST education. The results showed that the participants' conceptual understanding of NST improved at the end of the intervention.

Similarly, Khalil, Abdel Aal, Abu Naji, and Muhammad (2017) attempted to develop student teachers' academic achievement and reflective thinking skills through implementing a suggested program in nano-chemistry. This quasi-experimental control group design was conducted on a sample of (39) senior students majoring in Chemistry at the Faculty of Education, Assiut University. Analyzing the data collected by an academic achievement test and a reflective thinking skills test revealed that the participants improved in academic achievement and reflective thinking skills.

Lin, et al. (2015) investigated the perspectives of secondary school science teachers in Taiwan regarding the instruction of nanotechnology after implementing the "National Program on Nanotechnology". Moreover, the participants' perspectives on the perceived support provided by their schools as well as their intentions related to current and future professional development were examined. Based on a questionnaire survey method, the study was conducted on a sample consisting of 1600 science teachers working at 178 secondary schools who were selected via stratified cluster sampling. From those, a total number of 663 junior high school teachers and 632 senior high school teachers responded to the Teachers' Perceptions of Nanotechnology Teaching Scale. Analyzing the questionnaire data showed that teachers' familiarity with nanotechnology instruction was at above average level, and despite having high intentions to continue to engage in professional development, the participating school teachers reported that they did not receive the sufficient support from school.

Wischow, Brayn, and Bodner, (2012) conducted an interpretive case study to explore how two US teachers participating in an NCLT-PD program that extended for a year integrated the NST content into their curriculum as well as the effect on their PCK. Based on a constructivist perspective, the authors adopted a constant comparative method to analyze data extracted from semi-structured interviews, observations, and teachers' work documeNST. The findings highlighted that the new NST content helped the teachers change their orientations related to science teaching. Moreover, delivering the new content in their classrooms improved the teachers' knowledge of and connections to various areas the science content the teach. The new content also encouraged the teachers to implement new teaching strategies in their classrooms.

In a study conducted by Nichol and Hutchinson (2010), the focus was on examining the role of distance learning delivered through based video conferencing in the professional development of teachers in nanotechnology. Using a descriptive survey design, data was collected from a total number of 150 teachers taking part in a "Nanotechnology for Teachers" professional development course at Rice University by self-administered questionnaires. The results showed that the professional development course contributed to enhancing teachers' knowledge of developing lesson plans and concept questions, in addition to facilitating discussions among colleagues.

Lee, Wu, Liu, and Hsu (2006) conducted a descriptive survey study to report on K–12 Nanotechnology Program for teachers implemented by a National Taiwan University for 24 month. Surveying the perspective of the teachers working 169 schools which participated in the program pointed out that there was a positive impact on teachers' attitudes and interests toward learning about NST as a result of their participation in the program.

In view of the foregoing, the importance of developing nano-literacy for the students who will tackle NST applications extensively in the future becomes evident. In order to achieve this end, science teachers must be highly nano-literate.

Although some previous studies tried to develop teacher awareness, understanding, and knowledge of NST, the paucity of quality research in this field does not allow for definitive claims regarding the development of nano-literacy as an integrated concept for science teachers. Added to that, the majority of the studies reviewed were conducted on samples of student teachers rather than in-service teachers. This supports the contention that there is a pronounced need for investigating the effectiveness of a suggested professional development program in enhancing nano-literacy for science teachers, an aim the present study tried to achieve.

Problem of the study

Many studies tried to integrate NST content in the curriculum of various educational levels, however, literature indicates the absence of a solid understanding among science teachers regarding the best way for teaching such unfamiliar concepts (Cox, 2012).

Despite the overwhelming importance and potential of developing students' nano-literacy (thus the need for nano-literate science teachers as well), there is a dearth of research that documents teachers' nano-literacy levels in general (Leonidas, et al., 2022), and science teachers in particular.

The few studies that have been conducted in this respect demonstrate that teachers' nano-literacy levels range from weak to medium in terms of NST knowledge and understanding (see for instance, Ipek, Ali, Tan, Erkoç, 2020; Leonidas, et al. al., 2022;), which indicates science teachers' the need for more training to foster their awareness and knowledge of NST.

