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Addressing ethical and safety issues of nanotechnology in health and medicine in undergraduate engineering and technology curriculum

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ABSTRACT: In this article, the authors take a look at incorporating the concepts and developments of nanotechnology in the medical field into undergraduate engineering and technology based courses, with ongoing efforts to expand to a number of related disciplines. The idea is to educate students on the issues, both safety and ethical related, in order to provide them with a better understanding of these rapidly evolving, potentially life-saving, and yet exceedingly dangerous technologies. Module 7A: Nanotechnology in Health and Medicine contains two lectures based on the health, safety and ethical issues associated with nanotechnology, while also providing students with a glimpse of nanotechnology applications in the medical field. At the end of each semester that this module is implemented, students are surveyed and encouraged to provide feedback on the quality of the module. This is based on the module content, as well as presentation by the lecturer. By the end of this module, students are hoped to have a better understanding of the issues related to nanotechnology and apply that knowledge in the real world.

Keywords: Nanotechnology, health, medicine, ethics, education

INTRODUCTION

As nanotechnology is an ever-expanding field, it is important that the scientists and engineers of tomorrow are well-educated on the topic today. With the help of modern media, such as television, movies, literature and the Internet, information on advances in nanotechnology has become increasingly accessible to the public. Of course, no new technology goes without scrutiny by the public on ethics and safety. Which poses the question: how are engineers supposed to know how to safely and ethically deal with nanotechnology?

The simple answer to this question is to provide a curriculum that is infused with ideas on nano-safety and nano-ethics. Texas State University and the University of Texas at Tyler both offer courses that touch on nanotechnology issues to students from engineering and technology backgrounds. The programme, entitled *NUE: NanoTRA-Texas Regional Alliance to foster* Nanotechnology Environment, Health, and Safety Awareness *in Tomorrow's Engineering and Technology Leaders*, that incorporates nanotechnology curriculum in these courses was made possible thanks to the grant awarded by the National Science Foundation-Nanotechnology Undergraduate Education (NSF-NUE) to both universities [1].

The programme allows for many different topics on nanotechnology safety and ethics to be discussed. These subjects are organised into modules that are, then, integrated with current courses taught at the universities or are used to create entirely new courses altogether [2]. The modules are divided into two parts: Introductory (A) and Advanced (B). This article will be focusing on module 7A, which is Nanotechnology in Health and Medicine. This module was most recently implemented in the Texas State University course Philosophy 1320: Ethics and Society.

MODULE OBJECTIVE

The main goal of this module is to inform students on the potential risks and issues associated with nanotechnology in health and medicine. Before exploring this module, however, students are required to possess a basic understanding of human anatomy and a chemistry background of at least a high school level. The module is split up into two lectures:

- Lecture I: covering health, safety and general issues
- Lecture II: posing ethical questions and solutions

Coming out of this module, students will be expected to define nanotechnology issues in health and medicine, appreciate the role of nanotechnology in numerous medical fields, and be able to pose ethical questions and determine courses of action relating to nanotechnology in health and medicine [3]. Each module infused into a course at Texas State or UT-Tyler is required to meet ABET (Accreditation Board for Engineering and Technology) standards. These standards are put into place at selected universities in order to ensure graduates are receiving a quality education, and are being prepared to confidently enter the global workforce [4]. Module 7A meets three of the eleven required student outcomes of an ABET accredited course (see Table 1):

Table 1: Module 7A relationship to ABET programme outcomes [3].

Reference letter	Requirement
a)	An ability to apply knowledge of mathematics, science and engineering
f)	An understanding of professional and ethical responsibility
j)	A knowledge of contemporary issues

STUDENT RECEPTION

Certain sections of the Philosophy 1320 course offered at Texas State University are designated for science, engineering and technology students only. This allows for a more specific lesson plan catered towards these students' educational requirements.

At the end of the Fall 2013 semester, students enrolled in one of these courses were given the opportunity to evaluate the module. As seen in Figure 1, the majority of students gave the module positive marks. Over 56% of the students enrolled in this course gave the module an overall rating of *excellent* and over 68% of the students believed the module was of *excellent quality*. This feedback process helps those responsible for producing module content to make adjustments in order to perfect the students' learning experience.

