Opinions of Biology Teachers About Nanoscience and Nanotechnology Education in Turkey

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Abstract

The rapid development and impact of nanoscience and nanotechnology (NSNT) on economy has led policy makers and educators to focus on nanotechnology education. The two main views concerning appropriate level to teach nanoscience and nanotechnology (NSNT): The first favors teaching in higher education; the second recommends familiarizing and teaching in all grade levels. Aim of this study is to determine the opinions about NSNT education and to propose NSNT education for biology curriculum using the current status. A teacher interview form was used for data collection and applied to 121 biology teachers. Data collected via questionnaires were analyzed through quantitative descriptive analysis. Biology teachers' opinions of NSNT education focused on definition, awareness, importance and developments, benefits, applications, risks and ethical issues. Participants presented view of integrating nanotechnology topics into the curriculum and expected a positive impact on students' career preferences. Teachers believed that prior training and readiness were not meeting the required levels; also, difficulties such as conceptualization and mentally visualizing, technical and infrastructure deficiencies, were the serious obstacles to be overcome for successful implementation. High cost was also a negative impact on integration of NSNT in schools/classes.

Keywords: Nanoscience, Nanotechnology, Biology Curriculum, Biology Teachers.

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INTRODUCTION

Nanoscience is one of the most rapidly growing fields in science, technology, life sciences and engineering research: nanotechnology-related medicine, energy production, national security, environmental protection, and education. Nanotechnology involves designing, producing, using industry areas in textile, cosmetics, electronics from nanomaterials to nanointermediates to nano-enabled products (Foley & Hersam, 2006; Jackman et. al., 2016; OECD 2018). Soon, the nanotechnology level of a country will be expected to be a significant indicator of economic growth. Furthermore, nanotechnology is being spoken of as the driving force behind a new industrial revolution and is one of the "Key Enabling Technologies" of the European Union (URL).

The rapid development and impact of nanoscience and nanotechnology (NSNT) on economy has led policy makers and educators to focus on nanotechnology education (Laherto, 2010). The potential effect of NSNT made these fields a critically significant part of everyday life, to improving quality of life. The big picture is positive developments and commercialization, adoption of new technologies resulting from nanoscale R&D are expected to impact economic growth. A positive economic return in the form of benefits such as the creation of businesses, jobs, boost competitiveness and trade while supporting growth and sustainability are expected.

Knowledge gaps exist in secondary teacher training for NSNT education since the first stage of awareness, knowledge levels and attitudes of teachers should be determined with a need assessment. Only then further training, skills to be developed, qualifications can be planned, and effective programs developed. Literature contends studies mostly on case-by-case teaching and learning strategies to various target groups: teachers (Sgouros & Stavrou, 2019), engineers (Samal & Bharati, 2019; Vahedi & Farnoud, 2019), other professionals (non-science majors: Park, 2019), students including primary (Mandrikas, Michailidi & Stavrou, 2019) and secondary education (Stravou, Michailidi, Sgouros, & Dimitraidi, 2015; Ribeiro, Godoy, Neto & de Souza-Filho, 2018, Lati, Triampo, & Yodyingyong, 2019; Tirre, Kampschulte, Thoma, Höffler, & Parchmann 2019). Most of the literature report development of teaching modules, design of experiments; however, have not considered the awareness level of teachers. Teacher, student and higher education student interactions with nanoscientists from academia, industry and R&D institutions can bridge the gap between nano education and expectations of the job market. Several studies have shown that visual techniques such as models, applicable activities, simulations, movies, game-based learning, experiments, visual nanotechnology laboratory, etc. are effective to simplify the teaching of NSNT topics (Blonder & Sakhnini, 2012; Furlan, 2009; Gorghiu, Gorghiu, & Petrescu, 2017; Alpat, Uyulgan, Şeker, Altaş, & Gezer, 2017; Lu & Sung, 2011; Tarng, Chang, Lin, Pei, & Lee, 2011; Zor & Aslan, 2018). The use of interactive learning videos consisting of attractive visuals on NSNT added with online learning activities that support teaching innovations in the field of nanoscience (Xie & Lee, 2012). Furthermore, additional attractive experimental demonstration improves the level of students' comprehension and helps teachers to teach the subject (Nandiyanto et al., 2018).

Theoretical framework

There are two main views in the literature concerning suitability of grade levels to teach NSNT. The first view favors higher education for comprehension of topics and the related scientific background to teach NSNT concepts (Kulik & Fidelus, 2007). Furthermore, NSNT education at higher education level has gained popularity when compared to secondary level of education as indicated in the number of publications, programs and teaching materials offered (Bach & Waitz, 2012). The second view proposes teaching NSNT at all grade levels since raising scientific literacy level of students, to prepare them in the best way possible for the future is a necessity (Wansom et al., 2009). Support also come from researchers who argue that NSNT education is introduced to individuals at an earlier age and should continue to increase at every level of education (Ban & Kocijancic, 2011; Winkelman & Bhushan, 2017). Having a good NSNT education at primary and secondary levels will

be effective in the students' academic self-development, future career choices, citizen-science, and science communication (Karataş & Ülker, 2014).