In the Saudi context, a study conducted Al-Atiyat (2016) revealed that science teachers in the Tabuk region had poor levels of understanding and attitudes toward nanotechnology. Likewise, the results of other studies conducted on student teachers majoring in science in the faculties of education highlighted poor levels of knowledge and awareness of nanotechnology and its applications (e.g. Al-Tamimi, 2018).

Scanning Arab and foreign databases indicates that the research in science teacher nano-literacy still has a long way to go. The focus of the majority of the studies conducted was on measuring awareness and knowledge of nano concepts, while there is a dearth of research on developing nano-literacy for teachers in general and science teachers in particular. what is needed to take up the slack is to address the poor levels of nano-literacy for science teachers.

Questions of the study

The intent in this study is to address these questions

1. What are the concept and components of nano-literacy science teachers should possess?
2. What is the suggested professional development program aimed at enhancing nano-literacy for science teachers?
3. What is the effectiveness of the suggested professional development program in enhancing nano-literacy for secondary school science teachers in KSA?

Study hypothesis

The study focused on testing the following hypothesis: " There are no statistically significant differences between the mean scores of science teachers in the pre- and post-administrations to the nano-literacy test as a total degree and sub-dimensions"

Significance of the study

This study has both theoretical and practical aspects of significance. Theoretically, as previously explained, this study tries to fill a critical research gap stemming from the lack of studies examining nano-literacy in general and the development of nano-literacy for science teachers in particular. Moreover, this study invites attention to conducting further research in nano-literacy and its development strategies for both science teachers and students, as well as for research in the rigor conceptualization of nano-literacy and its dimensions and components.

Practically, this study can call the attention of those responsible for science teacher preparation and professional development to the importance of integrating nano-literacy into these courses to empower teachers in developing NST concepts for their students. This study can also invite science curriculum developers' attention to the significance of integrating nano-literacy concepts into the curriculum.

Limitations of the study

1. Time and place limits: this study is limited to a sample of secondary school female science teachers in KSA who voluntarily approved to participate online in the training program.
2. Time limits: the empirical study was conducted during the academic year 2022-2023.
3. Subject limits: this study is limited to investigating nano-literacy according to the conceptual framework introduced by Yawson (2012), along with the fourth dimension related to educational applications which was added by the researcher.
   - The study is also limited to the cognitive aspect of nano-literacy which includes six sub-domains, these are: Nanotechnology concept, history of the development of nanotechnology, characteristics and goals of nanotechnology, stages of the applications of nanotechnology manufacturing,

the applications of nanotechnology, and risks & ethical considerations of nanotechnology.

Terminology

The professional development program

The professional development program is defined in this study as a cohort of planned training experiences that are tailored to develop science teachers' nano-literacy, and delivered via an electronic training environment. These experiences cover the objectives, content, strategies, training activities, and evaluation, and are based on the elements of effective professional development, including group professional cooperation, reflection on teaching practices, and active roles of teachers.

Nano-literacy

Nano-literacy is defined in this study as the knowledge, abilities, and skills of teachers, as well as their potential to think critically and make decisions about nanotechnology-based products, services, and applications and use them in the science curriculum. This study focuses on the cognitive aspect of nano-literacy (nano-literacy awareness), which refers to the foundational knowledge and understanding of nanotechnology that educators possess. It includes their awareness of fundamental concepts, principles, and factual information related to nanotechnology and its applications. This cognitive aspect of nano-literacy is measured by the degree a teacher obtains on a test specifically developed for this purpose.

Effectiveness

Effectiveness is used in this study to refer to the change caused by the independent variable (i.e. the professional development program in the present study) to the dependent variable (i.e. nano-literacy) as measured by Black's Modified Gained Ratio.

Study method and design

In the attempt to answer the questions of the present study, a quasi-experimental approach based on a one-group pretest-posttest design was used. Accordingly, a randomly selected sample of science teachers participated in the nano-literacy suggested professional development program, and their nano-literacy levels were measured prior to and after the implementation of the intervention.

Population and sampling

The population of this study included all female science teachers at secondary schools in the Tabuk region. From these, a sample of (36) science teachers were selected voluntarily. During the implementation of the intervention, three teachers withdrew, thus the number of the final sample amounted to (33) teachers.

