**Chapter 6- Hugerat**

**Methods for Teachers to Share Nanotechnology with Students**

* 1. **Introduction**

Advances in nanoscience and nanotechnology in various fields of science have expanded in different directions. Studies in nanoscience can range from observing nanoscale items under a microscope in physics, to looking at bulk micro-material and small carbon dots in chemistry. Room-sized computers to thin laptops in computer science are also part of advancements based on nanotechnologies. The biological sciences also include nanoscience when one examines the behavior of a cell nucleus to study individual complex biomolecules at the nano-level.

In the last decade, nanotechnology and nanoscience have become essential to industrial applications and medical devices such as biodiagnostic sensors, drug delivery systems, and imaging tests. For example, in the food industry, nanomaterials have been utilized to drastically increase the production, packaging, shelf life and bioavailability of nutrients. In addition, nano-zinc oxides exhibit antimicrobial activity against foodborne bacteria, and a plethora of different nanomaterials are currently used for diagnostic purposes as food sensors to identify food quality and safety.[[1]](#endnote-2)

In the field of solar cells, nanomaterials are used to build new generation hydrogen fuel cells and innovative hydrogen storage systems capable of providing clean energy to countries that still rely on traditional, non-renewable, polluted fuels. However, the most significant advances in nanotechnology may fall in the broad field of biomedicine, especially for cancer treatment. Nanotechnology offers innovative solutions to overcome the limitations which arise from traditional chemotherapy and radiotherapy approaches.1

Recent advances in physics, chemistry, and material sciences have conferred nanomaterials with unique properties that are expected to enhance the treatment options of tumors that are resistant to current therapies. This may be possible due to nanomaterial’s innate cytotoxic activity and/or because of their ability to act as nanocarriers for the delivery of therapeutic molecules such as drugs, proteins, nucleic acids, and immune substances. These innovative biomedical applications are currently being utilized in a variety of clinical trials and soon they may produce significant developments in cancer treatment.1

Nanoscience and nanotechnology are considered essential subjects. The definition of nanoscience and nanotechnology always mentions the molecular level in traditional disciplines such as physics, biology, and chemistry. Along with biotechnologies, nanotechnologies are part of the 'converging technologies' as they are considered to specifically be able to 'improve human performance.' Some may argue that this aspect cannot be omitted when defining nanotechnologies and they are vocal in their ethical concerns regarding the use of nanotechnologies for this purpose.[[2]](#endnote-3)

In recent years there have been huge strides made in nanotechnological advances. Basic scientific innovations and practical developments have brought new challenges to academia. As a result, many science education systems around the world have revised their curricula to offer relevant nanoscience and nanotechnology education courses. All of these converging phenomena highlight the need to educate engineering and science students and equip them with the ability to design, analyze, and synthesize nanosystems. Nanotechnology education should be integrated into the first years of undergraduate engineering degree programs. Government, industrial, and university bodies need to foster collaborations with each other in order to educate nanotechnology students.[[3]](#endnote-4)

The motor development of nanosciences and nanotechnologies has made them rapidly become more popular by the day. Nanotechnology is an interdisciplinary topic. It involves designing and creating new materials, nanomachines, and nanodevices for applications that most people who live in industrialized areas enjoy daily. Recent advances and developments which use nanotechnology provide challenges for academia in regard to the proper education and training of a new generation of skilled engineers and talented scientists. These engineers and scientists need to possess the ability to apply knowledge in mathematics, science, and engineering in order to design, analyze and create nanodevices and nanosystems which are radically different from traditional technological systems.3

Some of the important questions in the field of contemporary science teaching are:

* Why do we choose to introduce the subject of nanoscience in high school?
* Is it just to satisfy the next generation of nano scientists?
* If the previous question is true, how do we implement it?

Educators in the field of science instruction understand well that perceptions regarding the nanoscale held by teachers will affect the perceptions of their students. It can be assumed that professional development programs could have implications as to what teachers consider most important to teach in their classrooms. This may affect how teachers will teach and how students will learn nanoscience concepts.

It is very important to note that many scientists, educators, and members of society claim that nanotechnologies open up new possibilities for the development of electronics, new materials, medicine, chemistry, pharmaceuticals, biotechnology, agriculture, and more. Therefore, it is very important to discover and share examples of innovative materials and scientific methods in nanoscience with students of all ages and make nanoscience a part of school curricula.

* 1. **Nanotechnology Education Contribution**

It is imperative to find appropriate and natural ways to incorporate nanotechnology into school science, technology, engineering, and math curricula. However, integrating essential concepts of nanoscience, traditional science and technology into middle school science courses may be particularly challenging.[[4]](#endnote-5)

Research from Sakhnini and Blonder was designed to identify entry points of eight concepts essential to nanoscience, science, and technology for introducing these subjects into middle school science and technology curricula. In this research, middle school science and technology teachers took a course that included all eight essential concepts for nanoscience, science, and technology in order to help them understand the essential concepts for these subjects in depth.Then they were asked to identify the point of entry in the existing scientific and technological curriculum for each of the essential concepts of nanotechnology, science, and technology. To further validate this research, two different groups of teachers participated in two consecutive phases of the study, the identification phase and the validation phase. The teachers in the identification phase identified the entry points of all eight essential concepts of science, nanotechnology, and technology in the science and technology curriculum. This reflects the relevance of the concepts of science, nanotechnology and technology from the teacher’s point of view in terms of pedagogical approach. Most of the identified integration points were verified in the second stage. Forty-two intersection points of concepts essential to science, nanoscience, and technology were proposed to be integrated into the science and technology curricula. All of the points offered at the identification stage were approved by a second set of middle school teachers at the verification stage.4