Several countries already have ongoing activities, programs and other resources for NSNT education at different grade levels (Nanokids, NanoLeap, NanoAventure, Nanonet organizes, young researchers exchange etc.), projects (Nanoyou, Nanosense, Time for Nano, Nanototouch, National Nanotechnology Initiative-NNI, Nanotruck, Saarlab Initiative, Irresistible etc.) and web pages about nanotechnology (web page of Cambrige University links, Understanding nano, Accessnano, NISE Network etc.). Therefore, the issue should be discussed by all stakeholders in society (Schank, Krajcik, & Yunker, 2007).

The field of nanotechnology is broad and is founded on the convergence of traditional disciplines to create, study, and apply materials at the nanoscale (Holland, Carver, Veltri, Henderson & Quedado, 2018). Integrating a new multidisciplinary science at the interface of different scientific and engineering disciplines into the secondary school is a significant endeavor; however, it can be spread throughout a well-designed secondary science education curriculum. For effective teaching, NSNT topics should be integrated into all fields of science (Tessman, 2009). Training environments that create multidisciplinary or interdisciplinary environments for early research experiences are fundamental to prepare the next generation of scientists and engineers (Holland, Carver, Veltri, Henderson & Quedado, 2018). In addition to the discussion about levels to teach nanoscience, the intrinsic abstract character of nanoscience leads to further hinderance in conceptualization (Ribeiro, Godoy, Neto & de Souza-Filho, 2018). Scale of nanometer may be too difficult to understand and imagine by younger age groups. For this purpose, education policies and plans are reviewed, necessary regulatory tools/measures developed at primary, secondary and tertiary level education (Wansom et al., 2009; Laherto, 2010). Other issue for NSNT education to be addressed is shortage of highly skilled teachers (Hingant & Albe, 2010). Teachers will be eventually responsible for teaching NSNT; however, if they have not received the necessary training, teaching these topics will be a major challenge (Greenberg, 2009; Hingant & Able, 2010). The NanoSense curriculum, funded by the U.S. National Science Foundation, will be possible to transfer knowledge of these issues to students when teachers develop understanding and awareness of NSNT (Blonder, Parchmann, Akaygun, & Albe, 2014). Therefore, before preparing students for the age of nanotechnology, more research must be undertaken in teacher education for nanotechnology. Huffman et al. (2015), have come up with integration of nanoscience concepts as another difficulty impacting teacher learning in nanoscience content. Furthermore, factors affecting awareness and knowledge level of teachers/ teacher trainees in NSNT should be determined and analyzed before implementing education programs (Hingant & Albe, 2010; Jones et al., 2013). Pre-service teachers' low level of understanding (Aslan & Şenel, 2015; Pektas, Alev, Kurnaz, & Bayraktar, 2015) and knowledge (Ekli & Şahin, 2010; Kumar, 2007; Senocak, 2014) of NSNT are well documented. Implications for increasing awareness level and knowledge of pre-service teachers in NSNT are clear.

Development of NSNT education programs for secondary level, called "Big Ideas" and promotion of student perception and comprehension of NSNT concepts will prepare them for future challenges of society in a new technology era (Hutchinson, Bodner, & Bryan, 2011; Stevens, Sutherland, & Krajcik, 2009; Tessman, 2009; Wansom et al., 2009). The topics and concepts most agreed upon by NSNT educators are: size and scale, structure of matter, forces and interactions, quantum effects, dimension dependent features, spontaneous formation, tools, models and simulations, science, technology and society (Hingant & Albe, 2010; Stevens, et al., 2009). Sixth-grade primary students successfully understand NST key concepts like 'size and scale' and 'size-dependent properties (Mandrikas, Michailidi & Stavrou, 2019).

Purpose of the Study

NSNT education is still a relatively new field rapidly developing. Therefore, Turkey also needs to adapt such policies and changes for NSNT education and research (Karataş & Ülker, 2014). There is need to plan and implement NSNT education at primary, secondary, undergraduate and

graduate levels. Presently nanotechnology is not in the Primary School Science and Secondary School Biology curricula. Nanotechnology topics are limited to 12th grade physics and chemistry courses in secondary schools with two lecture hours under the heading "Energy Resources and Scientific Developments" unit in physics curriculum and "Modern Physics Applications in Technology" unit in chemistry curriculum (Ministry of National Education [MoNE], 2017). There is a similar situation in the content of higher education (undergraduate courses) in Turkish universities. The hours of elective courses offered at undergraduate level for NSNT in engineering and science faculties of some universities are very short and of limited content. Some universities offer NSNT education at graduate level (Aslan & Şenel, 2015).

We hereby try to draw the attention to relevant stakeholders, educational and research institutions for NSNT as a new field of research and innovation affecting society. In addition to engineering sciences, fields of biology, physics, chemistry, life sciences, energy, and pharmaceutical sciences are also closely related to NSNT, therefore teacher education in basic sciences is crucial. Accordingly, efforts to ensure that students are nano-literate and that NSNT can be included in secondary education programs according to their levels. Lack of published work in the open literature for NSNT as a socio-scientific topic in secondary education has been emphasized (Gül, 2017). Due to NSNT being a new area of research in Turkey, there are few sources in Turkish, restricted to several media and articles.

