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Nanotechnology in The Curriculum: A Review of the Literature

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Nanotechnology, highly important in the 21st century, is the field in which major sciences are joining, blending, and integrating. It is an interdisciplinary field that can be included in chemistry, physics, biology, environmental sciences, and engineering. Nanotechnology provides connections between the sciences. This connection helps students to develop an understanding of the relationships between disciplines. Education about nanotechnology should be gradual and introduced at early ages. For this purpose, most countries are focusing on how to tailor nanoscience to their schools' curricula and how to fit nanotechnology into their science classes. When introducing nanotechnology to schools, researchers, project managers and teachers face a lot of questions: What subject to choose to teach about nanoscience? Can it be integrated into the school curriculum? In most countries, nanotechnology is not a mandatory subject, chapter or topic in the curriculum at any level, like Turkey, however, it can be integrated in the curricula in various ways. This study aims to identify the nanotechnology education in secondary schools of different countries and to focus on the possibility of integrating nanotechnology to their curriculum.

Keywords: nanotechnology, nanotechnology education, nanoscience, science curriculum

INTRODUCTION

While there is no single definition of nanotechnology, it can be defined as a multi-disciplinary field that includes chemistry, physics, biology, material science and engineering (Ernst, 2009; Gardner and Jones, 2009; Gardner, Jones, and Falvo, 2009). It is the science of small and ultra small things (Cavanagh, 2009). In fact, one nanometer is just one-billionth of a meter in size. Atoms are smaller still. It is difficult to quantify an atom's size and even they do not tend to hold a particular shape. But in general, a typical atom is about one-tenth of a nanometer in diameter. Sweeney defines nanotechnology as 'the emerging capability of human beings to observe and organize matter at the atomic level'. The term itself, nanotechnology, covers all aspects of the control and production of devices and systems by manipulating the material at the nanoscale level (Lakhtakia, 2006; Sweeney, 2006). Commonly, the nanometer scale of objects serves as a justification for considering a

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field as *nanoscience* or *nanotechnology*.

Nanotechnology has been described as the defining technology of the twenty-first century and will be the potential defining technology of the industrial revolution of the future (Ho, Scheufele, and Corley, 2010). While there are many applications of nanotechnology, it is yet to be seen if it will change society as profoundly as the first industrial revolution (Ghattas et al., 2012). Nanotechnology, from a business perspective, will create better and entirely new materials, devices, and systems. It means new jobs due to new markets. It is amazing that the science of small will have a huge impact in society. Nanotechnology applications can be summarized into several basic areas: Smart Materials, Sensors, Nanoscale Biostructures, Energy Capture and Storage, Magnets, Fabrication, Electronics, and Modeling (Bowles K., 2004).

During the past decade, nanoscience and nanotechnology (NST) have become major fields of scientific research and technological innovation. NST are advancing rapidly, and increasingly significant societal and economical prospects are attached to these emerging fields. Their growing socio-economic potential has attracted substantial investments from both the public and private sectors. Nanotechnological products have started to invade the markets. At the same time, the prospects of more significant applications and implications of NST have aroused active socio-scientific debate on various societal and global issues and ethical concerns (Laherto, 2010).

By 2015, there will approximately be two million workers globally in nanotechnology (Roco, 2003). Introducing nanotechnology into an educational environment can present a challenge both in creating an understanding of the topic and conveying the subject's career potential. Typically, new technologies start as a few comments in the technical publications and evolve into the widespread media as wild projections on how these developments can either create a wonderful future for everyone or destroy the planet. The truth is usually somewhere in between. During the early awareness stage, students are most eager to absorb any and all information. With the rapid pace of technology evolution, it is critical that educational institutions serve as the trusted resource for both students and industry and serve as the pioneer for training the future workforce.

The above mention of "science fiction", with some truth and some rumors, and the need for skilled and educated employees are both especially true for nanotechnology. Science and application of knowledge at the nanoscale will affect every market segment within the next decade. Students who will engage in this new technology not only need to comprehend new technical principles but must also recognize the implications and impact of nanotechnologyy (Fazarro D., Newberry D., Trybula W., Hyder J. 2012).