At the verification stage, 11 new points were added. The categorization of these points are described as follows: 19 income points were offered to be integrated during the teaching of chemicals in chemistry curricula; 12 in the life sciences; four for the physics and energy-related subjects; and seven in technological systems and products. The results of this study showed that multiple exposure opportunities could be offered to middle school students through their existing science and technology curriculum. The study also serves as an example of how other schools could integrate concepts of science, nano, and technology into existing science curriculum in Israeli middle schools and around the world.4

Nanotechnology is a modern trend. Therefore, it would be better to already introduce this subject to students in primary schools. These days, implementing nanotechnology education for schools is a common practice around the world. Technology education can use nanoscience and nanotechnologies to stimulate dialogue about important issues, for example, on the relationship between science, technology and society. As for the fact that nanotechnology is a reality, and not science fiction, it should also be included in higher education curricula. In research by Ban and Kocijancic, they present examples of innovative methodologies for teaching nanotechnology education including ongoing activities, experiments, computer-supported programs, materials for students and teachers, and so on.[[5]](#endnote-6) The investigators in this research proposed to include some topics related to nanotechnology in middle school curricula within the existing engineering and compulsory technology subjects and in one of the elective subjects. The proposed experiments were considered simple to perform and required only resources that are generally widely available.

Nanoscience and nanotechnology can be presented to students studying science and technology via teachers preparing activities for students such as experiments, demonstrations, etc. This can be done through encouraging a ‘science day’ that would focus on nanoscience and nanotechnology. The ideal solution would be to create a sustainable initiative to introduce engineering and technology education into the school. The initiative could be dedicated to modern nano-related technologies with a focus on relevance to everyday life. An important part of the initiative would be to hold courses for teachers who deal with and teach nanotechnology and prepare them for introducing the positive advancements that nanotechnologies provide.5,[[6]](#endnote-7) In several countries around the world, various institutions and museums offer exhibitions (‘nano day’) to schools and the general public. The same organizations arrange student group visits to educational institutions that research and develop nanoscience and nanotechnology topics. There are also workshops, seminars, interactive lectures and many online resources that provide information on nanoscience and nanotechnology topics.

There has been substantial development of nanoscience-based research and the widespread use of nanotechnological methods in both academic research and industry worldwide. One of the main goals of developing curricula around the world is to develop and educate future generations of nanoscience researchers. This can happen when there will be more of a focus on the history of nanoscience education, including curricula that will be assimilated into educational institutions for all ages. The field of nanoscience and nanotechnology education has gained in importance because of the motor development of nanoscience and the widespread use of nanotechnology in everyday life.[[7]](#endnote-8) To encourage nanoscience education, it is very important that a short history of the growth of nanoscience education is presented in the curricula timeline. It is also very important to execute nanoscience education projects within the schools in order to expose the subject to students.

### The need for nanotechnology and nanotechnology education pushed the USA and countries around the world to train a new generation of nanoscientists and researchers in these fields. To meet these needs and prepare the next generation of nanotechnology savvy leaders, nanotechnology education must be a priority.[[8]](#endnote-9)

The first article in the *Journal of Chemical Education* that included nanotechnology as a topic appeared in 1995.[[9]](#endnote-10) The subject quickly penetrated the scientific education system in the United States and around the world. In 2004, a national center was established in the United States called The National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT). This center is comprised of self-described, integrated, nano-educational component areas including learning research, nano concepts, courses, learning technology development, professional development, resource dissemination, networking and community building, and evaluation and assessment.

The center works to prepare curricula for all ages on nano chemistry and nanotechnology concepts and made these topics relevant to student social life. The project is named Big Ideas and it is designed to teach nanoscience to grades 7-12 and grades 13-18.[[10]](#endnote-11) The project focuses on the question: “Should nanoscience be considered a new discipline, or can it be spread throughout the secondary science education curriculum based on its interdisciplinary nature?” The project also emphasizes effective teacher professional development programs for inclusion of nanoscience into school curricula.10

* 1. **Teaching High-School Students Nanoscience and Nanotechnology**

Research in science education has identified the significance of nanoscience and nanotechnology to the scientific literacy of future generations. Many researchers have identified and noted nine Big Ideas related to nanoscience and nanotechnology. Based on these Big Ideas, a learning sequence can be developed for middle school students that focuses on size and scale, tools and instrumentation, size-dependent characteristics, and a scientific society.

In a study from Stavrou and co-workers, the Big Ideas teaching sequence was applied to a class of 15 high school students in eighth grade, ages 14-15 years-old.[[11]](#endnote-12) Seven meetings were held, and each lasted about ninety minutes. The course was structured based on the following topics.