The aim of this research is to present the current situation of NSNT education in Turkey, as a case, based on biology teachers' opinions. It is expected that this research will contribute to NSNT researchers with the significance of NSNT awareness. Research further addresses the issues of assessment of necessary NSNT subjects and content both for teachers and learners in secondary education. These knowledge gaps will be filled and research outputs/findings will be considered both as need assessment and elaboration of methodology to teach and evaluate NSNT, skills to be gained and finally recommendations to stakeholders for further action (Board of Education and General Directorate of Secondary Education).

Our main focus is to identify the opinions of teachers about the NSNT teaching process, to integrate nanotechnology topics in Biology curriculum and to develop a sample program to contribute to NSNT education. Without determination of awareness levels and knowledge of teachers in NSNT, need assessment cannot be developed for basic science teachers. Biology teachers will be the main stakeholders and contributors to achieve curriculum development and implementation.

Problem Statements

Problem statements are:

1. What are the awareness levels of biology teachers about NSNT teaching and learning process in formal biology courses in Turkey?

2. What are the aims/goals/objectives of NSNT education? What are the benefits of teaching NSNT topics to students?

3. Which subjects should be included in NSNT content and which biology curriculum topics may integrate learning with NSNT topics?

4. Which grade levels and lecture hours should NSNT topics be?

5. How should learning and teaching process be designed?

6. What may be the learning difficulties and deficiencies in NSNT content teaching process?

7. How can teachers be prepared for teaching nanotechnology subjects? Do they need in-service training on this subject?

METHOD

Research Model

Data were collected using the case study approach. The selection of approach was taken into account the purpose of the research, the role of the researcher, the data collected, the method of data analysis and how the results will be presented. The most common approaches include narrative, phenomenology, grounded theory, ethnography, and case study (Creswell, 2012). This study in which it was aimed to determine the opinions and suggestions of Biology teachers about the NSNT topics and was a case study carried out qualitatively. Qualitative methods can be preferred aimed at revealing a specific situation and conducted to provide a detailed assessment by obtaining in-depth data in the studies. Case studies are based on an in-depth investigation of a single individual, group or event to explore the causes of underlying principles (Woodside, 2010). An educational case study may be employed by a single teacher, by a group of colleagues who share an interest in a common problem or by the entire faculty of a school. Procedural stages are: (1) identify the problem and sub-problems; (2) data collection; (3) organize, analyze and interpret the data; (4) written report.

Sample

To accomplish the goal of qualitative research is to provide in-depth understanding and therefore, targets a specific group, type of individual, event or process, qualitative research focuses on criterion-based sampling techniques to reach their target group. There are three main types of qualitative sampling: purposeful sampling, quota sampling, and snowballing sampling (Creswell, 2012).

In this research, the purposive sampling method was used. Briefly, the method studies all situations encountered during a set of predefined criteria. Participant biology teachers were selected based on the following criteria: (1) Biology teachers who have knowledge and awareness about nanoscience and nanotechnology issues; (2) Biology teachers working in different types of schools rather than in a single school type. Three types of schools were identified: participants of the research were 59 (48.8%) female and 62 (51.2%) male biology teachers who work in secondary schools (Science 9.1%, Anatolian 55.4% and Vocational High School 35.5%) in Antalya 34.7%, Denizli 31.4%, Burdur 21.5%, and Ankara 12.4% provinces during 2015/2016 academic year. The necessary consent and permissions were obtained from the participating teachers.

Data Collection and Analyses

Opinions of the biology teachers were taken by using the NSNT interview form developed by authors. This revised form was used to collect data, consisted of teachers' socio-demographic characteristics (part 1) and semi-structured open-ended questions about teaching NSNT topics (part 2). The initial semi-structured form (version-1) was based on the literature and comparative analysis of curricula from different cultures/countries having NSNT subjects in secondary education. Version-1 had 10 items. Opinions of three biology teachers, two experts of the field and one language expert, were taken for content validity. Two questions were removed based on expert opinion since they were not related to the solution of the research problems. Moreover, two questions were combined because they were similar about evaluating the same case, and the form was given its final format with seven questions (version-2). Additionally, three other non-participant biology teachers, working in other schools, evaluated adequacy, clarity of the items and the interview duration (about 35 minutes).

There are two ways of analyzing qualitative data as descriptive analysis (framework analysis) and content analysis (thematic network analysis). The descriptive analysis examines findings with a

predefined framework that reflect participants' aims, objectives, and interests. Data obtained using the NSNT interview forms were analyzed with quantitative descriptive analysis; providing basic summary of the sample, observations which quantitatively describe or summarize distinctive characteristics of collected information. In the study, similar statements were gathered within categories and relations between data were structured. Teachers' opinions were grouped into seven major categories; their awareness about teaching and learning process in current situation, aims of the NSNT topics, content and integration, grade level and lecture hours, teaching and learning process, difficulties in learning, deficiencies, teachers training procedure. Opinions of selected teachers, thought to be of interest to the readers, are presented in the Results.

