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Scoping Review: Appropriate Big Ideas of Nano Science and Nanotechnology to Teach in Chemistry for Secondary School

Voo Lee Ha[1*], Denis Andrew Lajium[2]

[1]Fakulti Psikologi dan Pendidikan, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.
Email: kelascikguvooleeha@gmail.com
[2]Fakulti Psikologi dan Pendidikan, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.
Email: denisadl@ums.edu.my

CORRESPONDING AUTHOR (*):
Voo Lee Ha
(kelascikguvooleeha@gmail.com)

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ABSTRACT

In the last decade, the nanotechnology sector is rising to take over the manufacturing of consumer products including pharmaceuticals. Due to the rapid advancement of nanotechnology, Malaysia has also taken the lead by introducing nanotechnology to Form Five students in 2021 following the revision of curricula in 2017. While research on which big ideas in nanotechnology to teach is still lacking around the world, the goal of this scoping review was to identify appropriate big ideas of nanotechnology to include in the secondary school curriculum using the Model of Educational Reconstruction (MER). The scoping review was conducted by adopting a framework with five stages including (1) identifying the research question, (2) identifying relevant studies, (3) study selection, (4) charting the data, and (5) collating, summarizing, and reporting the results. From the 30 pertinent articles included in this paper, it was found that big ideas that were used in many of the included articles are size and scale, self-assembly, size-dependent properties, volume-to-surface area concept, and applications of nanotechnology. Students gave positive feedback when they learned this unit with hands-on activities, using models, and when they attend nanotechnology conferences, whereas teachers wanted more courses on teaching nanotechnology to be provided because most science teachers were trained before nanotechnology was included in science teachers' educational program. Overall, this study can be used to gain insights into the suitability of teaching nanotechnology concepts to secondary school students based on students' achievements in past studies as well as teachers' and students' perspectives.

Contribution/Originality: This study is one of the very few studies that investigated the appropriate big ideas or concepts of nanotechnology to be included in the curriculum for secondary schools. Though there were nine big ideas of nanotechnology identified, however, most of these big ideas of nanotechnology were too difficult for

secondary students to comprehend. This study also gives an overall insight into teachers' and students' perspectives on teaching and learning contemporary science as difficult learning units can temper students' interest towards learning the subject. Hence, this study contributes to the existing literature by suggesting big ideas of nanotechnology that have been adopted in the previous studies taught in secondary schools which had yielded positive achievement and perspective from the students.

1. Introduction

In the last decade, the nanotechnology sector is rising to take over the manufacturing of consumer products including pharmaceuticals. Malaysia Nanotechnology Association describes nanotechnology as an enabling technology as its ability to lead to more innovation across broader fields including agriculture, healthcare, information technology, energy production and utilization, homeland security and national defense, biotechnology, food industries, aerospace, material manufacturing as well as environmental improvement (UniMAP, 2010). Although Malaysia has been involved in nanotechnology since 2003, developed countries around the world are revamping efforts in research and development in this new technology to explore possibilities of nanomaterials for broader uses. The nanotechnology industries are expected to increase the demand for skilled workers in these fields, but the concern falls on the education system's ability to meet this demand (Sebastian & Gimenez, 2016). Developed countries such as the United States are financing the inclusion of nanotechnology courses in undergraduate engineering education by addressing technological, social, economic, and ethical challenges associated with nanotechnology through National Nanotechnology Initiatives (NNI) (Mohammad Yeakub Ali & Ismail, 2008). There is an increasing number of Asian countries moving in the same direction, offering nanotechnology courses for bachelor's degrees and master's degrees as part of university programs, with India leading the way with most universities offering bachelor's and master's degrees in nanotechnology, followed by Japan and Pakistan (EduRank, 2021). Recent decade showed that scholars (Bhushan, 2016; Blonder & Sakhnini, 2015; Hutchinson et al., 2009; Laherto, 2010) had been advocating the importance of incorporating nanotechnology in the chemistry subject for younger learners specifically to the secondary level chemistry as they believed this modern science would bring changes to the young learner's perception towards learning science.

Due to the rapid advancement of nanotechnology, Malaysia has also taken the lead in the field of education to reduce the gap between the nanotechnology industries and education. As a result, in 2021, Form Five students in Malaysia received their first introduction to nanotechnology, following the revision of curricula in 2017 to the *Kurikulum Standard Sekolah Menengah (KSSM).* This revision involved the reconstruction of the curriculum from the primary level to the secondary level and was conducted robustly to level the country's curricula with international standards to produce youth with 21st-century skills and high-order thinking skills while also producing holistically balanced human intellectually, spiritual, emotionally, and physically. STEM subject curricula were revised to develop scientifically literate students that would be able to apply scientific knowledge when making important decisions and solving real-life problems (Bahagian Pembangunan Kurikulum, 2018). This document specifically emphasized the importance of learning biology, physics, and chemistry to produce students that would venture into careers involving STEM fields who would play active roles in the development of the country and society. Scholars

(İpek et al., 2020b; Laherto, 2010; Laszcz & Dalvi, 2021; Lin et al., 2015b; Spyrtou et al., 2021) have contended the potential of nanotechnology in increasing students' awareness, interest, imagination problem-solving skills that can promote students' career planning. When learning nanotechnology, students have access to a plethora of science and technology development and contributions to their daily lives like nanoparticles in sunscreens, self-cleaning fabrics, and sports equipment thus, guiding them to understand underlying science concepts of the technological world hence increasing their interest in science. Nevertheless, the newly revised Chemistry curriculum that carries nanotechnology topics at the upper secondary level displayed the applications of nanotechnology in daily life without providing any interpretations of the underlying nanoscience concepts of the applications, giving the researcher insight that this topic is not adequately covered in Malaysian secondary school chemistry curriculum. Meanwhile, although the inclusion of nanotechnology in the curriculum has been gaining attention lately in many developing countries, Ipek et al.(2020a) and Laherto (2020) noted that there are still many countries' curriculum makers that have not yet decided on contents to be taught in the nanotechnology curriculum for the secondary school level.

