Teaching Engineering Ethics Through a Nanoscale Case Study

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Abstract - This paper presents a nanoscale case-study that applies an integrative approach to teaching engineering ethics. This case study involves an NSF-sponsored report on converging technologies for improving human performance. Public debate is widening, policy makers are demanding explicit consideration of ethical, legal, and social aspects, and popular books are explaining the achievements and promises of nanoscience. Since ethical decision-making is essential to the engineering profession – demonstrated by the ethics requirement in ABET approved engineering curricula -- engineers should be presented with the ethical implications of engineering within and among nanoscale applications. This case will illustrate the ethical complexity and convergence in engineering domains themselves and in engineering interfaces with other domains within the context of emerging technologies.

Keywords: engineering ethics, convergence, nanoscience

INTRODUCTION

One way to frame engineering ethics education is as *preventive ethics*. By anticipating ethical problems that could become ethical crises if left unattended, one may prevent such crises from occurring. To illustrate, consider an emerging trend in contemporary health care of 'preventive medicine.' From practitioners to patients, administrators to insurers, and private pharmaceutical R&D to public health officials and populations, much of modern medicine emphasizes and rewards those who attend carefully to health needs before serious illnesses arise and cultivate good health habits to minimize serious medical interventions later. Analogously, engineering students' introduction to ethics should include thinking about ethical issues in engineering before things go bad. Arguably, one vein of this 'preventive' ethic notion is implied in the ABET criteria by requiring engineering education to include an introduction to engineering ethical concerns. The focus of this paper is to present another potential vein of this 'preventive' ethic – using cases of or in emerging engineering domains to re-enforce the need to think ahead about potential ethical issues. This paper will present a nanoscale case-study that applies an integrative approach to teaching engineering ethics. The contemporary ethical landscape in engineering nanoscale domains is complex in the midst of converging domains in nanoscale research and potentially obscured if our pedagogical presentations seem fragmented, inconsistent, or irrelevant. To this end, this paper presents some pedagogical strategies through a nanoscale application case study.[2]

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[2] This example could be implemented in various engineering ethics education formats – section in a stand-alone course, ethics module, or integrated discussion in an existing engineering course. The presentation and evaluation is variable and depends upon the professor and context.

BRIEF CASE DESCRIPTION: *CONVERGING TECHNOLOGIES FOR IMPROVING HUMAN PERFORMANCE* (ROCO AND BAINBRIDGE 2004)[3]

> *"Science and technology will increasingly dominate the world as population, resource exploitation, and potential social conflict grow. Therefore, the success of this convergent technologies priority area is essential to the future of humanity"* (Roco and Bainbridge 2004, xiv).

"Convergent Technologies" currently refers to the synergistic combination of four major domains of science and technology: nano-science, biology, information technology, and cognitive science (NBIC Technologies). Each of these fields of knowledge and application is growing at rapid rates, singularly and collectively. 'Convergence' highlights, among many things, the integration and synergy of these fields, particularly from their origin – the nanoscale. Their confluence offers the promise of improving human life in numerous and diverse ways, while simultaneously challenging the realignment of traditional disciplinary boundaries to realize improvement potential and implying the unification of science based on the unity of nature.

This report is the result of a National Science Foundation and Department of Commerce sponsored event that brought together a large number of scientific leaders and policy makers from a range of fields. The report highlights and considers a number of issues judged to be fundamental – implications of unifying sciences and convergent technologies, evolutionary development and vision of this unification, the vision's impact on research guidance and goals for the short- and long term, and ways to transform and implement a national strategy. Particularly, the report underlines multiple implications of convergent technologies in specific areas of human activity – notably, working, learning, and aging – from societal levels of communities interacting to specie levels of human evolution.