RESULTS

The findings based only on teachers' opinions related to the NSNT education process are presented.

1-Teachers' opinions about NSNT topics in biology courses in Turkey.

All teachers (n=121) participating in the study stated that NSNT topics were not included in the biology curriculum at the time of their participation. Although nanotechnology topics are not presently included biology curriculum, most participants (69.4%) have stated that when related issues to nanotechnology were mentioned or even sometimes students asked questions spontaneously. In addition, these teachers put personal effort to teach topics relevant to NSNT as need arisen. The opinion of biology teachers are given below:

> "*We usually give information about daily use contents, application contents, and up-to-date developments among other topics in order to attract students and raise their attention and motivation in the classes. I can say that in this sense of NSNT topics are appropriate. The students are very interested in this subject, and they express that learning this subject may be very enjoyable" (B_{24}).*

Although nanotechnology topics are not included in the biology curriculum presently, these subjects are taught in the courses by numerous teacher's personal efforts, indicating a rationale for NSNT topics to be included in the biology curriculum.

2-According to the teachers, the aims of the NSNT education and the benefits to students learning about NSNT topics.

The following categories were created as general concepts of biology teachers' expressions of NSNT education aims/goals: definition of nanometer (37.2%), awareness (26.4%), importance and future (31.4%), development process and current development (18.2%), benefit and application areas (27.2%) and risks and ethical issues (4.9%). Some teachers expressed an opinion on the content of these categories as follows:

Opinion of the biology teachers are given below:

> *"The nano-scale is an abstract concept that cannot be seen and cannot be visualized in students' minds. First of all, it is appropriate to start from understanding of size" (B_{119}).*

> *"It is necessary to explain how nanotechnology can enter our daily life from the first appearance to the present day. Awareness of the students will be created if it becomes a part of our lives and especially supported by current developments" (B_{80}).*

"The benefits of engineered nanotechnology materials (medicine, medical devices, artificial organs, etc.) produced for mankind can be mentioned in that they improve human health and quality life" (B_{18}).

"We know the very useful applications that NSNT has added to us today, but I have also read an article on the potential risks to organisms and nature. Negative aspects, as well as negative cases, should be explained to the students in terms of the benefit-risk relationship" (B_{105}).

"Students will be fascinated to discover a new area of science. Nature is the best nanotechnology platform, some of these materials have been developed following direct inspiration from nature, such as the new types of solar photovoltaic cells, which try to imitate the natural nanomachinery of photosynthesis. NSNT offers teachers a new instrument to bring exciting science and technology into the classroom. Bringing 'nano' into the classroom means bringing the latest cutting-edge science and technology" (B_{11}).

Aims of NSNT education in biology curriculum as expressed by the participants are depicted below;

1. To define nanometer, give examples and compare the size with other materials, especially those related to biological materials.

2. To discuss relationship of nanotechnology with other science disciplines (physics, chemistry, engineering, etc.) and explain interdisciplinary science of nanotechnology.

3. To give examples of nanoscience in nature and history of nanotechnology.

4. To give examples of engineered nanotechnology products and application areas.

5. To describe the benefits of nanotechnology and discuss ethical issues, social impact, safety considerations, etc.

If NSNT was included in the Biology curriculum, Biology teachers were asked about impact of teaching NSNT topics to the students. The content analysis results were as follows: Awareness (15.7%), perception (16.5%), interest-curiosity-motivation (17.4%), career preference (8.3%), scientific thinking and research culture (24%), health (8.3%) and imagination (9.9%). In addition, the integration of nanotechnology topics in the biology curriculum will positively affect the students' career choices. Some teacher's opinions are as follows:

"It will lead up to new inventions made in our country on this field and it will broaden students' horizons on many areas, like choosing their professions, especially biochemistry, pharmacy, medicine and material engineering" (B_{99}).

"Students often complain about how information is going to be useful for us in everyday life. If they follow the current developments in this field, it can excite, motivate them and increase their interest in science" (B_{42}).

"In conclusion, we must follow the latest developments in the world. Therefore, we must integrate nanotechnology and many innovations about science into our curricula. Thus, research interests and employment opportunities in nanotechnology will increase in our country soon. We may train a scientist in this field" (B_{34}).

3-Teachers' opinions about NSNT content and integration of biology curriculum.

To define a nanometer and compare it with microscope (SEM and TEM), microbiological materials, DNA, RNA, cellular membrane, proteins, materials science may be used. Nanoscience