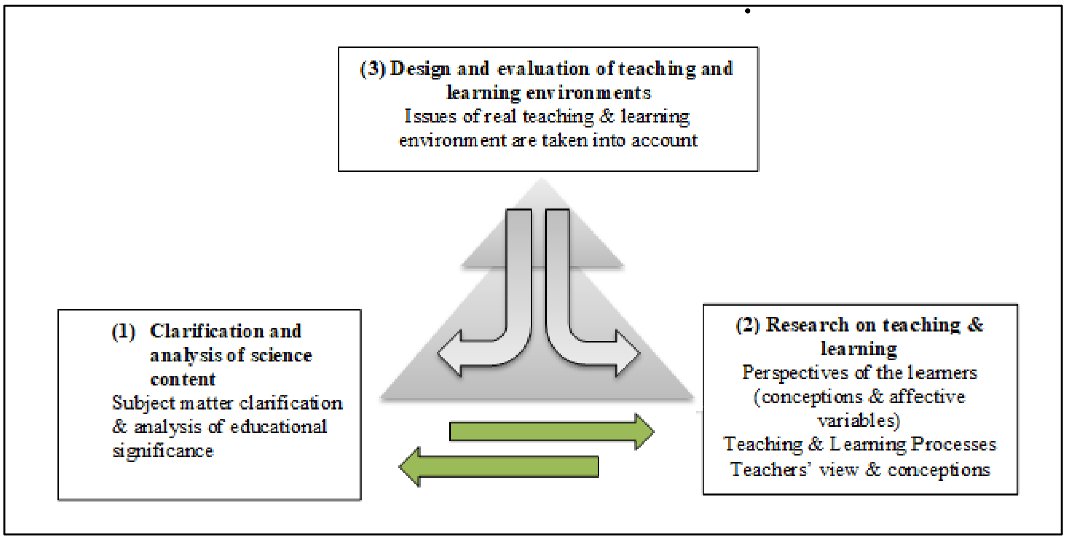
2. Literature Review

2.1. Theoretical Background

This study is conducted based on the Model of Educational Reconstruction, a model proposed by Kattman et al.(1996) to provide a theoretical framework to explore the possibility of teaching particular science concepts, principles, and views of the nature of science (Sgouros & Stavrou, 2019). It was designed to address the gap between science education research and the practice of science instruction balance hence facilitating knowledge absorption during the teaching and learning process. The key assumption of this model is that curriculum developers' awareness of the student's views of points may influence the reconstruction of the subjects hence where this current paper is aimed to answer. A deep understanding of students' conception can provide adequate understanding when referring to science content by the curriculum developers as well as to well provide significant guidance when planning science instruction in school practice (Duit et al., 2012).

According to Diethelm et al. (2012) paper, this model was refined by Duit et al. (2005) and was structured into three interrelated components namely (1) clarification and analysis of the scientific content to explore the educational significance of the content, (2)research on teaching and learning to explore perspectives of the learners and teachers as well as the teaching and learning processes and (3) design and evaluation of teaching and learning environments to analyze the design of instructional materials, learning activities, and teaching and learning sequences. This model has been implemented to analyze the educational perspectives of modern scientific topics nanoscience and nanotechnology in several research papers by Laherto (2010), Laszcz and Dalvi (2021), Stavrou et al. (2015), and, Spyrtou et al. (2021) and other fields that required empirical research to be incorporated into other subject curricula. Figure 1 illustrates the components of the Model of Educational Reconstruction (MER).

Figure 1: Three components of the Model of Educational Reconstruction by Duit et al. (2005)



The first component of the model aims to clarify specific science conceptions and content structure from an educational point of view. It was performed through qualitative content analysis of leading textbooks on the topics under inspection as scientific knowledge is often presented in an abstract and condensed manner. Students might have difficulties understanding them hence inaccessible to them and sometimes misleading. Science content structure may not be directly transferred for content structure for instruction instead, will go through a sedentarization process to make the content structure accessible for students as well as into context that makes sense for their understanding. Duit et al. (2012) also emphasized giving attention to science processes and the relevance of science in daily life and society when reconstructing science instruction just recently as part of the educational reconstruction. The second element of the model addresses empirical studies on learning settings including investigating students' perspectives like their interests, self-concepts, and attitudes. This also includes studies on teaching and learning processes, instructional methods, experiments, and other instructional tools as well as teachers' views and beliefs of the science concepts. The heart of the third component of the MER is the design of learning-supporting environments. It must be structured by the specific needs and learning capabilities of the students to achieve the goals set. Resources for designing activities relied on the research findings on students' perspectives (element #2) and results of the subject matter clarification (element #1). Various empirical methods through interviews, questionnaires on the development of student's cognitive and affective variables as well as video on instructional practice, are used to evaluate materials and activities designed as well as provide guidelines for the rearrangement of learning sequences and design of learning environments hence these elements.

This paper which focused on the big ideas of key concepts to include in teaching nanotechnology in secondary schools deals with the first and second elements of this model which is through the clarification and analysis of scientific contents as well as analysis of empirical studies in nanotechnology education. In the case of this paper, the content of nanotechnology has been documented therefore, through close examinations of a handful of published papers and books regarding the big ideas in nanotechnology, the appropriate concepts to be learned in the grade level in the questionnaire are identified. This method was employed in confidence by the author as these published papers have performed empirical studies through experimental research and interviews besides meta-analyses. Accordingly, this paper scrutinizes the effectiveness, perspectives, and teaching methods employed to teach the big ideas of nanotechnology from the critical perspective of science and technology studies hence, this paper also indirectly deals with the second and third elements of the model as the existing literature that taken into reviews in this paper deals with students and teachers' voice as well as conducive teaching environment to teach the concepts for nanotechnology.