Instrument of the study

Data collection was carried out by the "Cognitive Aspect of Nano-Literacy Test". The test had been developed by the researcher in an earlier study (Al-Atiyat , 2016) based on a checklist that included the concepts and domains of NST science teachers should master. The original form of the test included (40) items divided into seven domains. In the present study, however, the test was shortened it into six domains after combining the sixth dimension (i.e. Nanotechnology variations) and the seventh dimension (Risks of Nanotechnology) in one dimension. Thus, the final form of the test included six dimensions, namely: Nanotechnology concept, history of the development of nanotechnology, characteristics and goals of nanotechnology, stages of the applications of nanotechnology manufacturing, the applications of nanotechnology, and risks & ethical considerations of nanotechnology.

Validity was verified in the original study (Al-Atiyat , 2016) through Face validity for both the test and the checklist of NST concepts and domains. The psychometric characteristics of the test were also verified, in the original study, on a sample of science teachers in the Tabuk region, and the results indicated that the test enjoyed a high degree of discrimination coefficients. Moreover, the test reliability coefficient amounted to (0.90) as calculated by the split-half method.

In the present study, the reliability of the test was calculated by Cronbach's Alpha α after modifying it into six dimensions by means of administering the test on a pilot sample of (30) science teachers in the Tabuk region of the non-participants in this study. Results presented in Table (1) show the reliability coefficient values for the test as a whole and for its dimensions.

Table 1

Cronbach's Alpha values for the test as a whole and for its dimensions

N	Test dimensions	Statements	Cronbach's Alpha
1	Nanotechnology concept	3	0.872
2	History of the development of nanotechnology	2	0.803
3	Characteristics and goals of nanotechnology	6	0.860
4	Stages of the applications of nanotechnology manufacturing	3	0.883
5	The applications of nanotechnology	23	0.898
6	Risks & Ethical considerations of nanotechnology	3	0.918
	Total Reliability	**40**	**0.964**

Results presented in Table (1) reveal that reliability coefficient value for the test as a whole was high (α= 0.964 and ,(for the sub-dimensions ranged between (0.803- 0.918), which are high values indicating that the test enjoys a high degree of reliability, thus can be used. The following table shows the nano-literacy test specifications.

Table 2

Nano-literacy test Specifications

Serial	Main field	Concepts included	Number of items	Items
1	**Nanotechnology concept**	Defining Nanotechnology concept	3	1, 2, 3
2	**A brief history of the development of nanotechnology**	The history of nanotechnology evolution	1	4
		Fifth generation technology	1	5
3	**Characteristics and goals of nanotechnology**	Characteristics of nanotechnology	6	8 – 10 – 13 – 15 – 18 – 26
4	**Stages of the applications of nanotechnology manufacturing**	Materials used in the nanotechnology industry	1	17
		Stages of nanotechnology apparatus manufacturing	2	6- 7
5	**The applications of nanotechnology**	The field of biology and medicine.	10	19 – 20 – 22 – 23 – 24 – 28 – 29 – 30 – 31 – 32
		Physics	4	12 – 34 – 36 – 40
		Chemistry	1	35
		The field of environment	2	9 – 11
		Industry	1	37
		The field of food	3	16 – 27 – 33
		Military field	2	25 – 38
6	**Risks and ethical considerations of nanotechnology**	Ethical considerations of Nanotechnology	1	39
		Health	1	14
		Environment	1	21

The professional development program

This program was developed with the purpose of enhancing the cognitive aspect of nano-literacy for science teachers. The program aimed at achieving the following procedural objectives:

1- Developing science teachers' knowledge of nanotechnology concept.

2- Developing science teachers' knowledge of nanotechnology history of the development.

3- Developing science teachers' knowledge of characteristics and goals of nanotechnology.

4- Developing science teachers' knowledge of nanotechnology manufacturing applications stages.

5- Developing science teachers' knowledge of the applications of nanotechnology.

6- Developing science teachers' knowledge of risks and ethical considerations of nanotechnology.

7- Developing science teachers' knowledge of benefiting from NST in the curriculum and providing learning opportunities and content commensurate to helping students solve problems related to NST.