successfully utilizes *biomimetics* in materials engineering field, in production of artificial materials using natural mimicry. A well-known example is the lotus leaf and human skin, both hydrophobic surfaces, Geckos' feet, and adhesives, butterfly wings and photonic crystals, spider silk and high tensile strength fiber, human brain, and artificial intelligence and computing, etc. All these examples and more may be used in biology courses, to explain how scientists explore many manufacturing materials while inspired by nature. Ecology also has topics related to nanoparticles and their applications. For example, silver nanoparticles have a strong antibacterial capacity and these manufacturing materials are used in numerous products (refrigerator, etc.) to prevent or reduce the adherence of bacteria to surfaces. Nanoparticles and nanostructures are widely used in biomedical applications, such as tissue engineering and medical imaging. Diagnostic nanosensors and precise genetic screening devices allow early detection of various diseases, such as cancer, at the very onset of the symptoms, before the disease is perceived by the patient. Nanotechnology is already playing an important role in modern medical diagnosis and treatment technologies; opening new venues for future developments. These examples and more may be used in human physiology and health topics in the biology courses. In addition, nanotechnology and applications are widely employed in biotechnology and genetic engineering. Interestingly, participant teachers are of the view that daily life applications/cases can be successfully used to integrate nanotechnology topics into biology courses. More specifically NSNT topics may be integrated with nucleic acids, proteins, the cell, new trends in biological developments, ecology, human physiology, health, diseases (cancer, hereditary diseases, etc.) in the biology curriculum. Teachers' opinions about NSNT content were current developments (27.3%), importance and future directions (18.2%), fields of applicability (18.2%), implications (27.3%), research and innovation (4.1%), risks and ethical issues (5%). One of the teachers expressed her/his opinion on the content of these categories as follows:

> *"Students will be aware of this issue if the NSNT is given by supporting the up-to-date developments, from how it improved from the first appearance to the day-to-day, and how it has evolved into our homes and become a part of our lives" (B_{80}).*

4-Teachers' opinions about grade level and lecture hours.

Participants had variable opinions about the lecture hours and grade level; no consensus could be reached. The main reasons for diverse opinions were nanotechnology topics to be offered under a different unit (31.4%), while some teachers think that it would be appropriate to teach within other related biology units (68.6%). Teachers who thought nanotechnology topics should be given under a different unit, proposed 9^{th} and 10^{th} grade (11.6%) and total eight hours, 9^{th} to 12^{th} grades and 12 hours to teach nanotechnology topics (19.8%). The majority (68.6%) proposed nanotechnology topics to be integrated with biology topics. There were two different views about grade level and hours, the first group (11.6%) suggested four hours for 9^{th} and 10^{th} grades, and the second group (57%) six or eight hours for 9^{th} to 12^{th} grades. One biology teacher was of the following opinion, for this category:

> *"The topics of nanotechnology should be given in a spiral form starting from 9^{th} grade until 12^{th} grade. I think it would be appropriate to connect the subjects with each other within the unit" (B_{76}).*

Biology teachers' opinions about relationships of NSNT topics in the secondary curriculum were: Physics-chemistry (48%), physics-chemistry-mathematics (22.3%) and chemistry (25%); only to physics (11%). As stated by the participants, nanotechnology topics should be related not only with biology issues but also physics and chemistry issues, promoting interdisciplinary character of nanotechnology. In addition, some participants were of the view to relate NSNT to mathematics.

5-Teachers' views on learning and teaching design of the process.

Biology teachers have stated that the research method, projects, and traditional methods can be used in learning and teaching process of nanotechnology topics. Teachers think that visual and

audio materials (34.7%), making various applications (28.9%) and using presentations (16.5%) in the course will facilitate teaching. Teachers also stated that experiment-study-observation, module use, simple tools and materials design, demonstration applications, animation, documentary analyses, science fiction films, slides, interactive boards, and imaging technologies could be used for visual and audio materials. Some biology teachers were of the following opinion, for this category:

> *"Visual examples of more useful areas should be taken into consideration could discuss the global and national level of NSNT studies in our lectures. Non-contaminated fabrics, self-cleaning paint, molecular agents that can be applied to the body could be interesting to students if presented with proper, up to date visual content." (B_{11}).*

> *"Since we are unable to conduct experiments or use the laboratory to its' full extent, animated documentaries and appropriate science fiction films can help teach the subject." (B_{112}).*

> *"Experiments and observational methods can be used to teach nanotechnology. Students will be able to study with their teacher assigned by the related instructor in the universities many departments working in this field once a week. More practical training will be a more permanent solution than theoretical courses." (B_{55}).*

Based on these opinions, it may be more effective to support lectures with visual and auditory materials since NSNT topics are somewhat abstract

> *"Experts in the field can be invited to give lectures and practicals; in-service training can be organized" (B_{11}).*

The last recommendation is very important; because it reveals the fact that teachers do not have enough information and need further training on nanotechnology.

6-Teacher opinions about difficulties and deficiencies on the process of teaching NSNT content.