2.2. Educational Significance of Nanotechnology

Nanotechnology is a blend of engineering, physics, chemistry, biology, and medicine, and it requires a competent workforce for research, development, and manufacturing to sustain and grow in the industries. As was noted in the preceding section, scholars contend that besides offering nanotechnology to higher education level students, it is vital to start early by including the nanotechnology lesson for the younger learners to learn in the classrooms as this can help increase enrolment in the course in the universities hence increasing the chance to meet the industrial demand for skilled workforce in nanotechnology. The biggest challenge would be to attract students' interest towards learning science as students perceived science that they are learning in the classroom is getting more complex as they grow up thus leaving them feeling irrelevant to what they are learning in the classroom (K. Ban & S. Kocijancic, 2011; Montes et al., 2018). Roco et al. (2011) described this challenge for nanotechnology in education as a bottleneck for nanotechnology development for the future. Laherto(2010) described that students' enrolment in science courses at the secondary level has been decreasing due to students losing interest in science when the science concepts get more complex as they grew up. Spytrou et al.(2021) stressed that the reason behind the decline is that students felt school science seems disconnected from their daily lives and that introducing modern development in science and technology into the curriculum is underestimated in teaching science in the classroom. Fonash (2001) also relates that ill-informed parents, teachers, and society on science and technology development contributed to students' declined interest in science despite the youth growing up with technology, computers, and mobile devices, and student's enrolment in courses related to creating and manufacturing is declining. Most of them are unaware of nanotechnology, an emerging technology that scientists believed would keep the entire technological world evolving. Henceforth, it is believed that by introducing nanotechnology at the secondary level, students would perceive chemistry subject as more relevant to their lives a more modern than what they usually learn in school, and consequently their motivation to study chemistry and related subjects would increase (Blonder & Sakhnini, 2017). Besides, introducing nanotechnology to the curriculum would be beneficial to a country's development in all aspects including the economy besides to the students as the future leaders of the world to be an informed individuals if not skilled to create but, able to make the right decisions for tomorrow's nation. İpek et al. (2020a) have emphasized that having good nanoscience and nanotechnology knowledge at an early level of education can affect students' self-efficacy for academic and, future career choices, besides being science-informed citizens and literate when it comes to scientific communication.

2.3. Big Ideas

Science educators from around the world were concerned about the introduction of nanotechnology in secondary schools as this new topic are not within teachers' background knowledge nor curriculum material. The demand to teach nanoscience and nanotechnology at this level would require an exploration of how these subjects can be meaningfully introduced in secondary schools. Hingant and Albe (2010) explained that a better strategy for this purpose would be to systematically integrate new scientific ideas into the curriculum while keeping in mind to make the concepts more interdisciplinary. This would mean that the connection between nanoscience and traditional mathematics and science must be made explicit to students across the grades. They further explained that materials must be developed to support this learning core principle hence, they can ensure that curriculum, instruction and assessment can be aligned. Such materials developed based on agreed learning goals would help students develop an understanding of the relevant scientific concept and see the importance of nanoscience in their lives. While Sakhnini & Blonder (2015) argued that for students to develop an understanding of the world around them, educators must enable students to experience and value evidence in scientific activity by framing the curriculum in terms of big ideas. In other words, big ideas would enable students to experience how science enables us to understand how the world works.

Stevens et al. (2007) identified the seven big ideas to teach in the Nanotechnology curriculum from the National Nanotechnology Initiatives of the United States however, according to Blonder and Sakhnini (2017)**,** these big ideas displayed are a mix of new ideas such as self-assembling are not exclusively referring to nanoscience and nanotechnology only hence, further asking the question, "what concepts are considered as essential to grasping the understanding of nanoscience and nanotechnology. Selecting essential concepts appears to be an opportunity to reconstruct the existing contents in the curriculum that have been taught in science classrooms for decades. The big ideas developed by employing the Delphi study are, size-dependent properties, innovation and application of nanotechnology, size and scale, characterization methods, functionality, classification of nanomaterials, fabrication approaches for nanomaterials, and the making of nanotechnology. Sakhnini & Blonder (2018) argued that all these big ideas were developed based on the notion to prepare future nano workers as well as preparing citizens to be informed citizens that would be able to participate in debates on emerging science and technology.

Nanotechnology is a multidisciplinary subject thus it involves many fundamentals science concepts, therefore, to enable students to understand phenomena within nanoscience and across disciplines, review a book published by the National Science Teacher Association in the United States namely, 'The Big Ideas of Nanoscale Science and Engineering recognized nine big ideas to teach in nanotechnology, however, Hingant and Albe (2010) and Stavrou et al. (2015) demonstrated that this document did not specify which nano-related concepts should be taught and was not explicitly linked to current standards, making integration into the curriculum difficult. Stevens et al. (2007) insisted on considering which topics are important, which ones should be incorporated into the curriculum, appropriate level, instructional sequence, and connecting new ideas with the already part of the curriculum when teaching the topic of nanotechnology in the classroom. Additionally, this statement is an extension to Sakhnini and Blonder (2015)'s argument that for rendering those key concepts coherent and expedite their integration in the classrooms, one must clarify the big ideas and define the prior knowledge to understand the big ideas required to understand the new concepts and this should be selected according to students' grade level. Big ideas are the core of a domain and can become building blocks deeper understanding of science concepts Harlen et al.(2015) described what big ideas should be – big ideas should have explanatory power, and provide the basis for understanding issues whereas these could lead to enjoyment and satisfaction. Stavrou et al. (2015) added to consider the importance of students' reasoning ability when learning all the big ideas identified for nanotechnology. Therefore, it is imperative to add value to the present nanotechnology curriculum by selecting appropriate big ideas to be taught in the secondary level school.