The program was developed based on reviewing several studies (e.g. Sgouros, & Stavrou, 2019; Tuba Şenel Zor, & Aslan, 2018; Abu-Much, & Hugerat, 2017; Lin, Wu, Cho, & Chen, 2015). (Zarei, Najafi, Saadatmand, & Yarmohmadiyan, 2014; Tuominen, 2012). The following principles and tenets were considered in developing the program:

1. The program was developed on the basis of a set of major principles for effective professional development, namely: the program should be purposeful; the trainees should play active roles; the activities should be collaborative and tailored for group work, encourage reflection, and be linked to real teaching practices (Goodnight, Beuningen & de Graaff, 2023).
2. Social constructivism served as an underlying theory for training to help trainees teachers build their self-knowledge in a collaborative context based on dialogue and discussion.
3. The concept of nano-literacy introduced by Yawson (2012) along with practical application in teaching science and enriching the curriculum was adopted.

A varied set of training strategies were used, including lecturing and direct instruction, cooperative learning in small groups, brainstorming and discussion, group research and informational problem-solving on nano-literacy topics using participatory Wikis, reflective learning using blogs, and tweeting via the Twitter platform.

The program was implemented entirely online given its flexibility that is commensurate to the schedules of all trainee teachers. The program included a combination of synchronous and asynchronous e-learning, with a total of (14) synchronous and asynchronous sessions. The synchronous sessions (8 sessions) were held through the (Zoom) platform to hold simultaneous conferences for the participants.

With regard to the synchronous form, the first session was an introductory meeting and acquaintance among the group members. It also included introducing the goals of the program to the trainees, describing the roles of the trainer and trainees, identifying the activities to be implemented, and dividing the trainees into groups. This was followed by six synchronous sessions, each focusing on one aspect of nano-literacy :nanotechnology concept, history of the development of nanotechnology, characteristics and goals of nanotechnology, stages of the applications of nanotechnology manufacturing, the applications of nanotechnology, and risks & ethical considerations of nanotechnology.

The final session included summarizing the most important aspects of the program and discussing the trainee teachers' perspectives on the program in terms of the benefits gained and the practical implications in teaching science and enriching the curriculum. The synchronous sessions proceeded as follows:

1. Each session started with a review of the main points of the previous sessions.
2. Setting the procedural objectives for the new session.
3. Introducing the new content via lecturing and direct instruction by the trainer.
4. Engaging the trainees in group discussions and brainstorming on the new content.
5. Engaging in group work to solve the tasks and questions introduced through communication among the members of the small groups of (5-6 trainees) via WhatsApp.
6. A representative of each group presents the findings of the group via the “Zoom” platform.

7. Conducting closing discussions and summarizing the significant points of the session.

On the other hand, the asynchronous sessions included the use of some participatory/collaborative and collective tools by small groups of trained teachers (5-6 teachers) using participatory Wikis within a framework of a collective project to make a wiki for nano-literacy. In this project, the trainees would collect applied scientific content on all NST topics and concepts of interest under the supervision of the trainer. Furthermore, each trainee was assigned to write a tweet on Twitter regarding the content of each session, in addition to writing in their reflective blogs about the benefits of each of the synchronous sessions and commenting on other participants' blogs. Each synchronous session lasted for 2 hours.

In order to make the program rigor, the initial drafts of the trainer's guide and the trainee's book of the program were presented to a set of jury members of faculty members specialized in the subject of the program at the curriculum and instruction of science departments to judge some aspects, including as the adequacy of the program to achieve its goals, how the objectives were related to the content, the appropriateness of the strategies used, the employed activities, the accuracy of the scientific content, the convenience of the training methods, and the evaluation methods. The jury members suggested minor modifications to the program, which were considered. Moreover, a pilot implementation of the program was also carried out on a sample of six teachers of the non-participants in the main study to make sure that the program could be easily utilized, the required time was sufficient, and to identify any technical problems that would emerge. The results revealed that the program had clearly set objectives, in addition to strong motivation among the participants, the sufficiency of time, and the ease of applying strategies and training activities. Some technical problems emerged and were avoided in the final application of the program. By the end of this step, the researcher had answered Research Questions 1 and 2 of the present study.