Nanotechnology in Education

Nanotechnology materials are currently being utilized in our daily lives in many various ways, often without the direct knowledge of the consumer. Due to the explosion of uses of nanotechnology, there is a necessity to update the existing school science curricula by integrating nanotechnology-related concepts that are both relevant and meaningful to students' lives (Ghattas, 2012). NST has also become an interesting and important field from educational perspectives. Providing education in NST at different levels has been called for throughout the world. Calls for nanoscience education have been made not only with regard to the academic level: several bodies have argued that the contents of NST should already be taught in compulsory education, and the general public's awareness of and engagement in these emerging fields should be promoted (Laherto, 2011). The integration of nanoscience in the school curricula comes in response to nanoscientific development and the mission of educators to instill and arouse students' curiosity in learning about both what is and what will be more dominantly occupying the market. Educators integrate nanotechnology into their classes, create new courses and design academic programs in order to educate students and provide them with the skills needed to participate in the future nanotechnology workforce (Murday et al., 2010). Even the most experienced nanotechnology educators can find themselves wanting to explore a new area within this field or trying to keep up with nanotechnology education as it grows and evolves. Nanotechnology educators and scientists are disseminating ideas, information and experiences through workshops, conference presentations, journal articles, books, websites and professional organizations (Winkelmann et al., 2014).

The fundamental objective of nanotechnology is to model, simulate, design and manufacture nanostructures and nanodevices with extraordinary properties and assemble them economically into a working system with revolutionary functional abilities. Nanotechnology offers a new paradigm of groundbreaking material development by controlling and manipulating the fundamental building blocks of matter at nanoscale, that is, at the atomic/molecular level. Therefore, in order for students to face the challenges presented by nanotechnology, the following educational goals should be applied:

- Provide understanding, characterization and measurements of nanostructure properties,
- Provide ability for synthesis, processing and manufacturing of nanocomponents and nanosystems,
- Provide ability for design, analysis and simulation of nanostructures and nanodevices,
- Prepare students to conduct research and development of economically feasible and innovative applications of nanodevices in all spheres of our daily life (Uddin M., Chowdhurry R., 2001).

Nanotechnology should be taught by creating both knowledge-centered and learning-centered environments inside and outside the classroom (Edeistein A., 1996). Nanotechnology is truly interdisciplinary. Course design should incorporate science concepts from different fields (Drexier E., 1986).

The purpose of the study is to identify the nanotechnology education in secondary schools of different countries and to focus on integrating nanotechnology to their curriculum.

METHOD

To achieve the study aim, a literature review in the area of nanotechnology education and integration nanotechnology into school science curricula was conducted via internet databases and online journal archives with content related to 'nanotechnology', 'nanotechnology education', 'nanoscience', 'integrating nonoscience to the curriculum'. The review gets the information of European schools science curricula from the Nanopinion report. Nanopinion is monitoring public opinion on nanoscience technology in Europe. And that Nanopinion report is elaborated on the basis of information given by science teachers from Turkey and each of the 10 neighbor European countries and regions acting as national/regional coordinator. In Nanopinion report, the information gathered from the teachers' coordinators was collected through a survey designed to understand how their curriculum is structured and how nanoscience education can be integrated and linked to the various subjects. The sources of countries curricula come from scientific articles and the countries ministry of educations web sites which are referred in reference part at the end of the review.

FINDINGS

In the following part, the brief curricula structure of 10 different European countries and Turkey is given for understanding the nanoscience content in their science curricula and how to integrate nanotechnology to it.

Countries Review

Bulgaria

Education in Bulgaria is overseen by the Ministry Education and Science. The different science subjects have their own educational programs regulated nationally. Full-time education is mandatory for all children aged between 7 and 16. Students of the 13 to 16 years old are generally at the secondary school level. There are two kinds of secondary schools 'General secondary education schools' and 'Professional schools' (Eurypedia, 2011a). In Bulgaria, nanotechnology is not a mandatory subject, chapter or topic in any of the science curriculums at the secondary school level, but it could be integrated as sub-topics in Biology, Physics and Chemistry. The attainment target level for students would be to introduce an essential understanding of nanotechnology on the basis of theoretical knowledge supported by practical examples of nanotechnology products (Debry M., Lauritsen X., 2011).

Croatia

In the education system of Croatia, primary education is compulsory and lasts eight years (6-14 years). Secondary school education (14-18), which is not compulsory, lasts three or four years, depending on the type of education. The Ministry of Science, Education and Sports regulates the school program (Tsuladze L., 2012). In Croatia, nanotechnology is not a chapter in itself in one of the scientific subjects but addressed as a topic in the scientific curriculum. Nanotechnology is integrated in national curriculum only during the fourth and last year of secondary school (students age 17-18). Nanotechnology is integrated in the Physics curriculum under the chapter "Materials and Materials Properties", under the sub-chapter "Atoms, nucleus and elementary particles". The learning goals for students are to explain some of the effects of semiconductor electronics and nanotechnology. This chapter represents about 2 hours per school year. Nanotechnology is also integrated in the Biology syllabus under the chapter "Nature and Men", under the specific sub-chapter named "Sustainable Development". Here, the learning goals for students are to explain why there is a need to develop new technologies (fusion, new fuels and Nanotechnology). Biology represents about 2 hours per year (Debry M., Lauritsen X., 2011).