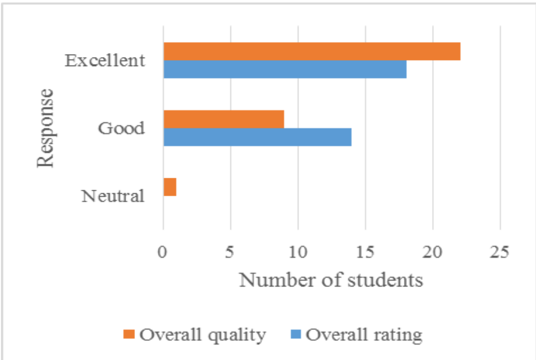

Figure 1: Student responses to module 7A in PHIL 1320 course.

TOPICS

Lecture I

Lecture I dives into the issues within health and medicine regarding nanotechnology. As new technology begins to emerge, the prioritisation of research can become scattered. Andrew Maynard specifies in his article, *Nanotechnology: A Research Strategy for Addressing Risk*, that the prioritisation of research is not simply a cut and dried process. It varies depending on the discretion of the science and policy communities and also must represent the standpoint of stakeholders. That being said, Maynard does list the control and testing of nanomaterials and safety practices as top priority considerations [5].

On another note, newly emerging nanotechnologies, primarily those with health and medicine applications, can come with a hefty price tag. Research conducted during a 2003 study shows that the average cost of developing and marketing of one new drug is roughly $800 million. It is predicted that the cost of the development and marketing of drugs using nanomedicine will greatly surpass that. Higher manufacturing costs result in higher retail costs, and higher retail costs result in fewer people receiving the medication they need. There exists a gap of disease burden between developed and developing countries, and the implication of high-priced nanomedicine only further widens the gap [6]. However, there is a light at the end of the tunnel for nanotechnology in medicine. As technology continues to grow and evolve, new, more efficient methods of manufacturing may come forth and help reduce the cost of producing nanomedicine and allow poorer regions access to new medicine and health care.

Another big issue of nanotechnology in health and medicine is the threat of cytotoxicity or the level of which something is toxic to living cells. Using nanoparticles in medicine can be dangerous as these extremely small substances can have adverse effects on biological macromolecules in humans. Nanoparticles are small enough to penetrate cell membranes and can access vital organs. Nanoparticles, with their high surface area to mass ratio, are extremely reactive and can trigger chemical reactions within the body or bond with other toxins and permeate cells they would normally have no access to [7]. Developing suitable drug delivery systems is a necessity when it comes to consumer health. In 2009, 95% of all new potential therapeutics had less than desired pharmacokinetics and biopharmaceutical properties. Higher quality drug delivery systems mean that the active drug molecule will only distribute to the affected site without harming healthy organs and tissues. By improving delivery systems with nanotechnology in this way, the efficiency of nanodrugs will increase and drug toxicity will diminish [8]. This is where nanocarriers come into play. A nanocarrier is a type of delivery system with the advantage of improving solubility of hydrophobic compounds in an aqueous medium. Using nanocarriers has been shown to increase the effectiveness and efficiency of chemotherapeutics. Two commonly used chemotherapeutic nanocarriers are liposomes and micelles (see Figure 2).

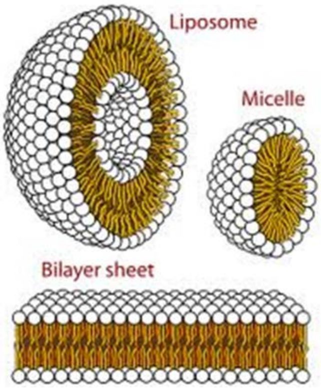

Figure 2: Liposome and micelle cross-sections [9].