There have been arguments stating that younger learners would be unable to comprehend the concept of nanoscience. Swarat et al. (2011) argued that size and scale concepts with nanoscience on the nano-scale objects are difficult because nano-scale things are not accessible for students to manipulate and engagement in hands-on activities is challenging since nano-scale objects are not visible to their naked eyes. However, size and scale notions of nanoscience are the fundamentals of nanoscience, particularly in terms of surface-area-to-volume-ratio and it is a concept that exists within the curriculum the same way students need to comprehend the concepts in many scientific processes like rate of diffusion, rate of reaction, growth and building structure of different sizes. A pilot study by Mandrikas et al. (2020) on 45 primary students, demonstrated that these students can understand the size and scale concept and 62% of these students can explain changes in the nano-scale objects using surface-area-to-volume-ratio concept when the teacher used varieties of activities, model and experiments when delivering the lesson. This result is consistent with Hingant and Able (2010)'s findings in their paper that, despite students' challenges grasping extremely small scales, hands-on experience with small-scale matter would be crucial to aid students' conceptualization, emphasizing the importance of tools and instrumentation in helping students understand invisible nano concepts.

While this study agrees that understanding this concept involving students' reasoning ability is a high cognitive ability, Mandrikas et al. (2020) have demonstrated that students as young as primary school can reach that cognitive level when teachers use modeling by utilizing readily available teaching materials to aid students understanding with abstract conceptions. In another research by Lin et al. (2015b) it was revealed that Grade 6 students who participated in the three hours camp activities for nanoscience in a science education promotion, 323 students had achieved significant improvement in understanding NST topics that were divided into Nanophenomena in the natural world, 'nanomaterials and their scaling effect and 'definition, characteristics and applications of nanotechnology respectively when these students participated in experiments about lotus effect, visiting nano exhibition and interactive puzzles.

Additionally, there are two key factors identified that should be addressed according to Ahmed (2012) while developing a nanotechnology curriculum, namely formulating concepts and organizing them in the curriculum. According to the construction of curriculum principles, specific concepts are expanded to more abstract concepts so that the curriculum content can be learned logically. Therefore, gradually arranging the small facts into big concepts of nanotechnology, is consistent with hierarchical curriculum content Besides, organizing the content should consider effective approaches either traditional, inquiry, problem-solving or environmental to ensure that the nanotechnology content can tackle the nature and unique characteristics both teachers' and students' styles and ability.

Based on the literature reviewed above, they provide insights to the researchers that it is imperative to identify big ideas and teach them in a logical sequence for the students to grapple with the concepts underpinning nanotechnology. These findings also revealed that although nanoscience concepts seem too high order to attain for younger learners, selecting appropriate big ideas to be taught based on empirical research findings and through various instructional methods, there are big ideas that are appropriate to be taught for younger learners. Consequently, there seems to be a need to review the literature regarding appropriate big ideas to teach in nanotechnology so that concepts can be taught according to students' cognitive ability in more detail to identify: (1) big ideas of nanotechnology to be included in the secondary school curriculum and (2) students' and teachers' perspective of teaching and learning nanotechnology in secondary schools. A scoping review was deemed most appropriate for these outcomes because of its ability to map rapidly the big ideas proposed and its effectiveness in each paper reviewed besides incorporating a variety of research designs and focusing on breadth rather than depth as is suitable to perform the research for this paper. To date, there have been no reviews conducted regarding this purpose. This paper will summarize the state of the current literature and identify gaps that will provide direction for future research.

3. Methods

The review was conducted following a framework developed by Arksey & O'Malley (2005). Other review papers that utilized this framework can be referred to as Cartagena et al. (2021), Levac et al. (2010) and Reinders et al. (2019). This framework adopted five stages which are (1) identifying the research question, (2) identifying relevant studies, (3) study selection, (4) charting the data, and (5) collating, summarizing, and reporting the results which will be explained below.

3.1. Stage 1: Identifying the Research Question

This review aimed to identify appropriate big ideas to teach in nanotechnology secondary schools. Arksey & O'Malley (2005) suggested that the research question addressed as the guide for the search strategies and started with a broad review to see available resources before narrowing the search. The author of this paper is an experienced chemistry teacher and has reason to believe that appropriate big ideas to teach in nanotechnology must be identified for secondary-level learners to have meaningful learning for this particular topic however, there are limited papers and research with the same purpose existing to date. Identifying research questions was necessary as direction for the review and to determine how relevant papers will be identified and selected. The research questions of this review are (1) What is secondary level students' achievement when learning certain big ideas of nanotechnology? and (2) Do students achieve better when learning nanotechnology with methods of delivery?

3.2. Stage 2: Identify Relevant Studies

3.2.1. Search terms

Key terms were selected to locate studies pertinent to the research questions outlined above. The search terms used are "nanotechnology education" "nanotechnology big ideas" or "secondary school nanotechnology". The single phase associated with nanotechnology such as "nanotechnology" or "nanoscience" does not include since these key terms generated irrelevant and unmanageable large results. The search was conducted through different sources which are electronic journals, reference lists, as well as existing networks, relevant organizations, and conferences. Inclusion criteria were English language, published from the 2000s until 2022, and must be peer-reviewed. The author chose the 2000s as the starting date as the introduction to nanotechnology at the secondary level was very recent and such a period would had covered the major changes in the education scenario around the world since that particular year. Foreign language materials were excluded considering the cost and time involved in translating materials. Whilst we had to adopt these limits for practical reasons, it is worth pointing out that potentially relevant studies could have been missed.

3.2.2. Electronic Databases

This paper utilized four databases namely, Pro Quest, JSTOR, Scopus, and Springerlink. The author believed that these databases would reach all the relevant journals within the same area of interest. Overall, there were 2463 articles found using the above search terms and databases.