Czech Republic

Education in the Czech Republic is free and compulsory for the elementary education which takes nine years, from ages 6 to 15. Most commonly, children attend a regular 9 year elementary school (Eurydice study, 2008/2009). Nanotechnology is not a mandatory subject, chapter or topic in the national curriculum but it is possible to integrate it to Physics, under the topic "Atomic Physics" representing 10 hours in the curriculum of the fourth year of study in Chemistry and Biology subjects (Debry M., Lauritsen X., 2011).

Denmark

The Danish curriculum has a national scope. It is formulated by the Danish Ministry of Education. Education is compulsory in Denmark for every child between 7 and 16 years old. This education can be given in a public school, in private school or at home, as long as accepted standards are met (Website of the Danish Ministry of Education). Every subject in the primary as well as the secondary school is described by the subjects' objective description, the attainment targets and the endpoints. In Denmark, Nanotechnology is not a mandatory subject, chapter or topic in the curriculum. However, it could be integrated as Nanoscience which includes elements of Chemistry and Biology (Debry M., Lauritsen X., 2011).

Finland

Finland has a nine-year long compulsory schools' system for children aged 7-15. The education system is publicly funded (Website of Finnish Ministry of Education). In Finland, nanotechnology is not a mandatory subject, chapter or topic in the national curriculum but due to the local adjustments it is possible to integrate nanotechnology in various ways. A research on the problematic to integrate nanotechnology in the Finnish curriculum was conducted by Antti Laherto in 2011. The research had the objective to initiate a process in Finland by learning from the views of Nanoscience and Nanotechnology-informed science teachers on the needs and prospects of nanotechnology education in secondary schools. The study brought out that incorporating nanotechnology into existing science courses appears difficult since these topics are not explicitly in the Finnish curricula (FNBE, 2003, 2004), and there is hardly any space for additional contents. On the other hand, arranging extra courses (optional for upper secondary school students) requires money for teacher person-hours. Many respondents of the study of Antti Laherto expressed that addressing nanotechnology in science lessons depends completely on themselves and other individual teachers (Laherto A., 2011). At the moment Finland is drafting a new Physics curriculum. The new curriculum was ready in 2014, but it is too early to present the outcome and the integration of nanotechnology topic. As per the application of nanotechnology, medicine and drugs could be connected to the Chemistry subject under the chapter "Organic Nature and the Society". There is already one sub-topic under that chapter about detergents, cosmetics and textiles (Debry M., Lauritsen X., 2011).

Germany

Nanotechnology is not a mandatory subject, chapter or topic in the curriculum. As in other countries, the subject nanotechnology can be related to Biology, Physics and Chemistry. In form 6 and 7 (12-14 years old students) the curriculum comprises a subject called Nature and Science where basic knowledge related to nanotechnology can be taught. According to the German Teacher Coordinator, teaching nanotechnology all year long is not possible due to the current structure of the curriculum but half a year would be feasible (Debry M., Lauritsen X., 2011).

Greece

Education in Greece is compulsory for all children 6-15 years old; namely it includes primary (Dimotiko), and lower secondary (Gymnasio) education. Nanotechnology is not a mandatory subject, chapter or topic in the curriculum of Greece and it is therefore not officially part of the secondary education curriculum. There have been some extra-curricular activities related to nanotechnology especially in upper-high school classes (grades 10-12, students ages 15 to 18). Since September 2011, a new course called "The Basic Principles of Scientific Research" has been introduced in the upper high school curriculum in grades 10 and 11 (ages 15- 17). Within the framework of this course, several projects related to nanotechnology were designed and implemented. The above course (duration 2 hours/week for a total of 52 weeks) provides the best platform for the introduction of nanotechnology subjects in a consistent way (theory plus laboratory activities) in the Greek secondary education curriculum. (Debry M., Lauritsen X., 2011).