Biology teachers' opinions about NSNT teaching difficulties and deficiencies categories were education (36.3%), mental visualization (28.9%), lack of technical infrastructure and implementation difficulties (23.1%) and high cost (11.6%). For education category participants stated that difficulties are inadequacy of in-service training, limited number of specialists in the field, availability of nanotechnology applications for teaching rarely available, lack of nanotechnology resources in Turkish. One teacher expressed her/his opinion on the content of these categories as:

> *"It is not possible for a teacher to tell the students in his/her class that he/she is unfamiliar and alien to a subject. Teachers should undergo both theoretical and practical training. I think that there are no qualified experts in the Ministry of National Education who can provide training on NSNT. A core group of trainer teachers can be trained in the subject in collaboration with universities; they can in turn serve as trainers to all other teachers" (B_{75}).*

Another biology teacher expressed his/her concern on the second category of mental visualization with this sentence:

> *"Mental visualization of these objects is rather difficult, and many studies have reported how young people lack the mental capacity to actually imagine something this small because of lack of experience/initial exposure. Even for adults, mental visualization of objects with the sub-micron size is extremely difficult" (B_{22}).*

Furthermore, ethical, legal and social aspects are important issues in process of learning and teaching. Numerous ethical questions are also raised in the field. For example; "*Could nanomaterials*

interact with biomolecules in an adverse manner, triggering a toxic effect? Could nanomaterials pass through protection barriers in cells? Will nanomaterials be dispersed in the environment? To what extent? Could this cause risk to ecosystems?" etc. Teachers had confused place on guiding and advising their students? Furthermore, they were concerned about ethical and social issues and demand information to better understand the socio-scientific issues of innovations. They reflected their expectations of scientists to better define the risks, reaching a clear consensus.

7-Teachers training process.

Biology teachers' opinions on the training process varied considerably: in-service-training (48.4%), field trips, visit laboratories (22.3%), individual efforts (18.2%) and communication, experience sharing (10.7%). The first and most important issue is low level of teachers' knowledge about nanotechnology. Some biology teachers were of the following opinions for in-service training and field trips, laboratory site-visits:

> *"Theoretical and practical in-service-training is absolutely necessary since many teachers know nanotechnology as a name. Besides, there is not sufficient information about nanotechnology and justification to learn it well. When these are taken into consideration, teachers will only cite nanotechnology as a superficial understanding. Naturally, they will not consider the subject significant. That is why teachers should be convinced of how important the subject is." (B_{17}).*

> *"I did not receive education on nanotechnology in my university years. I think many others have not either, no formal education in nanotechnology. Therefore, in-service training about current issues such as nanotechnology should be offered" (B_{45}).*

> *"First of all, it is imperative that teachers get training with university cooperation. These subjects must be given by the experts. For this reason, MoNE must be in close collaboration with academia. Training may be in the form of seminars, lectures, field trips, virtual software and presentations as programmed periodical agenda" (B_{55}).*

> *"Teachers should be visiting the national nanotechnology centers, science museums or the nanotechnology departments of universities within the scope of in-service training" (B_{106}).*

According to the biology teachers' opinions about in-service training category, teachers must get training about nanotechnology issues. They need theoretical and practical in-service training by experts about new developments in science and technology. Besides, biology pre-service teachers should be trained about nanotechnology.

Other biology teachers expressed his/her opinions on the category of individual efforts with this sentence:

> *"Unfortunately, since we did not get any training about nanotechnology at the university, firstly we must get in-service training and then improve ourselves by following scientific journals, articles and documentary programs depending on this education" (B_{22}).*

> *"A teacher must always keep himself updated not only on the field of biological issues but educational and scientific issues. In addition; they should have enough knowledge of pedagogy too. Since, science is constantly advancing, teachers must be open to scientific improvements and should follow scientific journals, watch documentaries, visit museums and have get information about current scientific contents" (B_{44}).*

In the light of these opinions, individual efforts are significant to enhance teachers' scientific literacy along with lifelong learning after in-service training. Some methods such as watching documentary publications and science fiction films, reading periodical journals, visiting museums,

talking with colleagues etc. may help to enhance their scientific literacy. One biology teacher was of the following opinion, for communication and experience sharing category:

> "*Biology teachers who are working in different schools may interact with social media or EBA* (which is a legal social online platform established and supported by MoNE for teachers and students) *and obtain materials they can use throughout their education life. All kinds of resources, materials and information can be shared by all teachers" (B_{111}).*

DISCUSSION

NSNT education aims/goals/objectives which were determined by the participants are; the scale of a nanometer, interdisciplinary structure of nanotechnology and relations with other branches of science, in natural and engineered examples of nontechnical products and applications, benefits and contradictive plots of ethics, impacts, and safety. According to the participants, if NSNT topics are integrated into the biology curriculum, it will help increase awareness, interest, scientific thinking, research culture, solve scientific problems, imagination of the students; while promoting career planning. Teachers' approach to the potential of NSNT topics were positive. As these topics lead students to develop analytical thinking, gain different perspectives, increase curiosity and motivation. Thus, it is thought that the students can change their way of understanding nature and live positively and obtain very important gains for future life. Similar to our findings, Laherto (2011) found that many teacher participants suggested NSNT issues be addressed in class as it will have the potential to increase students' interest in science and technology, in general. Furthermore, our findings are in line with those of Jakman et al. (2016) who emphasized developments in NSNT to enable today's understanding and appreciation of nature, easily establish relationships between events that they meet in daily life to develop new materials and methods. Sakhnini and Blonder (2016) emphasized combination of teachers and scientists to include different viewpoints when a new science curriculum is planned. The findings from teachers' opinions show that integration of NSNT topics into the biology curriculum may give chance to follow-up science and technology era to students and contribute to civil society. Additional contributions in the areas of ecology, health, and economy are foreseen. As new methodologies of disease diagnosis and treatment using NSNT are developed and replace conventional remedies for disease protection will be also beneficial for the students. The inclusion of NSNT topics into the biology curriculum is expected to increase the number of scientists working on the NSNT fields. As a reflection of this, students will be able innovative for new products, contribute to the national economy significantly, reduce foreign dependency for technology, increase prosperity level and reach a level of global scientific competition. The main purpose of nanotechnology can be summarized as the production of materials in a controlled manner and the improvement of the quality of life and the use of efficient resources. This technology, symbolizing a new era in social transformation for some people, has started to take place in many products and production processes with its intelligent character (Güzeloğlu, 2015; Mandrikas, Michailidi & Stavrou, 2019). In addition, students will also be able to become aware of environmental conservation and grow up as pro-environmentalist citizens. As the quality of life can be increased by curing many diseases and even the life span of people can be extended. NSNT offer teachers a new instrument to bring exciting science and technology into the classroom. Nanotechnology is presently used in numerous devices with which young generations are very familiar, such as computers, mobile phones, iPods, etc. NSNT offers the possibility to improve properties of materials design new ones. Bringing NSNT into the classroom means bringing in the latest cutting-edge science and technology and talking about very exciting future scientific developments.