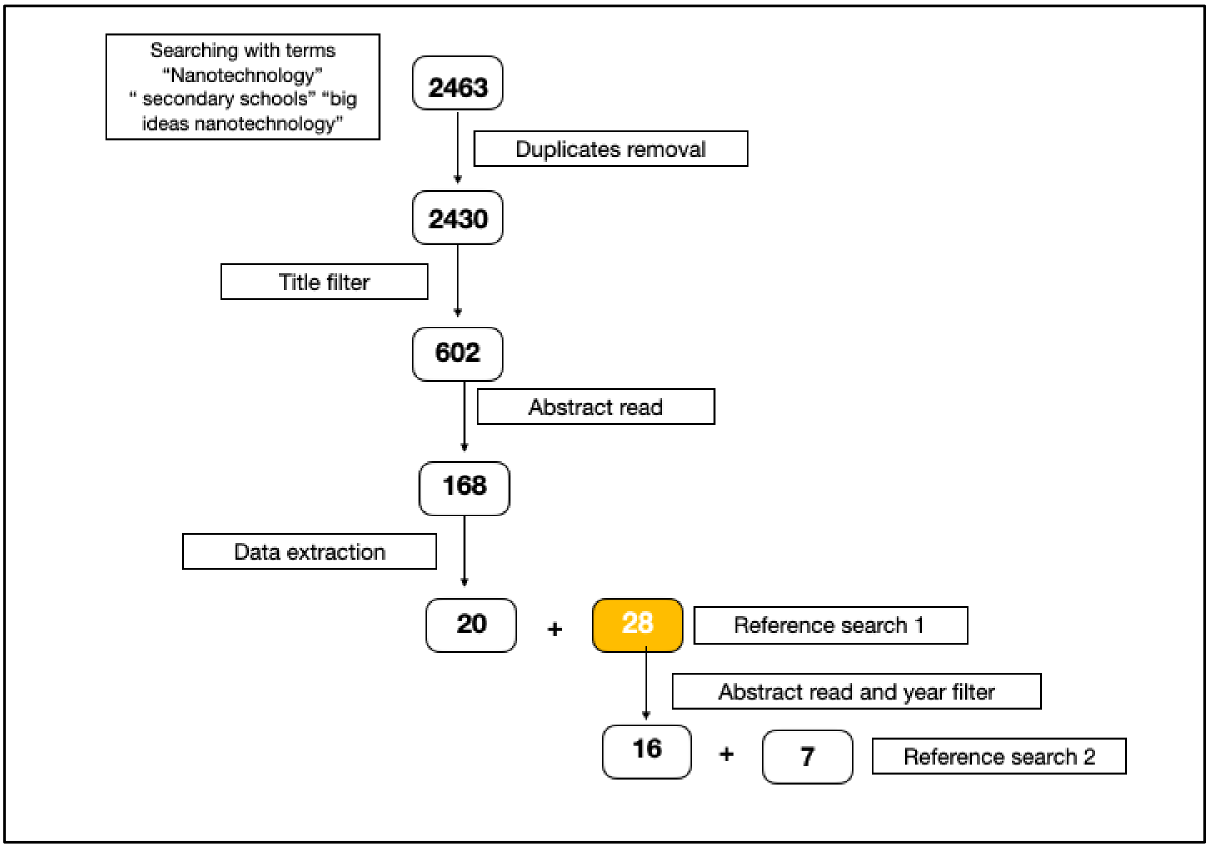
3.2.3. Stage 3: Study Selection

Researchers included quantitative, qualitative, and mixed designs research and several systematic literature reviews. The studies selected must be performed on students or teachers who are especially teaching chemistry or other science subjects. All potential articles were exported to the Mendeley application whereby duplicates were excluded. This step was then followed by reviewing the abstract and finally screening the full text. Articles that do not meet the inclusion criteria or did not focus on the topic of the current study were excluded. Excel computer program was used as a database as well as to classify the data gained for this study purpose.

During this stage, duplicated titles between these four databases were removed leaving only 2430 articles. The second author read the titles of all articles and remove irrelevant articles thus reducing the number to 602 articles. The first author read the remaining abstracts and removed irrelevant articles hence further reducing the number of articles to 168 articles for full-text review. The next step would be to read the full text by focusing on its methodology specifically on their sample study that must involve teachers and students of secondary schools. This inclusive criterion has reduced the number of articles to 20 to be included in this scoping review. The authors had an average 80% agreement rate after reading the full articles.

Besides, to ensure that there are no articles were missing, relevant titles from the reference lists of the 20 articles were examined in the same way describes above in the initial search results. From the reference lists, 28 relevant articles were found. After screening the abstract for closely related articles that potentially would answer the research question of this article, and selecting articles only from the year 2009 onwards, there were 16 papers were taken into the final review for this scoping review purpose. The reference of these articles was also reviewed, and there were seven articles pertinent to this scoping review. Hence, this selection procedure resulted in a total of 43 articles being reviewed. The summary of the study selection is shown in Figure 2 below.

Figure 2: The search process and study selections. A total of 43 articles are to be reviewed for scoping review.



3.2.4. Stage 4: Chart the data

The fourth stage of scoping review framework was to organize the data from the selected articles. The researcher is utilizing Microsoft Excel for this purpose and authors, title, publication year, location of study, purpose, research methods, interventions, key findings, and limitation of the study were the data collected for this stage.

3.2.5. Stage 5: Collate, Summarize and Report Results

The last stage of the Arksey & O'Malley (2005) framework was to organize the relevant findings into themes, by selecting results based on their relevance to the research questions. Therefore, sample size, participants, methods, and outcomes were included and reported in the results section below.

4. Results

This study initially found 2463 articles from electronic databases has been reduced to 47 articles after the abstract was reviewed. After researcher has performed full-text screening, 30 articles were selected to be included in this study that was found related to the research aims. See Appendix.

4.1. Demographics

Articles selected dated as early as 2004 and the latest paper pertinent to this current paper is 2021. However, only six articles were published between 2004 – 2010 while 24 articles were published between 2011- 2021. Of the selected articles one was from respectively Malaysia, Chile, Spain, Thailand, and Egypt, five were from Israel, and 16 were from the USA. All articles were published in English. All articles employed students and teachers while three of the articles employed experts and researchers as their respondents. The sample size for the articles collected was between 10 – 200 students and four to – 49 teachers.