* 1. Introduction
  2. How small is a nanometer?
  3. How can we ‘see’ the nano world?
  4. Size-dependent characteristics: Change of surface area to volume ratio
  5. Explain the behavior of different textiles (hydrophilic and hydrophobic) when absorbing water droplets
  6. Explanation of color changes in nanoparticles
  7. Risk assessment of nanotechnology

Data were collected through questionnaires, interviews, student worksheets, and field comments. The results indicated positive encouragement in the teaching of science, nanotechnology, and technology even at lower levels of education.11 The study of Stavrou et al. clearly showed that the teaching-learning sequence developed for eighth graders provided them with valuable insights on basic ideas in the fields of nanoscience and nanotechnology.11 The findings of the study made it possible to assess that the whole process can improve student understanding of nanotechnology and their awareness of social and ethical issues related to nanotechnology, science, and technology. The study findings were found to be consistent with the findings of the other researchers.[[12]](#endnote-13),[[13]](#endnote-14)

However, students had difficulty understanding and comparing micro-level sizes. This could be attributed to the lack of daily exposure of what these objects are and their difficulty in understanding the absolute size and relative size of non-objects. Moreover, the concept of space-to-volume ratio was quite difficult for children to describe because of their limited logical abilities to assess proportions. Therefore, instead of focusing on the ratio, we focused on increasing the surface area as the objects became smaller which was a concept more easily understood by the students. The main difficulty faced by the students in trying to explain the change in the optical properties of gold had to do with their idea that properties remain unchanged in all dimensions. It is worth noting that this perception is still deeply ingrained in student teachers.[[14]](#endnote-15)

Teaching preliminary scientific topics for high-level nanotechnology is no small task. Blonder and Dinur introduced a nanotechnology study module designed for high school students.[[15]](#endnote-16) The model presented a unique way of adapting advanced content to the level of high school students through constructivist pedagogy where students were at the center of learning. The study elaborated upon the idea of the transition from teacher-focused pedagogy to pedagogy. This idea transferred control of the learning environment from teacher to learner. This research included student interviews and a semantic differential questionnaire to learn about motivation and perceptions of students.

Findings from this research showed that students were interested in the subject of LED and that the researchers found that that this topic enhanced their motivation to learn more about LED, nanotechnology, and chemistry. Also, the student-centered pedagogy which was selected for the study methodology provided a positive, ongoing motivation for the students. In addition, the study results indicated that combining applied modules of nanotechnology using appropriate instructional methods in high school science classes could provide unique solutions for enhancing low enrolment percentages in science subjects.

* 1. **Introducing Nanoscience and Nanotechnology Courses in High Schools**

In many parts of the world, nanotechnology is considered the future technology of the 21st century. Nanomaterials are objects of intensive research in various scientific fields. Thus, it is important that today’s students in current educational systems become more familiar with this subject. It is imperative to present the subject in the context of chemistry education in school and to provide science teachers. Science teachers are usually unaware of this subject. However, specific study materials and teaching methodologies on nanotechnology have been developed.[[16]](#endnote-17),[[17]](#endnote-18),[[18]](#endnote-19)

Ter Horst and team designed a nanotechnology teaching module built according to a guided learning concept. It was designed for chemistry classes in high schools with reference to standard German educational standards of that time.18 However, it could be adapted to other country’s educational standards. Their nanotechnology module focused on zinc oxide particulate matter particles in four parts. The descriptions of each unit were:

* Unit 1 - How Does “Nano” Work
* Unit 2 - How to Produce “Nano”
* Unit 3 - Why Do You Need “Nano”
* Unit 4 - “Nano”: Risks versus Potentials

During and after the implementation of each unit, the responses of the teachers and students were recorded and the responses showed that the subject of “Nano” as well as the textbook were highly appreciated. Many of them confirmed that they would use this teaching module at their school even though the topic seemed quite demanding. Teachers also rated the unit as refreshing because it offered new and interesting topics to teach chemistry education in the school and that these topics were also related to modern research. This indicates that there was an interest in this topic that had not yet been addressed during regular science classes. Teachers stressed the relevance of the topic and that it addressed many educational standards in the regular curriculum. Therefore, it seems that it is a worthwhile task to bring the subject to schools and to develop new teaching concepts related to nanoscience and technology.

Curricula should be characterized by flexible yet aggressive and timed actions to integrate new scientific and technological discoveries. To this end, a teaching and learning sequence (TLS) can be designed and completed within a few teaching hours so that they can be integrated into existing curricula. Because of the great importance of the subject of nanotubes, and especially carbon pipes, this topic was chosen. Although pipes and tubes have already been used in a wide variety of applications, there are impressive indications of their use for additional, innovative, future applications. It is very important to inform citizens about scientific issues in our technological world. Therefore, a TLS for high school students that focused on carbon nanostructures was developed and implemented by Velentzas and Stavrou.[[19]](#endnote-20)

From an educational point of view, students could be presented with the important idea that some of the interesting features at the nano level are related to the structure of the material. During the development of TLS, students could focus on extremely small particles. Therefore, models and analogies were based on this idea as the main teaching tool for use.19