Italy

Italy's school curricula are formulated at national level by the Ministry of Education, University and Research with no regional differentiation. Education is compulsory from age 6 to 16 and covers the first cycle of education which correspond to 8 years and the first two years of the upper secondary education (Eurypedia, 2011b). Nanotechnology is not a mandatory subject, chapter or topic in the curriculum in the Italian secondary schools' curriculum. At this very moment, the Licei (students preparing for university) and Istituti (Technical schools) are regulated according to a reform from 2010. The first cycle of graduates will complete their education in the school year 2014-2015. The program of the new reform has neither been sufficiently defined nor have new school textbooks. According to the Italian Teacher Coordinator, the unclear school program is an opportunity to fill in the "empty" space with desired topics. A lot of freedom is currently given to the teachers. The issue is whether teachers will take advantage of that or rather rely on 'old' safe curricula and habits. The degree of provided support may be crucial to push them in either direction. There are some attempts led by universities to propose nanotechnology topics but mainly offered to selected groups of interested and excellent students. The courses are carried out at academic facilities but are not publically available (Debry M., Lauritsen X., 2011).

Romania

Nanotechnology is not a chapter in the science curriculum (Chemistry, Biology or Physics) in Romania. As nanotechnology is a very new science, the majority of science teachers do not have basic knowledge about the subject to be able to teach it. Neither The Romanian Ministry of Education, Research, Youth and Sports nor Teacher Training Centres for Professional Development organizes courses in this field. Compulsory education lasts 10 years (student aged 6 -16). Students aged 12 to 14 belong to the last two years of first phase of lower secondary education for which the curriculum is nationally standardized. Nanotechnology could be integrated in the Chemistry curriculum (13-14 years) which has an obligatory chapter about atoms, ions, molecules (only introductory explanations/ notions). The second phase of lower secondary education (Gymnasium) provides general, specialized or vocational courses (students aged 14 to 16 years). At this stage, the curriculum contains an advanced chapter about atoms and their structure, ionic compounds, molecules (polar and non-polar), ionic and molecules networks, complexes which could be well combined with nanotechnology examples (Eurypedia, 2011d).

Spain

Spain has a decentralized education system, which distributes the education responsibilities among the State, the Autonomous Communities, local Authorities and schools. The Ministry of Education sets the general organization of the education system on the basis of minimum requirements for schools, minimum core curriculum and international cooperation in education. The Autonomous Communities (17 regions) have an administrative responsibility within their territories of schools' creation and management, as well as their new development of syllabuses and regulation of levels, branches, grades and specializations, education inspection, supervision of textbooks and other curriculum-related materials (Eurypedia, 2011e).

Students aged 12 to 16 are attending the last years of secondary school forming part of the national compulsory education. At this level, nanotechnology and nanoscience education is not a mandatory subject, chapter or topic. Students in the last years of secondary school follows a well-defined curriculum, but teachers have the possibility to make some changes and this way integrate some short examples and experiments on Nanotechnology.

Students aged 16 enter the first year of the Bachillerato (university preparation), which is not a compulsory education. At this level, the curriculum is more strictly defined since students have to acquire a certain level in order to pass an admission exam for university. Nanotechnology is addressed as a topic in the first year of high school in chapters of a compulsory subject named Sciences for the Contemporary World. The subject is flexible and holds various possibilities for integrating nanoscience and nanotechnology-related lessons. The subject aims to foster understanding of the importance of science in the society among the students and it has the purpose to give the students a basic knowledge of science which can help them read information and news about science from a critical and objective perspective.

Science for the Contemporary World is given 2 hours per week, under which nanotechnology is compulsory 8 hours per year (excluding homework assignments). One of the main objectives of the subject is to make students discuss about scientific knowledge of social interest relative to materials (among others) so that students can evaluate critically what they read in newspapers or see on TV from a more objective perspective (Debry M., Lauritsen X., 2011).