NSNT topics in biology curriculum are recommended as; general concepts about NSNT, development process and current developments, importance, applications and usage of NSNT, project and application studies, risks and ethics by the respondent teachers in this study. Majority of teacher respondents in the present study were of the view that overlapping NSNT topics and concepts can be regarded as constituents of a common multidisciplinary area, therefore curricula can be designed to integrate them (Stevens et al., 2009; Hingant & Albe, 2010; Laherto, 2011). In biology NSNT relationship to nucleic acids (DNA, RNA), proteins, inorganic constituents, cellular structures, new

developments in life sciences, ecology, human physiology, health, diseases (cancer, hereditary diseases, etc.) can be efficiently used in the biology curriculum.

In this study, teachers could not reach an agreement about the grade level and course hours to teach nanotechnology topics. Some teachers proposed nanotechnology topics to be offered under a different unit, while others thought of integrating with biology topics such as genetics, nucleic acids, ecology, biotechnology, etc. However, they agreed to use examples from everyday life while teaching nanotechnology topics in biology. Although participants were aware of NSNT to be multidisciplinary and related it, with biology, physics, chemistry; they were uninformed about the almost no relationship of NSNT to mathematics. Similarly, nanotechnology brings people from different disciplines together: including materials science, physics, chemistry, biology, pharmacy, health, food technology, textiles, computer, electronics (Porter & Youtie, 2009). Nanotechnology can, therefore, be integrated into these fields (Laherto, 2011; Whitesides & Love, 2007). Studies conducted in Turkey is only limited by physics and chemistry 12^{th} grade at secondary schools and universities. However, NSNT should take its place in the Turkish secondary science curriculum, preferably starting as early as primary education. Individuals trained in NSNT will adopt nanotechnology quickly in society and motivate young people to pursue careers in nanotechnology-related areas, moreover, they will help build a political bottom line for necessary education reforms (Foley & Hersam, 2006).

Participants emphasized the importance of using visual and audio tools in teaching nanotechnology subjects, our results are in agreement with those of other on using visual techniques and laboratory practicals as effective tools to simplify teaching and learning of NSNT topics (Blonder & Sakhnini, 2012; Furlan, 2009; Gorghiu, Gorghiu, & Petrescu, 2017; Alpat, Uyulgan, Şeker, Altaş, & Gezer, 2017; Lu & Sung, 2011; Tarng, Chang, Lin, Pei, & Lee, 2011; Zor & Aslan, 2018). Nanotechnology should be taught by creating both knowledge-centered and learning-centered environments inside and outside the classroom. Life-long learning, activities that encourage creative and critical thinking should be given the highest priority since NSNT has been advancing so rapidly (Srinivas, 2014). Using YouTube® videos for latest advances is more efficient than traditional methods and YouTube videos help the students to learn complex concepts of nanoscience and nanotechnology. Moreover, YouTube documentaries may be an excellent way to disseminate nanoscience to society. Technology can play a powerful role in facilitating interactive learning both inside and outside the classroom (Sebastian & Gimenez, 2016). Students can participate in nanotechnology research development projects and laboratory experiments all over the world via the internet. They can be given opportunities to work directly with established nanotechnology research centers (local, regional, national, international) to gain hands-on experience (Srinivas, 2014). Therefore, combination of competent teachers and effective teaching methods are required to find a way to simplify the complexities in NSNT topics (Nandiyanto et al., 2018). In addition to the theoretical aspect, collaboration with academia in nanotechnology, nanotechnology centers/institutes or industrial establishments operating in this field in the scope of visits, observation and implementation activities may be offered for teachers to practice and participate actively during training. Contributions of academia and the non-academic sector will promote public services to the education sector. Successful practices for university-school partnerships in teaching contemporary sciences as NSNT have been reported worldwide. For example; there are many nanotechnology-related companies in Finland, so the respondents' suggestion for discussing NSNT by means of industry visits seems like a feasible method (Laherto, 2011). In addition, since information and communication technologies are so common and well developed, we have reached the conclusion that teachers should be in constant contact with their colleagues to share knowledge, resources and materials they have acquired during their NSNT education, and that they should act in a collaborative way to prepare for NSNT topics. There is a need to link community colleges with high schools on the one side, separate undergraduate institutions on the other. A closer and more effective link between these organizations will enable more effective communication techniques. It will also result in more appropriate science educational activities and provide for a well-prepared and diverse workforce for the nanotechnology and other emerging STEM (Science, Technology, Engineering and Mathematics) fields (Srinivas, 2014). This view of Srinivas (2014), though indirectly, seems to support the outcome of our research in terms of cooperation and communication among teachers.