Velentzas and Stavrou prepared a module where students study and examine the various geometric structures of polyurethane carbon tubes in a C60 fullerene Bucky ball, also known as single-walled carbon tubes. This module was prepared in order to introduce nanotechnology to the students via presenting some of the interesting features at the nano level which are related to the structure of the material. While watching a video, students could be informed about what nanotechnology is, how scientists in the field of nanoscience work, and what are some products and applications of nanotechnology in everyday life. Students could watch a video in parts and a teacher-guided discussion could follow each part. The module steps could be presented as follows:

* Step 1: The different forms of carbon
* Step 2: The structure of fullerene
* Step 3: Measurements using models
* Step 4: The length of a C–C bond
* Step 5: The size of nanoparticles
* Step 6: The types of carbon nanotubes
* Step 7: Technological applications

### **Application of Nanotechnology in Different Fields**

Science and technology continue to advance in the fabrication of micro- and nanodevices for a variety of industrial, consumer, and biomedical applications.[[20]](#endnote-21) Microscopic devices that have a length of less than 1 mm but more than 100 nm and that combine electrical and mechanical components (MEMS) have been produced and some are in commercial use.8 A variety of sensor types using these devices are used in industrial, consumer, defense, and biomedical applications. Various micro- and nanocomponents are used in instruments and other industrial applications such as micromirror arrays.[[21]](#endnote-22)

The largest of the MEMS applications include accelerometers. Around 90 million accelerometer units were installed in vehicles in 2004. Other MEMS applications include:

* Silicon-based piezoresistive pressure sensors for manifold absolute pressure sensing for engines and disposable blood pressure sensors
* Capacitive pressure sensors for measuring tire pressure
* Thermal inkjet print heads
* Micromirror arrays for digital projection displays
* Optical cross-connections in telecommunications
* Chemical/biosensors and gas sensors
* Microresonators
* Infrared detectors and focal plane arrays for Earth observation, space science, and missile defense applications
* Picosatellites for space applications
* Fuel cells
* Hydraulic, pneumatic, and other consumer products

MEMS devices are also being pursued for their use in magnetic storage systems. In this case they are being developed for super compact and ultrahigh-recording-density magnetic disk drives. NEMS are produced by nanomachining in nanochemistry based on top–down and bottom–up approaches.[[22]](#endnote-23) Some examples of other applications include microcantilevers with integrated sharp nanotips for scanning tunneling microscopy (STM) and atomic force microscopy (AFM). Quantum corrals are formed using STM by placing atoms one by one.

Other applications include AFM cantilever arrays for data storage, AFM tips for nanolithography, dip-pen lithography for printing molecules, nanowires, carbon nanotubes, quantum wires (QWRs), quantum boxes (QBs), quantum-dot transistors, nanotube-based sensors, and biological (DNA) motors. Additional MEM examples are: molecular gears formed by attaching benzene molecules to the outer walls of carbon nanotubes; nm-thick films for magnetic rigid disk drives and magnetic tape drives; nanopatterned magnetic rigid disks, and nanoparticles. Nanoparticles are used in magnetic tape substrates and coatings. Nanoelectronics can be used to build computer memory devices using individual molecules or nanotubes to store bits of information, molecular switches, molecular or nanotube transistors, nanotube flat-panel displays, nanotube integrated circuits, fast logic gates, switches, nanoscopic lasers, and nanotubes as electrodes in fuel cells.[[23]](#endnote-24)

### **Investments in Nanotechnology**

The financial sector will play a key role in transferring technological knowledge from research centers to industry and to markets. Sizeable investments, especially seed phase investments, are needed for the development of new products and processes and for the penetration of new markets. A closer cooperation between the financial community and nanotechnology companies can help to overcome these barriers. By the end of 2004, venture capitalists had already invested $1 billion into nanocompanies, nearly half of that alone in 2003 and 2004. It is expected that most of these nanotechnology companies will be sold through trade sales.[[24]](#endnote-25)

For successful investments, two aspects will be of critical importance: timing and target selection. Applying technical due diligence to these companies will be essential for making acquisitions. The difficulty and expense involved in building up nanotechnology companies suggest that the future winners in this sector will be well-funded companies and institutes that can attract and nurture the scientific and technical expertise needed to understand nanotechnological problems and challenges. Moreover, the long lead times involved in moving from concept to commercialization necessitate a considerable long-term commitment to projects.[[25]](#endnote-26),[[26]](#endnote-27)

The questions facing every investor in the field of nanotechnology are as follows:[[27]](#endnote-28)

* What will make the investments in this company successful?
* When will we see the initial public offering?
* When will there be an initial public offering for this nanobiotechnology company?
* What will make these companies successful investments?

It is an integral part of research and development organizations in a wide range of industries and sophisticated investors in the field of nanoscience and nanotechnology. Nanotechnology can help this happen as it has been proven in the past. With an experienced team, an innovative and stable business model, and strong partnerships with enterprising scientists in the field of nanotechnology….. What generally moves a company from an initial public offering to a market value of a few billion dollars is a useful nanoproduct and its transfer to the market.27

* 1. **AFM to Nano**

By global definition, 'nano' refers to the nanometer scale. Many definitions emphasize the fact that nanoscience and nanotechnology study phenomena on a scale where characteristics are significantly different from those on a macroscopic scale. Thanks to the development of tools such as AFM, nowadays scientists and technologists are able to not only observe but also manipulate nanoscale sized objects. However, when focusing on a scale, one should clearly define the field boundaries including: (i) what is the upper size limit of an object to still be considered nano? and; (ii) should all the dimensions of the object measure several nanometers or is one enough? These questions remain controversial.