Turkey

In Turkey, primary and secondary schools are part of the compulsory education. The Ministry of National Education is responsible for preparing curriculum, maintaining coordination between educational institutions and construction of school buildings for the compulsory education of Turkey (Eurypedia, 2011f). Since 2012, Turkey has a 12 years compulsory education system enclosing ages 6 to 1. Primary school lasts 8 years (students aged 6-14), while secondary education lasts 3-4 years (students aged 14-18) and includes all the general, vocational and technical education institutions. Nanotechnology is not a mandatory subject, chapter or topic in the curriculum at any level in Turkey's compulsory education curriculum however, nanotechnology can be integrated in the Turkish curriculum in various ways. In the first year of secondary education (students aged 14-15), the Chemistry subject contains a chapter about matter and its properties goals and the changes in the properties of matter at nano-scale. This would give students an understanding of the magnetic property of nano-materials and elements as well as different surface area of nano-materials. The time spent for this chapter is 3 lessons of 40 minutes in a school year. At the same school year, the Chemistry subject also has a chapter about atomic models introducing students to modern atomic theory. Here the students could be taught about the difference in the Physics rules of macro and nano-sizes, and the relation between quantum model of atom and Nanotechnology. The time spent for its chapter is one lesson of 40 minutes of the school year. The Chemistry chapter of the same year called "Our Lives" could hold lessons about the effect of nanoscience and technology in our lives. Time spend for this chapter is 2 lessons of 40 minutes. During the second year of secondary education (students aged 15-16), the Chemistry chapter on Chemical synthesis and Reaction Rate could hold information about synthesis of Nanomaterials and the difference between the reaction rates of nano-particles and macro particles. Time spent for this chapter is 2 lessons of 40 minutes of a school year. During the 3 year of the secondary education (students aged 16-17), one Chemistry chapter focuses on Thermo Chemistry. It is possible to focus on the advantages of using nano-materials for the storage of energy. The time spent for this chapter is 1 lesson of 40 minutes. The curriculum has not contained any nanotechnology subjects previously.

In Turkey, some of the schools have an extra preparation year before secondary education (students aged 14-15), where students have a science course which covers Chemistry, Biology and Physics. Most beginner level materials of nano-science activities can easily be integrated into this year since there the subject contains no predefined curriculum (Debry M., Lauritsen X., 2011).

Even though Turkey gives a relative important place to the school autonomy in terms of instruction organization, current researches confirm that teachers do not have flexibility to regulate the contents of the school programs and the special needs and circumstances of the class into account. This structure of the educational system has an impact on the attitudes and practices of teachers toward the development and organization of the curriculum. The reform introduced in Turkey in 2000 has not enabled to increase the autonomy of teachers for the choice of teaching content, methods and materials (Öztürk İ.H, 2011).

CONCLUSION AND RECOMMENDATIONS

This review is undertaken to investigate the curricula of countries (Turkey and its neighbour 10 European countries) for understanding the content of nanoscience and nanotechnology in it and is it possible to integrate nanotechnology to their science education curricula. The review provides Turkey and 10 European country profiles that include a brief introduction on the school system and curriculum at secondary level followed by information on the possibility to include nanotechnology.

As literature suggests, nanotechnology is not a mandatory subject, chapter or topic in the secondary schools' curriculum of the countries except Spain. Nanotechnology is addressed as a topic in the first year of high school in chapters of a compulsory subject named Sciences for the contemporary world in Spain. In Greece, also nanotechnology is not a mandatory subject but there have been some extra-curricular activities related to nanotechnology especially in upper-high school classes. In Croatia, nanotechnology is also not a chapter in itself in one of the scientific subjects but addressed as a topic in the scientific curriculum. Nanotechnology is integrated in national curriculum only during the fourth and last year of secondary school. Nanotechnology is also integrated in the Physics curriculum in Croatia. In Bulgaria, Czech Republic, Denmark, Finland, Germany, Italy and Turkey, nanotechnology is not a mandatory subject, chapter or topic in any of the science curriculum at the secondary school level, but it is possible to integrate it to Physics, Chemistry and biology as topic or sub-topic. It is possible to integrate nanotechnology in the Finland secondary schools' curriculum also. According to researchers, addressing nanotechnology in science lessons depends completely on themselves and other individual teachers.

The overall conclusion that can be drawn from this study is that it is possible to introduce nanotechnology at the secondary and high school level to increase students' understanding of nano-related science concepts.

Beyond integrating the nanoscience to the curriculum, schools have to give opportunities to students to practice nanoscience by workshops, experiments and different activities. Teachers who become certified in a single scientific discipline science may need to address interdisciplinary connections to prepare themselves to work with innovative and emerging science topics such as nanotechnology. Furthermore, teachers need professional development to help them finding ways to connect nanoscience to the existing curricula. This can be done by specific guidance of making connections between new and old topics, and by showing exactly where and how in the curriculum the new concepts can be embedded. In addition, the teachers need professional development to provide instructional materials, workbooks and technology and to help in finding ways how to use the new materials. Teachers may also need help in making adaptations to the curriculum to fit their students, and workshops can support teachers with ideas of how to make those adaptations.

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