Procedures of the study

The following procedures were followed to implement the empirical study:

1. Developing, adjusting, and verifying the scientific consistency of the suggested program in a pilot experimentation.
2. Pre-administration to the nano-literacy test.

3. Implementing the suggested program for a six-month period.
4. Post-administration to the nano-literacy test.
5. Collecting raw data and conducting statistical analysis.

Results of the study

Research Questions 1 and 2 were answered through the method and procedures of the study presented above. The following paragraphs presents answer to Research Question 3, and discussion and interpretation of the results.

Research Question 3 states "What is the effectiveness of the suggested professional development program in enhancing nano-literacy for secondary school science teachers in KSA (as a total degree and sub-dimensions)?". In order to answer this question, the study tested the following hypothesis: " There are no statistically significant differences between the mean scores of science teachers in the pre- and post-administrations to the nano-literacy test as a total degree and sub-dimensions". To test this hypothesis, the researcher calculated the means, standard deviations, and the Paired Samples T Test values to determine the statistical significance of the difference between the mean scores of the female teachers participating in the pre- and post-administrations to the nano-literacy test as a total degree and sub-dimensions (see table 3).

Table 3

Results of T test for the significance of differences between the mean scores of the teachers in the pre- and post-administrations to the nano-literacy test as a total score and sub-dimensions (N = 33)

Dimensions	Test	Mean	Std. Deviation	df	t	Sig.	Statistical significance
Nanotechnology concept	Pre	1.091	0.765	32	13.791	0.00	Significant at (0.01)
	Post	2.576	0.502				
History of the development of nanotechnology	Pre	0.788	0.650	32	9.712	0.00	Significant at (0.01)
	Post	1.727	0.452				
Characteristics and goals of nanotechnology	Pre	1.515	0.667	32	29.270	0.00	Significant at (0.01)
	Post	4.667	0.777				
Stages of the applications of nanotechnology manufacturing	Pre	1.061	0.609	32	15.739	0.00	Significant at (0.01)
	Post	2.606	0.496				
The applications of nanotechnology	Pre	6.485	1.482	32	31.715	0.00	Significant at (0.01)
	Post	18.909	3.066				
Risks & Ethical considerations of nanotechnology	Pre	1.030	0.684	32	15.385	0.00	Significant at (0.01)
	Post	2.545	0.506				
Total	**Pre**	**11.970**	**3.293**	**32**	**50.747**	**0.00**	**Significant at (0.01)**
	Post	**33.030**	**4.496**				

Results presented in table (3) show that the total value of "t" test amounted to (50.747), while the "t" values for the sub-dimensions ranged between (9.712- 31.715), which indicates that there are statistically significant differences at the level (0.01) of significance between the mean scores of the teachers in the pre- and post-administrations to the nano-literacy test as a total degree and sub-dimensions in favor of the post-administration. Accordingly, the study hypothesis was refuted.

In order to demonstrate the effectiveness of the professional development program in enhancing nano-literacy for the participants, Cohen's d equation was used. The results were interpreted based on the value of (d) according to the following formula:

$$d = \frac{t}{\sqrt{N}}$$

Where:
The square root of the sample size
$\sqrt{N} = \text{Square root of sample size}, t = t \text{ value}, d = \text{effect size}$
…….

d = 0.2 is a small effect.
d = 0.5 is a medium effect.
d = 0.8 is a large effect.

This means that the value of (d= 0.2) indicates a small effect size, while the value of (d= 0.5) indicates a strong effect size of the independent variable on the dependent variable (see table 4 for detailed results).

Table 4

Results of Cohen's d equation for determining the effectiveness of the professional development program in enhancing nano-literacy for secondary school science teachers

independent variable	dependent variable	t	d	effect size
The professional development program	Nanotechnology concept	13.791	2.401	large
	History of the development of nanotechnology	9.712	1.691	large
	Characteristics and goals of nanotechnology	29.270	5.095	large
	Stages of the applications of nanotechnology manufacturing	15.739	2.740	large
	The applications of nanotechnology	31.715	5.521	large
	Risks & Ethical considerations of nanotechnology	15.385	2.678	large
	Total	**50.747**	**8.834**	**large**

Results presented in table (4) point out that the values of Cohen's d as a total degree and sub-dimensions were high (ranging between 1.691- 8.834), which indicates that the suggested professional development has large effectiveness in enhancing nano-literacy for secondary school science teachers participating in this study. Thus, the researcher has answered Research Question 3.