Since the new technological revolution, we have witnessed the existence of two different technological approaches. These approaches are top-down or bottom-up. They contribute greatly to raising discussions around the definition of nanoscience and nanotechnologies.[[28]](#endnote-29) Developments in nanoscience from top to bottom refers to minimization. The opposite technological approach, from the bottom up, constitutes the building objects by assembling molecules or aggregates. This approach refers to the opposite direction of miniaturization: it starts with molecules to form larger objects.

In the new scientific age, nanotechnology will significantly change the future of humanity. As a result, nanoscience offers the possibility of sustaining diverse technologies and different scientific disciplines that converge upon a common goal. Nanomaterials, with their amazing and unusual properties, are becoming more common in our daily lives. This has led most countries in the world to include nanoscience in science education at various levels. Nanoscience education has become part of the curricula of several universities and high schools around the world. Nanoscience and nanotechnology institutes for science teachers have been established to upgrade high school teacher knowledge and understanding of the latest developments in nanoscience.[[29]](#endnote-30)

Because science subjects have a pyramidal structure, the introduction of nanoscience into schools requires new paradigms in science education. Therefore, we cannot simply remove some older topics from curricula and replace them with nanoscience foundations. A few years ago, the atomic power microscope (AFM) was developed based on the short-term interaction of Van der Waals interactions. Using an AFM allows for studying biological samples up to an atomic resolution. Information on topography, roughness, friction, adhesion, elastic properties, interaction between edge and sample surface, distributions of electric field, magnetic field, resistance, surface potential, and more can all be obtained by the AFM in nanometer resolution.

Planinšič and Kovač presented an innovative model of teaching while using an AFM. This model was proven successful as an introduction to nanophysicsfor high school students as well as for physics teachers.[[30]](#endnote-31) The model demonstrated the two operating modes of the AFM (touch mode and oscillation mode) as well as some basic principles that limit the resolution of the method. This model could be used in the classroom during class as a demonstration experiment, a simple lab experiment, or a home experiment that students can do on their own.[[31]](#endnote-32) This proposed model can be easily constructed by teachers or students and it can demonstrate the basics of AFM detection. In addition, it is designed to be taught in a short time frame, suitable for demonstration in nanoscience lectures. This could easily be a good model for introducing the subject of nanoscience and nanotechnology into the school curriculum or in other interdisciplinary subjects in science.

* 1. **Introducing Nanotechnology Topics to Middle and High-School Students**

There are various arguments that justify the introduction of nanoscience and nanotechnologies in classrooms. The preliminary questions that are expected to precede the development of any curriculum are:

* Which public is targeted?
* Is the subject aimed for a minority or for all students?
* What are the long-term goals for introducing this topic in this curriculum?

One of the important topics in science teaching is the interconnection between science, technology and society. Innovative articles and ideas have dealt with nanotechnologies as a socio-technological issue. In 2008, research presented by Zenner and Crone proposed activities for teaching nanotechnology and societal issues at the middle school level.[[32]](#endnote-33) Since then many programs around the world have included training graduate students to bring nanotechnology to the public.

Many scientists emphasize the importance of introducing nanoscience topics into educational curricula for all student types and ages. This is in preparation for encouraging future nanoscientists and helping to fulfil the global lack of nanoscientists and nanotechnologists.10,[[33]](#endnote-34) When preparing intervention programs in STEM on the subject of nanoeducation, special attention should be paid to three points:

* Consideration of the essential interdisciplinary nature of nanoscience itself.
* Dealing with the importance of meeting the limitations of the education system, such as, the latest standards and scientific concepts in the field of nanotechnology.
* Gathering an interdisciplinary team of scientists, educators, and researchers to design appropriate curricula. The curricula should include the topic of nanoscience in society. The curricula should be designed at an appropriate level for each school and with age-level appropriate equipment.

These three points are of particular importance in the design of relevant curricula and the development of resources or pedagogical assessments in nanoscience. The researchers Schank et al. argued that this development in nanoscience will be a catalyst that will lead to a substantial modernization of the scientific educational system for high school students worldwide.[[34]](#endnote-35) Nanoscience and nanotechnologies are required for updating standards, for creating connections between traditional disciplines, and ultimately for advancing true interdisciplinary teaching that conforms to the modern realities of science.[[35]](#endnote-36)

Therefore, many education systems around the world are working hard to ensure that nanoscience-educated workers are adequately trained. This need has become urgent for two reasons. First, most of the industrialized countries are fiercely competing among one another to lead in the number of scientific and engineering advancements. In addition, the number of students currently choosing STEM careers, their academic skill sets, and their scientific literacy levels, especially in nanoscience, are considered insufficient. It is the educational system’s duty to provide future citizens with tools to make informed decisions. Courses designed to better train and educate students in nanoscience may be slightly different from programs aimed primarily at training the future nano power in nano content and practice and instilling the concept of nano-literacy.10,33

* 1. **Nanoscience, Nanotechnology, and Society**

The National Science Foundation in the U.S. funded a program at the University of Wisconsin-Madison which included training undergraduate students to bring nanotechnology to the public. This program approached nanotechnologies as a scientific technological issue and aimed to present nanotechnology and society issues at the middle school level. As a result, activities were created for middle school students in order to enhance their nano-literacy.32

Research by Berne also argued the significance of introducing ethics at the graduate and undergraduate level, not just in high school.[[36]](#endnote-37) Berne examined ethical issues in nanoscience and nanotechnology and he/she described three overlapping levels of inquiry in the field of nano-ethics. In addition, his/her research suggested materials that could be used to clarify student questions and to encourage participation.