The report thematically outlines major areas of relevance of convergent technologies for improving human performance, realizable in the next 10-20 years. Additional and expanded descriptions are present in the report, but I will briefly present a few. Highest priority was given to 'The Human Cognome Project,' which refers to a multi-disciplinary effort to understand the structure, functions, and potential enhancement of the human mind. For example, NBIC convergence of scientific and engineering fields will result in direct fast, broadband interfaces between the human brain and machines that will transform work in factories, control vehicles, enable new sports, and provide instantaneous access to needed information of any kind anywhere. Comfortable, wearable sensors and computer processors will enhance our awareness of our current physical health condition, environment, presence of chemical pollutants or potential hazards, as well as information about local businesses, attractions, or natural resources. A second theme outlined and prioritized improvements in human health and physical capabilities. Combining technologies and treatments will compensate many physical disabilities and eradicate some handicaps. The human body will be more durable, healthy, energetic, easier to repair, and resistant to many kinds of stress, biological threats, and deterioration from aging. Another theme proposed an NBIC system called 'The Communicator' that would enhance group

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[3] The material for this case is a report that can be consulted at different levels of detail, which would be particularly relevant for the kind format engineering ethics education takes at one's particular venue. The report is available in a printed volume of almost 500 pages for approximately $50 and an on-line version (see references). Since I teach a stand-alone engineering ethics course, the initial overview (approximately 30 pages) works well as the primary source.

and societal outcomes. It would remove communication barriers caused by physical disabilities, different languages, geography, distance, or knowledge gaps. Therefore, the effectiveness and cooperation internally and externally in schools, governments, corporations would be greatly enhanced in terms of productivity, creativity, design, and development from this globally-networked society.

Finally, the report offers and explains a number of recommendations for the fundamental transformation of science, engineering, and technology. This report summarily recommends a national research and development priority area on converging technologies focused on enhancing human performance. The report includes particular recommendations to scientists and engineers, educational institutions, private companies and research foundations, state and federal governing agencies, professional societies, and the press.

CASE DISCUSSION[4]

When approaching this case, the goal is to encourage students to consider what makes nanoscience and convergent technologies focal points of certain kinds of ethical reflection that are not present in other scientific disciplines (*e.g.*, chemistry or biology). To highlight the phenomena, I suggest framing the discussion in terms of the hopes and concerns of convergent technologies.[5] This strategy will display the ethical novelties, complexities, and foundations interfacing and interweaving the case.

Prior to framing potential hopes and concerns (along with moral justifications) of convergent technologies, discussion could begin with moral reflections about designations and underlying assumptions. For example, the report is proposing a redefinition of science and engineering disciplines, goals, and purpose through disciplinary interfaces. Is a discipline defined by what is done, who is doing it, what it produces, or how it is being done? Depending upon kinds of answers, science and engineering will most likely not continue to maintain the perceived strict division between theory and practice. Convergent technologies display new kinds of technology developing with engineering design and manufacturing taking place at the molecular level among multi-disciplinary teams and projects. Nanoscience is framed in the report as truly multi-disciplinary and interdisciplinary. These re-definitions should be presented as having ethical significance consequentially and deontologically, as well as being relevant to ethical discussions of professionalism and expertise.

The concept of 'convergent technologies' is founded upon a number of assumptions; I will note two. First, diverse technologies converge from the origin of the nanoscale and on integration at that scale. Apparently, proponents presuppose that the fundamental building blocks of matter in all the sciences originate at the nanoscale. Furthermore, profound and revolutionary advances in science and technology will only be realized at the interfaces of previously 'separate' scientific disciplines because each discipline will be needed to create tools to form and transform matter for these technologies. For example, mathematics and computer science will be needed to

[4] Since I have presented a general explanation of an integrative approach and argued for its necessity elsewhere (Hipp 2007), this essay will simply proceed with a general discussion strategy for this case.

[5] A most helpful resource for discussion starters and ethical talking points is the joint report from the Royal Society and the Royal Academy of Engineering on nanoscience and nanotechnologies listed in the references.

conjoin with NBIC technologies to map matter as an integrated, hierarchical system. Second, improvement in human performance through technological integrations and applications becomes realistically possible through this evolution of science, whereas such improvement would be hindered or unattained without convergence re-configuring scientific disciplines.[6] Thus, if certain 'correct' decisions, investments, frameworks, and visions are realized currently, then many dreamed improvements may be actualized.