These results demonstrate that the professional development contributed substantially to the development of nano-literacy for the participating science teachers. It is also evident that the gains exceeded the statistical significance to the practical significance that justifies the implementation of the program on a regular basis to enhance the trainees' nano-literacy. Thus, these results are considered de facto evidence of the significant contribution of the program to the development of the cognitive aspect of nano-literacy for the participating teachers.

The results of the present study extend the generalizability of these reached by previous related studies in terms of the positive impact of the various professional development programs delivered to science teachers in developing their knowledge, awareness, and understanding of NST concepts (e.g. Feldman-Maggor, et al., 2022; Michailidi & Stavrou, 2022; Sgouros & Stavrou, 2019; Zor & Aslan, 2018; Wischow, et.al, 2012).

The results reached can be explained as follows:

1. The program introduced direct content knowledge associated with NST concepts, in addition to encouraging teachers to collect novel content knowledge and editing it in a participatory manner through participatory wikis, which eventually helped in the forming a new background knowledge for teachers.
2. The participating teachers played active roles in building their own knowledge within a collective context based on dialogue and discussion, aligned with social constructivism principles. Strong self-motivation was also observed among teachers to develop and foster their knowledge of NST concepts, which enhanced their nano-literacy.
3. The activities and tasks of the program included a direct connection between NST concepts and real classroom teaching practices, along with taking advantage of this connection in enriching the introduced science curriculum, thus providing a realistic perspective of the acquired cognitive aspect of nano-literacy.
4. Writing blogs encouraged teachers to engage in reflective learning, thus enhancing their gains from the cognitive content in terms of improving their teaching practices.
5. The focus of the program on effective professional development features had a strong impact on fostering the effectiveness of the program in improving teachers' nano-literacy.
6. The online implementation of the program considered the different conditions of teachers, such as appropriate time schedule, and encouraged them to cooperate asynchronously by collecting and editing scientific material in a collaborative manner through the participatory wiki platform and taking

advantage of the potential of social networks utilized in the program.

Recommendations of the study

In light of the results reached, the study made the following recommendations:

1. Adopting the professional development program introduced in this study as a program for pre- and in-service teachers to develop their knowledge of nano-literacy.
2. This program should be follow by new phases that focus on other aspects of nano-literacy, including the critical thinking skills, decision-making, and educational implications.
3. Leverage social networks such as Twitter, blogs and wikis in the implementation of professional development programs in light of their significant roles in achieving the features of effective professional development.
4. Delivering professional development programs online, which aligns the conditions of teachers as demonstrated in this study.
5. Introducing NST concepts in teacher preparation courses at the faculties of Education in accordance with the conceptualization of content knowledge presented within the TPACK framework.

Suggestions for further research

1. Investigating the effectiveness of a program that integrates the other aspects of nano-literacy in developing the various dimensions of nano-literacy for science teachers.
2. Examining the effectiveness of a professional development program in fostering nano-literacy for different STEM disciplines teachers.
3. Replicating the program suggested in the present study on a sample of students at the Faculty of Education.
4. Conducting a qualitative follow-up study to investigate the effect of the current professional development program on nano-literacy for the student teachers who completed this training.

References

Abu-Much, R., & Hugerat, M. (2017). Lab Activities for Introducing Nanoscience to Teachers and Students. *International Journal of Educational and Pedagogical Sciences*, *11*(5), 1154-1158.

Açıkel, B. (2018). Exploring high school teachers' and students' experiences in the development of interactive exhibits on nanotechnology applications integrating responsible research and innovation: Practical approaches, challenges and benefits.

Al Husseiny, F., & Saab, J. M. (2024). Education's Role in Integrating Nanotechnology in the Curriculum for the Future. In *Revolutionizing Curricula Through Computational Thinking, Logic, and Problem Solving* (pp. 118-132). IGI Global.