Ethical and social aspects of nanoscience and nanotechnology at the university level must be taken into account.32 Some references provide only narrative reports on various innovative courses and they detail objectives assigned to these initiatives. In addition, XYZ discussed difficulties encountered, and decisions made in regard to content and people needs in nanoscience course development and teaching. The researcher Sweeney in 2006 was able to identify and analyze how researchers grasp the social and ethical dimensions of a ‘nano work’ summer program (Sweeney, 2006).[[37]](#endnote-38) Sweeny focused on researchers working in the fields of nanoscience and nanotechnology at the University of Central Florida as well as science and engineering graduates who participated in this NSF funded program.

The University of Wisconsin at Madison in the U.S.A developed a course entitled: Nanotechnology and Society. It was designed and led for a semester for graduate students who participated in another course called, Science and Engineering Courses and Nanometers in Society. The course was based on encouraging open discussion among students from various fields.[[38]](#endnote-39) The objectives assigned to this course were as follows:38

* Introduce the broad field of nanotechnology and the basic science and technology.
* Consider the societal implications of nanotechnology in the context of social, scientific, historical, political, environmental, philosophical, ethical, and cultural ideas from other fields and prior works.
* Develop questioning, thinking, idea producing, and communication skills, both written and verbal.

It is very important that social and ethical implications should be integrated into university science courses to ensure that future scientists do not neglect them. At the University of Wisconsin in the U.S.A., they created a university course entitled Little Wonders: The Impacts of Science, Technology and Human Health on Nanomaterials. The course was designed to address some of the ethical and social implications of nanotechnologies.32,[[39]](#endnote-40) A physicist named Jaszczack and a historian called Seely reported difficulties in integrating nanoscience and nanotechnologies into educational curricula.[[40]](#endnote-41) They sought to emphasize the equal importance and interconnections of basic sciences, engineering, and the social implications of nanoscience and nanotechnology.

Researchers Toumey and Baird preferred the term “interactions” over implications to introduce the idea of joint development of nanotechnology and society.[[41]](#endnote-42) They wanted various initiatives taken at the University of South Carolina to "nurture a community of nanolithic universities.41" They described various programs and activities from undergraduate courses to outreach programs in order to discuss social and ethical interactions of nanotech with laymen. They claimed:“We need to develop a plan for the metric assessment of nanoliteracy at USC: quantitative measures of nanoliteracy and its progress, and qualitative interpretations of participants’ attitudes and values, to complement narrative accounts like this one.”41

Some argue that individual liberties could be jeopardized by the development of invisible devices that rely on nanotechnologies. These devices could be used for surveillance purposes which could intrude upon the privacy of people. Or, these devices could be designed for the field of nanomedicine.[[42]](#endnote-43) In addition, nanoscience, physics, biology, chemistry, computer science, and cognitive science can share common research themes, thereby leading to a convergence of concepts. Bio-nanotechnologies can potentially influence humans by improving their performance and from this raise ethical concerns.20 This is especially concerning if these improvements are implemented in the military.42

Nanoscience and nanotechnology do have interactions with society. Nanoparticle toxicity, for example, remains largely unknown. Due to the potential to enhance economic conditions, many countries have engaged in fierce competition to develop nanotechnologies. However, it is important to ensure the protection of workers who work with nanoparticle technologies and consumers who buy products that contain nanoparticles. Measures must also be taken to protect the environment from nanoparticle scattering. Overall, nanoelectronic advancements are leading to smaller and faster devices with increasing autonomy.42

* 1. **Nanoscience and Nanotechnology Professional Development for Teachers**

In order to allow teachers to incorporate the subject of nanoscience into their science lessons, the obstacles that hinder the introduction of nanoscience and nanotechnology must be overcome. This may be addressed via enhanced training in their professional development.[[43]](#endnote-44) There is now a broad consensus regarding the need to promote nanoscience teaching as an interdisciplinary topic. This should be done in teacher professional development programs and for student curricula. Teachers often focussed on one field from the field of science when being trained. Therefore, they may not feel comfortable when it comes to instructing topics from other scientific fields. This reluctance to deal with nano-related topics that they are not familiar with may be exacerbated by rapidly evolving developments in nanoscience. Detailed nanotechnology development plans need to be developed for current teachers.[[44]](#endnote-45) Professional development courses can be designed to help current teachers be less fearful of bringing nanotechnology into their course curricula and help them address student questions.