Liposomes are structures, approximately 100 nanometers in diameter, containing an aqueous core and surrounded by a phospholipid bilayer used for drug encapsulation. These structures are ideal for drug delivery as the internal core can house hydrophilic drugs, while the outer phospholipid bilayers can contain hydrophobic chemotherapeutics. Furthermore, the liposomes small size permits easier permeability into affected areas all, while still delivering a relatively large and effective dose of a drug to cancer cells. Exploiting these properties allows for the minimisation of unsolicited side-effects. Micelles, on the other hand, are much smaller than liposomes; only about 20-80 nanometres in diameter. Although they cannot carry as large a dose as liposomes due to their size, micelles can penetrate tumour tissue faster and easier than liposomes [10].

Alongside drugs and medicine, nanotechnology is also being incorporated into surgical practices. Examples of these nanoscale surgical tools are scalpels, forceps, etc, equipped with sensors that can be inserted into the body to accurately measure vitals during surgical procedures. Other applications of nanotechnology in surgery include micro-catheters attached to wires or optical fibres to take internal photographs of the human body, and micro-cutters that can be used to remove arterial plaque [11].

With all of these ideas and applications, nanotechnology has the potential to change medical practices altogether. By improving the way medicine can be delivered, the entire infrastructure of the health care system may change radically. Furthermore, a change in the infrastructure of the health care system would call for retooling of facilities (hospitals and pharmacies), and retraining of medical workers. However, as nanotechnology will improve and increase efficiency of medical practices, it is expected that the cost of this overhaul is to be recovered very quickly.

Lecture II

Following the issues in the first lecture, lecture II proposes questions around the ethics of implementing nanotechnology on humans. One issue is this: can newly emerging nanotechnology be used to cause detrimental effects? Who is to say that the nanomachines implanted in a patient cannot be reprogrammed to do harm? Also, to a lesser extent, these nanorobots could also be used for unsolicited surveillance and monitoring. Another question to ask is whether the benefits of nanotechnology outweigh the risks. Yes, the implications of these technologies are ground-breaking and scientists have found ways to better control them, but nanoparticles, with their small size, are still highly dangerous and the possibility of cytotoxicity is always conceivable [12].

When it comes to funding, the research for studying and inventing new nanomedicine, where should this money be prioritised? It can go to funding preventive medicine in order to keep the population from attaining new or existing diseases or it can be directed towards curative medicine to cure patients who are already sick. Within cancer research, funding has been seen to go more towards curative rather than preventive medicine. However, other fields of research may find backing preventive medicine to be the best course of action [13].

Once this is all said and done, the next step is to ask, who is going to receive this medicine? Are we morally obligated to provide personalised medicine to everyone or just to those who can afford it? The production and distribution of nanomedicine can become extremely costly, and those with limited resources (low-income patients, developing countries) may draw the short end of the stick in this case [14]. Once these products are on the market, companies will want to generate a profit in order to make up for the heavy expenditures, increasing prices and limiting availability.

If the society wants to harness the full potential of nanotechnology in medicine, one needs to assess not just how far one can push the technological advancement envelope, but also how to effectively deliver medicine to everyone who needs it. Nanotechnology has the ability to improve the quality and functionality of the lives of people who suffer from disease and disability. Humanity has a moral obligation to minimise suffering wherever possible and maintain the welfare of patients and the interests of society [15].

CONCLUSIONS

Nanotechnology is a field that has undoubtedly been picking up steam in recent years. The idea of using nanotechnology in collaboration with medicine is an ingenious, but hazardous notion. It is vital to the safety and wellbeing of society that tomorrow's scientists and engineers who study and develop these technological advancements are well-educated on the subject matter. Understanding the societal impacts of nanotechnology is just as important as understanding the health risks involved; one cannot be designated over the other. Utilising this course module in amalgamation with other modules is a prominent way to ensure today's students are made aware of, and are capable of, managing contemporary and impending issues considering nanotechnology in not just health and medicine, but in all other fields.