4.2. Research Methods & Outcomes Measures

Most of the articles related to the current paper's research aims employed mixed methods 16 articles. These 10 articles utilized qualitative methods and five articles utilized quantitative methods. Regarding the outcome measures, the pertinent articles adopted various instruments for this purpose. There were 11 research-adopted questionnaires that either utilized the Delphi questionnaire, random surveys, ASAVA model, and S-STEM survey. There was six research that utilized pre-post tests to measure the outcomes of their research, six research used interviews to collect data, and three research relied on students' answer in worksheets after the intervention. There was three research adopted descriptive statistics to analyze collected data, three analytical articles, and three articles employed qualitative assessment of students' and teachers' answers on worksheets. The researcher also included one systematic review article as pertinent research on the current paper.

4.3. Interventions

Regarding types of interventions implemented in the pertinent articles, this current paper identified interventions ranging from the use of nanotechnology modules to hands-on activities, the use of computer software for workshops and conferences for teachers and students to testing a teaching-learning sequence (TLS), and didactic proposals as well as meta-analysis. All of these interventions were deemed to be appropriately analyzed as it enables the researcher to answer this current paper's aims.

The inclusion criteria for selecting the articles is that they must explore nanotechnology units from two perspectives based on the MER elements – clarification and analysis of science content and research on teaching and learning. The most common articles found were clarifying which nano concepts taught that would be attainable learned by the students (n = 15) while 14 articles were found to weld on the research from teachers' and learners' points of view. Most articles related to clarification of science content used the intervention of hands-on activities and the Delphi process or questionnaire in some way to select appropriate big ideas on nanoscience concepts for the secondary school regardless of which subject is suggested for insertion. Meanwhile, research on students' and teachers' perspectives on the teaching and learning of nanotechnology also used intervention with hands-on activities and nanotechnology modules, workshops for teachers, and summer camps or conferences for the students. Of all the articles selected, only Bryan et al. (2015) articles of meta-analysis found that identify nanotechnology content for pre-college students and teachers which gives the researcher idea that articles of the same kind for teaching nanotechnology in secondary schools are scarce.

4.4. Nanoscience concepts for secondary schools

There are eight big ideas of nanotechnology identified by Stevens et al. (2007) based on the National Nanotechnology Initiatives (NNI) but from the current findings of this research, we can conclude that only several nanoscience concepts and big ideas are included in these articles with most of the them teaching size and scale concepts and applications of nanotechnology. Seven studies teach the interventions' size and scale concepts and other big ideas. Hutchinson et al. (2009) study that aim to investigate students' interest in a variety of nanotechnology phenomena found that through interviews and surveys, students were most interested in activities related to size and scale. Additionally, other studies employed this big idea along with applications of nanotechnology like Quirola et al. (2018), Sakhnini and Blonder (2018), science discipline subjects, into the existing curricula for Chemistry, Biology, and Physics as these scholars intend to maintain the nature of nanotechnology as interdisciplinary units. The process of reaching consensus was participated by expert teachers in all three science subjects during nanotechnology courses and through the designing of didactic proposals to produce a teachers' handbook.

Blonder & Sakhnini (2012) also included more big ideas like self-assembly and size-dependent properties in nanotechnology courses for teachers. The self-assembly concept was also taught in Shipley and Lopez-Silva (2008)'s study to examine students' ability to learn the concept through hands-on activities and computer simulation. It was found that of 41 students, 77% of them were able to provide correct answers in the molecular self-assembly design tasks after intervention thus concluding that this concept is within the capabilities of secondary school students. Besides Blonder & Sakhnini (2012), the size-dependent properties were studied in another two articles along with the size and scale concept. Bryan et al. (2015) agreed that these two concepts had the greatest attention when it comes to selecting nanotechnology's big idea to teach to secondary school students in their systematic review article. Mandrikas et al. (2020) found that by using their teaching-learning sequence (TLS), even primary students can successfully understand size and scale, and size-dependent properties.

As for the volume-to-surface area concept in nanotechnology, five studies were found testing students' proportional reasoning ability to understand this concept. Taylor (2008) and Taylor and Jones (2009) specifically studied students' ability to understand this concept by using ASAVA instruments and pre-post tests after one week of class instruction intervention. This intervention which included investigation activities for the students revealed that there was a significant correlation between students' proportional reasoning ability and their understanding of volume to surface area relationship. Bryan et al. (2015) also included this concept in their meta-analysis to sort big ideas that had been examined in empirical studies around nanotechnology content for pre-college students. Stavrou et al. (2015), on the other hand, discovered that students with limited proportional reasoning ability would face challenges to explain the concept of volume-to-surface area relationship after implementing their TLS to eighth-grade students if teachers did not find alternative ways to explain this concept in a way that students could easily understand. However, an analytical article by Bowles (2004) emphasized to the inclusion of volume to surface area relationship into his TLS when introducing nanotechnology into the existing curriculum as it is one of the main concepts to understand the rate of reaction based on changing the size of surface area.

As for applications of nanotechnology, there were seven studies (Bowles, 2004; Hutchinson et al., 2011; Moyses et al., 2010; Quirola et al., 2018; Sakhnini & Blonder, 2016, 2018) that included applications of nanotechnology in their classroom instruction intervention, or meta-analysis. Although Sakhnini and Blonder (2016) and Moyses et al. (2010) introduced applications of nanotechnology and its impact on society only in their classroom intervention, these articles seem to have a consensus that this big idea can bridge the gap between the novelty of learning contemporary science to students and teachers and real life outside the classroom and be able to shift students' interest towards learning nanoscience concept as well as increasing students' awareness on how the world works and the ethics on implementing nanotechnology in daily life.

4.5 Students' Perspectives

According to MER, the development of instructional activities and research on issues about teaching and learning processes including students' perspectives is closely linked and interrelated with each other. Findings from interviews would provide guidelines for designing a TLS. The findings demonstrated 11 empirical research on students' perspectives involved with various interventions that utilized nanotechnology modules, instructions delivered through TLS that incorporated multimedia tools, and hands-on activities. However, studies by Blonder & Sakhnini (2015) and Delgado et al. (2015) explored students' perspectives through their participation, test results, and survey at nanotechnology conference and summer camp that teaches size and scale concept.