For pre-service teacher professional development, organizing courses in scientific methods dealing with interdisciplinary and state-of-the-art topics including nanoscience and technologies could be offered. In addition, in order to provide teachers with in-depth explanations of nanotechnological phenomena and discussion approaches one needs to create educational material in the field of nanoscience and nanotechnology.34 In their article, Tomasik et al. states: "Training the next generation of nano-workers is a major challenge for promoting the advancement of nanoscience."44

To encourage current and pre-service teachers to integrate nanoscience and nanotechnology into their classrooms, online nanoscience and nanotechnology workshops have been developed for middle and high school teachers. In these online workshops, teachers can acquire knowledge in science and nanotechnology and obtain various resources to incorporate nano-scientific topics in their classrooms. At the end of these professional development programs, participants are encouraged to build their own nanoscience module that could be taught to students. Subsequently, these models can also be evaluated anonymously by two other participants.44

The subject of scientific inquiry is generally included in school curricula and the application of inquiry-based lessons including nanoscience is currently offered in most global curricula. There are several goals for conducting these workshops. First, they aim to improve secondary teacher understandings of nanomaterial phenomena and to make them more cognizant of the connections between nanoparticle science, technology, and traditional disciplines. Second, they aim to address pedagogical goals of advancing reflections upon inquiry-based teaching and scientific learning. Overall, these workshops aim to improve skills for the application of inquiry-based methods for all participants. To achieve these goals, one needs to examine the development of a teacher’s professional knowledge base and to design effective professional development for high school teachers in nanoscience. This will include addressing how to add effective lessons regarding nanoscale phenomena to science lessons. Five main factors were shown to influence teacher choices when presenting nanoscience concepts in their classes: relevance, student motivation, curriculum flexibility, technical considerations, and knowledge base.

* 1. **Nano Green Technology for Food Processing**

Since the beginning of time, one of the most important challenges facing humanity was how to preserve foods. Finding a balance between supply and demand for food in a sustainable way ensures the long-term survival of the human race. Tremendous global population growth over the past several centuries has also heightened the need for sustainable food production and food processing technologies. ~~Green technologies in~~ Major challenges in the food processing sector include the need to reduce the generation of toxins resulting from these processes. Social factors affect consumer perceptions of current and emerging agri-food technologies. These social factors include nanotechnology, the need for biodiversity, and the importance of biodiversity in maintaining sustainable food systems.[[45]](#endnote-46)

The food processing sector is a diverse sector that includes the use of various raw materials, processes and end products. This sector must pay particular attention to maintain quality, safety and nutritional properties of food products through green technology. Various nanotechnologies such as biological preservation, electromagnetic wave heating, electric and magnetic fields, non-thermal technologies, etc. have been used…. Nanotechnology has created opportunities to reduce toxic by-products resulting from food processing methods and to ameliorate the environmental impact of many harmful food production and processing practices.