Al-Atiyat, P. (2016). The levels of science teachers' understanding of nanotechnology domains and their attitudes toward the applications of this technology. *Educational Sciences*, 24 (1), 127-166 (in Arabic).

Al-Douri, J. (2022). The contribution of nanotechnology to technological innovation. *Fikr Magazine*, (33), 184-185 (in Arabic).

Al-Mafarji, Z. (2023). The legal framework for the use of nanotechnology. *Journal of Sustainable Studies*, 5 (1), 1731-1762 (in Arabic).

Al-Salwi, W., Al-Suwaidi, B., & Al-Hakimi, P. (2020). The effect of a suggested course in nanotechnology on the development of concepts and attitudes among science student teachers at the Faculty of Education, Taiz University. *Journal of Educational Research and Studies*, (13), 28-63 (in Arabic).

Al-Tamimi, P. (2018). The levels of nanotechnology concepts' awareness for male and female students enrolled in the educational diploma at the University of Hail. *Arabian Gulf Message*, 39, (148), 41-57 (in Arabic).

Al-Taqbi, H., & Al-Ghuwaij, L. (2021). The effectiveness of nanotechnology in general education science curriculum. *Educational Journal*, (18), 563-575 (in Arabic).

Baghdadi, M. (2020). Female science teachers' awareness of "nanotechnology" at secondary school in Makkah Al-Mukarramah. *Reading and Knowledge Journal*, (225), 131-164. (in Arabic).

Cox, E. K. (2012). *Nanotechnology and secondary science teacher's self-efficacy* (Order No. 3517477). Available from ProQuest Dissertations & Theses Global. (1032674482).

Dorouka, P., Papadakis, S., & Kalogiannakis, M. (2020). The influence of digital technology on young children's" nano-literacy.". In *ISCAR (International Society of Culturalhistorical Activity Research)*

Regional Conference 'Crisis in contexts', e-proceedings (pp. 308-320).

Dorouka, P., Papadakis, S., & Kalogiannakis, M. (2021). The Contribution of the Health Crisis to Young Children's Nano-Literacy through STEAM Education. *Hellenic Journal of STEM Education*, *2*(1), 1-7.

Eid, S. (2021). A suggested program in Nano Science and Technology for developing science student teachers' evaluative thinking skills and awareness of nanotechnology issues and its biological and environmental applications. *Journal of the College of Education*, 37 (12), 379 – 437 (in Arabic).

Feldman-Maggor, Y., Tuvi-Arad, I., & Blonder, R. (2022). Development and evaluation of an online course on nanotechnology for the professional development of chemistry teachers. *International journal of science education*, *44*(16), 2465-2484.

Friedersdorf, L. E. (2020). Developing the workforce of the future: how the national nanotechnology initiative has supported nanoscale science and engineering education in the United States. *IEEE Nanotechnology Magazine*, *14*(4), 13-20.

Gana, S. C., Aji, E. O., & Gimba, R. W. (2020). Awareness of nanoscience and nanotechnology among science teachers in science and technical schools in federal capital territory Abuja, Nigeria. *AU E-Journal of Interdisciplinary Research*, *5*(1).

Ha, V. L., & Lajium, D. A. (2022). Scoping Review: Appropriate big ideas of nanoscience and nanotechnology to teach in chemistry for secondary School. *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, *7*(12), e002016-e002016.

İpek, Z., Ali, D. A., Tan, Ş., & Erkoç, F. (2020). Awareness, exposure, and knowledge levels of science teachers about nanoscience and nanotechnology. *Issues in Educational Research, 30*(1), 134-155.

Jad, E. (2022). A suggested environmental nanotechnology program to develop environmental problem-solving skills and strategic thinking among biology, geology and environmental sciences student teachers. *The Egyptian Journal of Scientific Education*, 25 (1), 1–44 (in Arabic).

Khalifa, M., Khalil, A., Shehata, Sh., Abdel Fattah, & Lundy, G. (2020). The effectiveness of teaching an enrichment unit in chemistry using the web quest strategy on the comprehension of some nanochemistry concepts and the attitudes toward e-learning for first-year secondary school students. *Studies in University Education*, (48), 419 – 427.