Findings showed that after interventions with teaching nanotechnology concepts in the classroom or attending conferences and summer camps, these students were found to demonstrate positive reactions upon being introduced to nanoscience and nanotechnology. Curreli et al. (2020) study found that Omni Nano Model online textbooks and physical implementation helped students to learn nanotechnology in advance. Meanwhile, in Shipley and Lopez-Silva (2008) and Chua and Kapurdewan (2020) studies that implemented hands-on activities to introduce nanotechnology revealed that students who were exposed to these interventions were able to answer correctly and able to explain the concept of acid and bases and the structure of atoms when given an intervention related to nanoscience when given test or during interviews. Meanwhile, Khamhaengpol et al. (2021) study revealed that while nanotechnology hands-on activities demonstrated students' high mean scores for basic science process skills but recorded the low average mean score for students' skills in the engineering design process. Moreover, in Stavrou et al. (2015) study, students revealed that they have difficulty understanding and comparing sizes at the micro-level due to their limited experience with nanoscale and micro-scale objects. Intervention with short exposure also produced similar results in the Laszcz and Dalvi (2021) study in which students were found to be able to make general statements about the size and scale of nanomaterials but unable to explain it on a deeper level. Besides, it was found that there is also potential confusion among the students when teachers used incorrect metaphors to explain the mechanism of the atomic force microscope (AFM). However, Laszcz and Dalvi (2021) concluded that despite students' inadequacies to understand deeply the size and scale concept, students appreciate the model used to simulate an AFM and students were eager to learn new science learning units of nanotechnology. This study also demonstrated a change in students' attitudes toward STEM subjects as well as their interest in a career related to nanotechnology.

Sebastian and Gimenez (2016) explored students' perspectives on using YouTube documentaries to introduce nanotechnology revealing that students think that the documentaries have interesting themes and contents and are useful for them. Meanwhile, when students used modeling software to learn the atomic scale phenomenon in Xie & Pallant's (2011) study, students achieved solid understanding and were able to apply the knowledge gained in new contexts based on downloads and the number of task submissions. For the nanotechnology conferences and workshops, in Blonder and Sakhnini (2015), it was revealed that students agreed that it was worthwhile to participate in the conference and had made a significant difference in their knowledge of nanotechnology compared to before they attended the conference. This finding is consistent with Delgado et al. (2015) study on the effect of learning size and scale during the summer camp which revealed that students had achieved descriptively high levels of overall scores after 12-hour learning of size and scale concept in a semi-structured interview.

4.6. Teachers' Perspectives

In the MER, teachers' perspectives were just as equally significant as students' perspectives however, the researcher only managed to find two articles that address teachers' perspectives in the articles exploring clarification of science content. The first article is by Quirola et al. (2018) which introduced the didactic proposal to introduce nanoscience and nanotechnology into the high school curriculum in Physics, Chemistry, and Biology. In this article, they collected teachers' responses during the designation of the didactic proposal and discovered that most teachers involved in this project lack knowledge of nanoscience and nanotechnology as most of them were trained before nanotechnology was included in the science teachers' educational programs. The second article by Huffman et al.(2015) explores the effectiveness of NanoTeach to train teachers to integrate NST content into their classes through case studies analysis revealed that teachers who participated in this program had demonstrated 60-75% mastery level from a field test results after participating in the course. The NanoTeach provide two weeks of professional development through face-to-face and online interactions, as well as peer group discussions among the teacher, and then these teachers were required to teach any nanoscience concepts and nanotechnology to their students by incorporating it into either Biology, Chemistry, or Physics according to their timeline. Huffman et al. (2015) study also revealed that after the course, teachers wanted to learn more about the nanoscience concept than pedagogy knowledge from the DESI framework questionnaire which is also consistent with Mandrikas et al. (2021) study which had demonstrate that teachers need more instructional knowledge to teach nanotechnology when they were implementing a 5E TLS designed community of learning consisted of experienced in-service teacher, science education researchers, scientists and museum experts for 9 months in primary schools.

5. Study Limitations

Of the 30 studies included, only six listed at least one limitation in the discussion section of the articles. The most common limitation is sample teachers' lacking nanotechnology knowledge or teachers' domain expertise was not inclusive of all three science disciplines as demonstrated by Quirola et al. (2018) and Sakhnini & Blonder (2018). Other studies commonly mentioned small sample sizes which limit the generalization of their findings. Pelleg et al. (2011) introduced the nanotechnology module to only students from science and engineering magnet schools rather than typical high schools hence the results from his findings cannot be generalized to other types of school students. Meanwhile, Mandrikas et al. (2020) had only implemented their TLS in small exposure and presented by the researcher themselves rather than teachers of the schools which can risk biases. Moreover, since there were only a small number of articles that mentioned its limitations, therefore there is probably a risk of bias if the authors included in this review did not include all the true limitations of their studies.

6. Discussions

This scoping review examined 30 peer-reviewed research articles that incorporated studies of appropriate big ideas to be taught in teaching nanotechnology in secondary schools and students' and teachers' perspectives on learning nanotechnology. Five big ideas were employed consistently in the included articles and had been empirically proven to be meaningful and comprehensible for secondary school learning, which are the size and scale, applications of nanotechnology, surface area to volume, size-dependent properties, and self-assembly. These studies revealed that students can perform well when they were given tests, as well as answering questionnaires. These findings were consistent with the MER whereby the clarification of the subject content was made according to students' abilities. Moreover, students and teachers had shown to favor learning the contemporary and cutting-edge learning units given it was delivered through effective methods of teaching which also satisfied MER's second element, research on students' and teachers' perspectives.