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BIOGRAPHIES

Dr Jitendra S. Tate is an Associate Professor of Manufacturing Engineering in Ingram School of Engineering at Texas State University. Dr Tate has established safe handling practices for industrial (such as nanoclay) and engineered (such as carbon nanotubes) nanoparticles in his research and teaching, dealing with advanced polymer nanocomposites. Dr Tate is a mechanical engineer by training and has 16-plus years of academic and two years of industry experience. His research areas include developing, manufacturing; and characterising the high-performance polymeric nanocomposites for rocket ablatives, fire-retardant interior structures of mass transit and aircraft, lighter and damage-tolerant wind turbine blades, and replacement of traditional composites using bio-based materials. He served as PI on NSF-NUE grant NanoTRA-Texas Regional Alliance to Foster

Nanotechnology Environment, Health, and Safety Awareness in Tomorrow's Engineering and Technology Leaders (2013-15). He has mentored undergraduate African-American students under NASA-PAIR at NC A&T University, an HBCU, and Hispanic students under H-LSAMP at Texas State. He is a member of AIAA, ASME, ACMA, ASEE, and SAMPE. He is a recipient of a prestigious national teaching award, the 2009 Dow Chemical Educator of the Year by the Society of Plastics Engineers' Composites Division.

Mr Roger Hernandez is an Undergraduate Research Assistant in Ingram School of Engineering at Texas State University. He is an undergraduate manufacturing engineering major with a minor in applied mathematics. He has been working as a research assistant with Dr Tate in the Advanced Composites Laboratory since spring 2015. He has worked on the NSF-NUE project from spring 2015.

Dr Craig Hanks is Professor and Chair of the Department of Philosophy at Texas State University. Dr Hanks previously held the NEH Distinguished Teaching Professor of the Humanities at Texas State University. A winner of seven teaching awards, including the highest recognition at Texas State University and the University of Alabama in Huntsville, he has more than 25 years of experience teaching philosophy of technology, engineering ethics, responsible conduct of research, and professional ethics. He has served Texas State on the Institutional Animal Care and Use Committee (IACUC) and the Institutional Review Board (IRB), which he chaired for three years. He was a visiting associate professor at the Stevens Institute of Technology, and has offered short courses and seminars on philosophy and ethics for teachers from high school through post-doctoral. His book *Technology and Values* (Wiley-Blackwell, 2010) is in revision for a second edition, and a new co-edited book *Ethics and Emerging Technologies* is scheduled for 2017. He is a member of the International Society for Philosophy and Technology, a member of the editorial board for Philosophy in the Contemporary World, and an editor for the book series Philosophy of Engineering and Technology (Springer).

Dr Walt Trybula is an Adjunct Professor at Ingram School of Engineering and past Director of the Nanomaterials Application Centre. Dr Trybula is a nationally recognised advocate for nanotechnology safety. His 30-plus years of experience in the semiconductor and nanotechnology industries provide him the ideal background for addressing safety issues associated with new technology. Both an IEEE and an SPIE Fellow, he is recognised for promoting nanotechnology applications for commercialisation. His presentation in September 2007 to the Congressional Nano Caucus addressed safety questions, as well as electronics and photonics applications. His industrial experience enables him to guide start-up companies into commercialisation channels while evaluating technology risks. He is a member of the Texas Emerging Technology Fund's technical review committee and is the current chair of the Oklahoma OCAST nanotechnology proposal review committee.

Dr Dominick E. Fazarro is an Associate Professor of Industrial Technology and Industrial Management in the Department of Technology at the University of Texas at Tyler. Dr Fazarro develops nanotechnology education with a management focus in the Industrial Management Programme. Dr Fazarro and team of experts are completing an on-line nano-safety certification. He taught occupational health and safety in the Regulatory Science Programme for the Department of Agriculture at the University of Arkansas at Pine Bluff (an HBCU) and also served as data manager for a $2.5 million NSF STEM HBCU-UP grant. Dr Fazarro is an authorised outreach trainer of OSHA and a member of the Association of Technology, Management and Applied Engineering (ATMAE) and IEEE. He is also a senior member on the IEEE nanotechnology council. He contributed to *Lateral Diffusion of Nano Education: Developing the New Workforce* in the book Nanotechnology Education and Workforce Development: What You Need to Know (CRC Press). Dr Fazarro founded the IEEE nanotechnology branch student chapter at UT Tyler, which is the second in the world. Drs Fazarro and Trybula, along with professors from Rice University, received funding from the Susan Hardwood Grant in 2010 to train workers in nanotechnology safety.