In this study, NSNT education difficulties and deficiencies were determined that lack of teachers' knowledge, mental visualization, lack of technical, infrastructure and implementation difficulties and high cost. Similarly, according to Bamberger and Krajic (2012), there are two reasons hampering teachers to implement nanoscience and nanotechnology activities in class: (1) teachers' instructional beliefs, content knowledge, and self-efficacy and (2) lack of instructional materials, time limitations, and administrative issues. These concerns are thought to be results of teachers' low level of preparedness about nanotechnology education. If teachers are aware, they will also use the low-cost training materials about nanotechnology; participate or benefit from research through projects about how to teach nanotechnology at an early age. The subject must be at basic level of understanding to teach NSNT in the secondary level for students to comprehend. Current and controversial issues on ethics, social impact, safety, etc., should be addressed to prepare students as citizens (Sgouros & Stavrou, 2019). In the study, most Biology teachers stated that they already teach basic NSNT and mention current scientific developments in class due to their personal interest and effort, although NSNT is not presently offered as a subject(s) in the Biology curriculum.

Our findings show that teachers do not have enough knowledge about NSNT and they need further training as courses/practices. Furthermore, most teachers feel low in self-efficacy and inadequate about NSNT. For this reason, it is seen that both theoretical and practical training are required to be given by the qualified and equipped people in the field of NSNT. There is clearly a need for comprehensive in-service training on the NSNT by close collaboration of all qualified stakeholders. Teacher education should be a major aim to realize NSNT education successfully. In agreement with our results, Laherto (2011) strongly recommended in-service training for teachers if NSNT is to be included in the curriculum. Furthermore, once they have the basic knowledge; they can support each other, share knowledge, difficulties, successes, dilemmas, give feedback to each other to sustain the self-efficacy of teachers, create a community of practice, follow developments from publications (Blonder and Mamlok-Naaman, 2016). Schank et al. (2007) suggest that one of the great reasons preventing teachers from transferring NSNT topics into the classroom environment is the inadequacy of their professional development. Challenges for the integration of nanoscience into both high school and college classrooms can be overcome with proper professional development of science teachers (Greenberg, 2009; Sgouros & Stavrou, 2019). Sgouros & Stavrou (2019) developed a teaching module integrating NSNT topics together with science communication, addressing ethical and risk issues for science teachers to be transmitted to the general public for citizen-science. For nano-literate students, there is a need for nano-literate teachers. Their results support our training framework proposals. Both theoretical and practical training delivered by qualified and equipped people in the field of NSNT are required. However, our findings lead us to conclude that in-service training or courses organized by the MoNE are far from addressing teacher training and other more recent approaches that are necessary to build new skills and competences. Most research results have shown that, teaching NSNT topics can be the way to success only if they are accompanied with theoretical teaching, experimental or virtual laboratory approach by the participation of a team of faculty members specializing is the way to success (Potkonjak et. al., 2016). An alternative to a traditional face to face class is an online-courses, distance learning and they may help teachers' fundamental knowledge of NSNT topics (Winkelman & Bhushan, 2017). Furthermore, invitation and participation of speakers from industry and research centers will be useful tool to enhance course quality (Srinivas, 2014). Here, executing experiments with crowded classes may be one drawback; the other may be reluctance of science teachers to carry out demonstrations during teaching. Teachers must be skillful in teaching topic relating to technology so that students' level of understanding may improve. MoNE, especially the Council of Higher Education, academic and research institutions have very important duties to promote nanoscience education. Government, industry, and academia in close collaboration is a necessity for NSNT education (Srinivas, 2014).

CONCLUSION

Unlike the other areas of science education, NSNT education is still in its infancy. The understanding and research on how to teach the core ideas of nanoscience and nanotechnology are emerging technology. Development of nanoscience education materials as well as research into "how

students best learn nanoscience" is a necessity of the 21st century. A solid foundation is critically important to students, who must be prepared with universally applicable knowledge and skills needed to understand various technologies and applications that are constantly being proposed and invented. Disseminating the grand visions of nanotechnology to students is equally important, as among them there are future generations of scientists, engineers, and technicians who will help realize and advance the visions. For the effective teaching of NSNT, topics should be integrated into all fields of science. Today's most attractive field, obviously significance and impact of NSNT will gradually increase soon; necessitating increased level of awareness before university.

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