Khalil, A., Abdel Aal, T., Abu Naji, M., & Muhammad, S. (2017). The effectiveness of a suggested program in nanochemistry in developing student teachers' reflective thinking skills. *Studies in Higher Education,* (13), 5-25.

Lee, C. K., Wu, T. T., Liu, P. L., & Hsu, S. (2006). Establishing a K-12 nanotechnology program for teacher professional development. *IEEE Transactions on Education*, *49*(1), 141-146.

Leonidas, M., Anna, S., Euripides, H., & Petros, K. (2022). What does "Nanoscience –Nanotechnology" mean to primary school teachers? *International Journal of Science and Mathematics Education, 20*(6), 1269-1290.

Lin, S. Y., Wu, M. T., Cho, Y. I., & Chen, H. H. (2015). The effectiveness of a popular science promotion program on nanotechnology for elementary school students in I-Lan City. *Research in Science and Technological Education*, *33*(1), 22–37.

Mandrikas, A., Michailidi, E., & Stavrou, D. (2020). Teaching nanotechnology in primary education. *Research in Science & Technological Education*, *38*(4), 377-395.

Mandrikas, A., Michailidi, E., & Stavrou, D. (2021). In-service teachers' needs and mentor's practices in applying a teaching–learning sequence on nanotechnology and plastics in primary education. *Journal of Science Education and Technology*, *30*(5), 630-641.

Menon, D., & Devadas, M. S. (2019). Engaging preservice secondary science teachers in an NGSS-based energy lesson: A nanoscience context. *Journal of Chemical Education*, *96*(3), 528-534.

Michailidi, E., & Stavrou, D. (2022). Supporting the implementation of a nanotechnology teaching-learning sequence through post-induction science teacher mentoring. *International Journal of Science Education, 44*(2), 297-323.

Nichol, C. A., & Hutchinson, J. S. (2010). Professional development for teachers in nanotechnology using distance learning technologies. *Journal of Nano Education, 2*(1-2), 37-47.

Sakhnini, S., & Blonder, R. (2015). Essential concepts of nanoscale science and technology for high school students based on a Delphi study by the expert community. *International Journal of Science Education, 37*(11), 1699–1738.

Sgouros, G., & Stavrou, D. (2019). Teachers' training in developing nanoscience and nanotechnology teaching modules in the context of a community of learners. In *Bridging Research and Practice in Science Education* (pp. 339-356). Springer, Cham.

Spirtou, A., Manou, L., Peikos, G., & Papadopoulou, P. (2018). *Investigating the Secrets of the Nanoworld*. Athens: Gutenberg - Dardanos.

Spyrtou, A., Manou, L., & Peikos, G. (2021). Educational significance of Nanoscience–Nanotechnology: Primary school teachers' and students' voices after a training program. *Education Sciences, 11*(11), 724.

Toumey, C., & Baird, D. (2006). Building nanoliteracy in the university and beyond. *Nature Biotechnology*, *24*(6), 721-722.

Tuba Şenel Zor, & Aslan, O. (2018). The effect of activity-based nanoscience and nanotechnology education on pre-service science teachers' conceptual understanding. *Journal of Nanoparticle Research, 20*(3), 1-22.

Tuominen, M. T. (2012). *Nanotechnology Training for K12 Science Teachers at the NSEC Center for Hierarchical Manufacturing*. Retrieved from http://eprints.internano.org/1908/

Wischow, E. D., Brayn, L., & Bodner, G. M. (2012). Secondary science teachers' development of pedagogical content knowledge as result Of integratıng nanoscience content in their curriculum. *World Scientific 8*(2), 187-209.

Yawson, R. M. (2012). An epistemological framework for nanoscience and nanotechnology literacy. *International Journal of Technology and Design Education, 22*(3), 297-310.

Zarei, M., Najafi, P., Saadatmand, Z., & Yarmohmadiyan, M. H. (2014). Evaluation of the dimensions of professional development program for teachers in the field of nanotechnology from the viewpoints of Isfahan teachers. *Research in Curriculum Planning*, *11*(41), 23-33.