Initially framing the discussion in terms of the hopes and concerns of convergent technologies, references to the rapidly increasing investments being made by governments and businesses worldwide could be made (European Commission 2004). For example, the United State's 21st Century Nanotechnology Research and Development Act of 2003 allocated nearly $3.7 billion to nanotechnology from 2005 to 2008, compared with $750 million in 2003. The investments highlight the diverse and profound benefit potential. However, many kinds of sources warn of backlashes due to 'nano-hype'[7] (3i 2002) and uncertainties about the impact of convergent technologies currently and in the future.[8] Thus, uncertainty of the hopes and benefits being realized in light of the various kinds of investment can be juxtaposed with the uncertainty of adverse effects' weighted probabilities and possibilities.[9] Within this artificial juxtaposition, one can combat the false dichotomy by fleshing out exaggerated benefits and risks through discussions of sound evidence, the role of expert, and professionalism.

To highlight one discussion vein, I propose using this case to consider assessing and controlling risk. This ethical reflection displays multiple moral issues from various moral foundations. Some examples include the following: deontological justifications of universalizability and reciprocity toward current and future generations; utilitarian justifications of the greatest good for the greatest number; virtue justifications of honesty, trust, and stewardship; or, micro-ethical foundations from the *NSPE Code* emphasizing health, safety, and environmental obligations.

From these general ethical foundations, one could determine which prong of ethical reflection in risk assessment about convergent technologies to pursue. In acknowledging multiple particulars and varying levels of integration in one discussion vein of the case, students are reminded regularly of the complexity and necessity of ethical reflections applicable to engineering domains. For example, acknowledge multiple complexities and considerations in assessing and controlling risk -- identifying a hazard (*e.g.*, toxicity), probability of exposure to a hazard, associated consequences, extent of exposure correlations, exposure pathways, quality and quantity correlations related to exposure, etc. – and principles guiding risk management that are derived from moral foundations (*e.g.*, whenever possible, always substitute less hazardous for

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[6] Some even call this change a scientific 'revolution'; however, this 'framing' debate is complex and contentious (Baird, *et al* 2004; Foster 2006).

[7] My use of 'nano-hype' refers to the misguided perception or promise that nanotechnology will fix everything.

[8] Some suggest that longer term future developments may bring self-replicating nano-entities that might overwhelm the world (Joy 2000; ETC 2003)

[9] For example, some have questioned the adequacy of current regulatory frameworks to deal with developments from convergent technologies, particularly whether applications will deepen the gap between 'developed,' 'developing,' and 'undeveloped' countries (Arnall 2003).

more hazardous). To provide a concrete example for students to connect the human enhancement aspirations of convergent technologies with the discussion of assessing and controlling risk, I suggest manufactured nanoparticles in a current research project.[10] The specific example chosen could be used as a platform to present various guidelines or recommendations from the students on courses of action regarding the research and product. Which industrial applications should continue and why? What are the hazard potentialities and probabilities? Do they prohibit or permit continued and future development of the particular manufactured nanoparticle? Which regulatory agencies would be responsible for continued oversight? When should society be informed of their use in a product or method?

CONCLUSION

Convergent technologies provide and excellent opportunity to discuss the complexity and necessity of ethical reflection. NBIC convergent technologies display domains with which engineering interfaces. Furthermore, the case demonstrates that engineering methodologies, knowledge, and ethical reflection are and should be integrated. In engineering ethics education, the case can be used to display numerous moral issues arising from various moral foundations that can be discussed collectively or separately. The discussion vein presented about assessing and controlling risk in this case can be integrated and connected to other kinds of cases (*e.g.,* environmental). Finally, the case also highlights the need to avoid extremes and refrain from exaggerating benefits or risks.

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[10] Ayusman Sen recently visited our campus and presented his research in an interdisciplinary science studies lecture series sponsored by the USC Nanocenter. His research displays numerous features highlighted – multidisciplinary team, inter-university research groups, convergent technologies, etc. Also, his team's research on catalytic nanomoters have applications that could be connected to some of the visionary examples for enhancing human abilities and societal performance given in the case report. For a brief summary of research, see Freemantle 2005.

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