Stevens et al. (2007) identified nine big ideas in nanotechnology following NCLT Faculty Nanoscale Science and Engineering Education (NSEE) Workshop in 2006, but researchers discovered that most articles addressing big ideas in nanotechnology employed only one or two big ideas in them except for Sakhnini and Blonder (2018) study that performed a Delphi study on selecting most suitable big ideas of nanotechnology from teachers and nanoscientist point of views. Moreover, most studies that implement to test the effectiveness of TLS and didactic proposals, did not put nanoscience concepts in separate units instead they insert these concepts into relatable learning units in the existing curriculum. Perhaps when done in this way, students can understand that nanotechnology is not a foreign scientific concept but instead a progression of science and technology development just as the nature of science is rapidly changing. One suggested the reason why it was not recommended that all nine big ideas be taught in secondary schools is due to students' limited capabilities to understand the concepts introduced to understand nanoscience. Blonder & Sakhini (2012), Huffman et al. (2015), Laszcz and Dalvi (2021) and Sgouros et al. (2019) have agreed that while nanotechnology might encourage students to learn science, most topics are too complex for them to grasp. Furthermore, MER requires that scientific concept clarification examine the constraints of scientific theories and concepts and consider whether ideas or terms might impede learning thus they must undergo a critical review of their significance for students' conceptions and learning.

The application of nanotechnology is one of the most commonly utilized big ideas in teaching nanotechnology in conjunction with other big ideas, as demonstrated in Bowles (2004), Hutchinson et al. (2009), Moyses et al. (2010), Quirola et al.(2018), Sakhnini and Blonder (2018), and Stavrou et al. (2015), MER approved the use of nanotechnology applications to teach these topics since this approach also addressed the ethical and societal aspects associated with the ideas (Kattmann et al., 1996). This big idea was thought to be necessary for students to make decisions about the benefits of nanotechnology in contributing to an improved standard of living as well as its possible risks (Stavrou et al., 2015). Hutchinson et al. (2009) stated that students would be more motivated in participating in nano-scientific activities if they could perceive the connection between the lesson and their daily life. Furthermore, according to Sakhnini & Blonder (2016), when the big idea represents relevant contexts, it makes science more meaningful to students because they could learn how modern science works and the role of science and technology in finding solutions to everyday life problems. These points shed light on why it is desirable to incorporate nanotechnology applications to increase students' interest because of its significance in today's culture through consumer products, advertisements, mainstream entertainment, and books.

While the novelty of nanotechnology increases students' interest in learning science, Stavrou et al. (2015) showed that students had trouble understanding size and scale comparison at the micro level due to their lack of experience in everyday life after implementing their TLS. Students were unable to describe the notion of surface-to-volume ratio due to the lack of proportional reasoning abilities. This limitation may be resolved by employing analogies and models to help learners in utilizing their imagination to comprehend size comparisons. This result was reinforced by Laszcz and Dalvi (2021), who discovered that students like the usage of models to emulate AFM instruments, which are also a tool in nanotechnology that is not available in secondary schools. In contrast, Mandrikas et al. (2021) and Laszcz and Dalvi (2021) studies found that most teachers who participated in implementing their TLS on nanotechnology applications reported that they need more instructional knowledge on teaching nanotechnology. This finding highlights the importance of providing additional nanotechnology workshops for educators and teachers to avoid student misconceptions, such as those held by Huffman et al. (2015) with NanoTeach, Quirola et al. (2018), and Stevens et al. (2007) as most teachers were trained before the inclusion of nanotechnology in secondary school curricula.

From the students' perspective, it is worth noting students think that self-paced learning activities on an internet platform are interesting and useful as demonstrated by Sebastian & Gimenez (2016), Curreli & Rakich (2020), Xie & Pallant (2011). According to Hutchinson et al. (2009), students would be enthusiastic to engage in the activities held in online learning platforms on nanotechnology because they saw a connection between the topic with their interests and their everyday lives. Besides, it was also demonstrated that novel topics and activities that require their active involvement would also increase their interest to learn the topic. Additionally, the nanotechnology conference and workshops held by Sakhnini & Blonder (2015) at the NanoIsrael 2014 conference that had benefited 100% of students who attended the conference also showed that both students with prior knowledge and without topics had learned significantly from the conference. These findings on students' perspectives and perceptions towards alternatives to teaching nanotechnology showed that despite students may have difficulty in understanding some nanoscience concepts. There are numerous ways to assist students in learning and working toward this goal is worthwhile because it has been empirically proven that students who learned nanotechnology, as well as students who were interested in science-related careers, demonstrated a positive shift in their attitude toward learning science. Hence, doing research on students' and teachers' perspectives in the MER would be important contributors when contemplating teaching innovative modules.

7. Limitations & Strengths of The Review

The primary limitation of a scoping review methodology would be the lack of quality assessment of the included articles. However, Arksey & O'Malley (2005) stated that scoping study does not seek to assess the quality of evidence and is consequently unable to determine whether the studies could provide robust or generalizable findings. While the quality assessment was not a goal of this current study, quality should be considered before the findings were to be applied when selecting big ideas of nanotechnology to be taught in secondary school. While this scoping review had limitations owing to the nature of the methodology, the present study compiled information from studies with a wide range of interventions and methodologies and was performed with transparency and rigor on the inclusion criteria. This study can give an overview of the available literature on what nanotechnology big ideas countries throughout the world have employed to assess its applicability for secondary school teaching.

8. Conclusions

This scoping review identified appropriate big ideas of nanotechnology to be taught in secondary school science, as well as students' perspectives on what they are learning through various interventions of teaching methods, and teachers' perspectives on TLS, modules, or didactic proposals implemented to their students. Each analyzed element in this review is consistent with the MER, a model commonly employed in most of the included articles too. A recommendation for future research would be to explore the long-term effect of applying these big ideas to learn nanotechnology on students' choice of the subject field in university or college which requires longitudinal research. It has become evident that even though there are nine big ideas in nanotechnology, there are only five big ideas that are appropriate for secondary school students and their capabilities, given teachers used various teaching methods to deliver nanotechnology teaching while not all included articles employed all five big ideas. Furthermore, interventions in nanotechnology teaching methods for certain big ideas may have enhanced students' acquisition of nanotechnology knowledge and their perspectives toward learning this novel topic unit. This review gives insight for educators and curricula designers to consider only appropriate big ideas to be taught in secondary schools due to student's cognitive abilities and therefore, can become a meaningful learning unit for them.

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