1. . J. Hulla, S. Sahu and A. Hayes, *Hum. Exp. Toxicol.*, 2015, **34**(12), 1318. [↑](#endnote-ref-2)
2. . J.P. Dupuy, *La revue du Mauss*, 2004, **23**, 408. [↑](#endnote-ref-3)
3. . S. Ozel and Y. Ozel, presented in part at Proceedings of the 5th WSEAS/IASME International Conference on Engineering Education, Heraklion, Greece, July, 2008. [↑](#endnote-ref-4)
4. . S. Sakhnini and R. Blonder, *Nanotechnol. Rev.*, 2018, **7**(5), 373. [↑](#endnote-ref-5)
5. . K. Ban and S. Kocijancic, presented in part at The Second World Conference on Technology and Engineering Education, Ljubljana, Slovenia, September, 2011. [↑](#endnote-ref-6)
6. . A. Laherto, *Sci. Educ. Int*., 2010, **21**(3), 160. [↑](#endnote-ref-7)
7. . A.E. Greenberg, *ACS Nano*, 2009, **3**, 762. [↑](#endnote-ref-8)
8. . M.C. Roco, *Nat. Biotechnol*., 2003, **21**, 1247. [↑](#endnote-ref-9)
9. . L.A. Coury Jr, M. Johnson and T.J. Murphy*, J. Chem. Educ.,* 1995, **72**, 1088. [↑](#endnote-ref-10)
10. . S.Y. Stevens, L. Sutherland, P. Schank and J. Krajcik, *The Big Ideas of Nanoscale Science and Engineering*, NSTA Press, Arlington, Virginia, 2009. [↑](#endnote-ref-11)
11. . D. Stavrou, E. Michailidi, G. Sgouros and K. Dimitriadi, Teaching high-school students nanoscience and nanotechnology, *LUMAT Int. J. Math Sci. Technol. Educ*., 2015, **3**(4), 501. [↑](#endnote-ref-12)
12. . S. Swarat, G. Light, E.J. Park and D. Drane, *J. Res. Sci. Teach*., 2011, **48**, 512. [↑](#endnote-ref-13)
13. . A. Magana, S. Brophy and L. Bryan, *Int. J. Sci. Educ*., 2012, **34**(14), 2181. [↑](#endnote-ref-14)
14. . D. Stavrou and M. Euler, presented in part at the ESERA 2013 Conference: Science Education Research for Evidence-Based Teaching and Coherence in Learning, Nicosia, Cyprus, 2013. [↑](#endnote-ref-15)
15. . R. Blonder and M. Dinur, *J. Nano. Educ.,* 2012, **3**, 1. [↑](#endnote-ref-16)
16. . R. Blonder, *J. Nano. Educ.*, 2010, **2**, 67. [↑](#endnote-ref-17)
17. . J.H. Tomasik, S. Jin, R.J. Hamers and J.W. Moore, *J. Nano. Educ*., 2009, **1**(1), 48-67. [↑](#endnote-ref-18)
18. . N. ter Horst, T. Wilke and T. Waitz, presented in part at New Perspectives in Science Education, Conference Proceedings, Florence, Italy, 2015, March, 2015. [↑](#endnote-ref-19)
19. . A. Velentzas and D. Stavrou, *Chem. Teach. Int*., 2021, 3(1), 45. [↑](#endnote-ref-20)
20. . M.C. Roco and W. Bainbridge, *J. Nanopart. Res*. 2005, **7**(1), 1. [↑](#endnote-ref-21)
21. . Scott and Miller, 2012. [↑](#endnote-ref-22)
22. . Y. Lee, K. Kozar and K. Larsen, *Commun. Assoc. Inf. Syst.*, 2003, **12**(1), 50. [↑](#endnote-ref-23)
23. . Bharat, 2016 [↑](#endnote-ref-24)
24. . Farshchiet al., 2011 [↑](#endnote-ref-25)
25. . Lauterwasser, 2006 [↑](#endnote-ref-26)
26. . Lawrence, S. 2005 [↑](#endnote-ref-27)
27. . R. Paull, J. Wolfe, P. Hébert and M. Sinkula, *Nat. Biotechnol*., 2008, **21**(10), 1144. [↑](#endnote-ref-28)
28. . D. Vinck, *Les Nanotechnologies*, ed. Le Cavalier Bleu, Paris, France, 2009. [↑](#endnote-ref-29)
29. . T. Gyalog, *Europhys. News,* 2007, **38**, 13. [↑](#endnote-ref-30)
30. . G. Planinšič and J. Kovač, *Phys. Educ.*, 2008, **43**, 37. [↑](#endnote-ref-31)
31. . K.E. Drexler, *Phys. Educ.*, 2005, **40**, 339. [↑](#endnote-ref-32)
32. . G.M. Zenner and W.C. Crone, in *Nanoscale Science and Engineering Education*, ed. A.E. Sweeney and S. Seal, American Scientific Publishers, Valencia, California, USA, 2008, 621-647. [↑](#endnote-ref-33)
33. . L.A. Bryan, S. Daly, K. Hutchinson, D. Sederberg, F. Benaissa and N. Giordano, presented in part at The Annual Meeting of the National Association for Research in Science Teaching, New Orleans, USA, April, 2007. [↑](#endnote-ref-34)
34. . P. Schank, J. Krajcik and M. Yunker, in *Nanoethics: The ethical and social implications of nanotechnology Can Nanoscience Be a Catalyst for Education Reform?* ed. F. Allhoff, P. Lin, J. Moor, J. Weckert, Wiley Publishing, Hobeken, New Jersey, USA, 2007, 277-289. [↑](#endnote-ref-35)
35. . P. Hurd, *J. Res. Sci. Teach*., 2002, **39**, 3. [↑](#endnote-ref-36)
36. . R.W. Berne, *Nanoscale Science and Engineering Education*, ed. A.E. Sweeney and S. Seal, American Scientific Publishers, Valencia, California, 2008, 547-566. [↑](#endnote-ref-37)
37. . A. Sweeney, *Sci. Eng. Ethics*, 2006, **12**, 435. [↑](#endnote-ref-38)
38. . C. Tahan, R. Leung, G. Zenner, K. Ellison, W. Crone and C.A. Miller, *Am. J. Phys.,* 2006, **74**, 443. [↑](#endnote-ref-39)
39. . C.A. Miller and S.K. Pfatteicher, in *Nanoscale Science and Engineering Education*, ed. A.E. Sweeney and S. Seal, American Scientific Publishers, Valencia, California, 2008, 567-576. [↑](#endnote-ref-40)
40. . J.A. Jaszczak and B.E. Seely, in *Nanoscale Science and Engineering Education*, ed. A.E. Sweeney and S. Seal, American Scientific Publishers, Valencia, California, 2008, 591-619. [↑](#endnote-ref-41)
41. . C. Toumey and D. Baird, in *Nanoscale Science and Engineering Education*, ed. A.E. Sweeney and S. Seal, American Scientific Publishers, Valencia, California, USA, 2008, 577-589. [↑](#endnote-ref-42)
42. . J. Schummer, in *Nanotechnologies, Ethics and Politics*, UNESCO Publishing, Paris, 2007, 79-98. [↑](#endnote-ref-43)
43. . E. Hoover, P. Brown, M. Averick, A. Kane and R. Hurt, *J. Nano. Educ*., 2009, **1**, 86-95. [↑](#endnote-ref-44)
44. . J.H. Tomasik, S. Jin, R.J. Hamers and J.W. Moore, *J. Nano. Educ*., 2009, **1**(1), 48. [↑](#endnote-ref-45)
45. . J.I. Boye and Y. Arcand, *Food Eng. Rev*., 2013, **5**(1), 1. [↑](#endnote-ref-46)