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Introduction

Engineering is based on hard sciences. It is not possible to build a bridge, a car, a computer, a refrigerator, or anything considered sophisticated, without a good grasp of physics, chemistry, mathematics, or even biology. While based on the hard sciences, engineering can be considered as art, as a process of creative problem solving.

The concept of engineering as an art stems from two central ideas. First, hard sciences do not provide a complete closure of scientific facts, equations and material properties that will be required to make a piece of machinery or device work under many different conditions over its life span. There is always inherent uncertainty regarding the operation of a given device, which needs the implementation of layers of *a priori* assumptions by the engineers who built it. It is almost impossible to engineer a sophisticated instrument with the precision of physical principles or mathematical formulae. In the process, engineers always leave a few details to their feelings, more accurately to their gut feelings, which is akin to a process an artist goes through. For that reason, many devices and processes work sufficiently well before we completely understand why they do. If a final product works well, then, it has to be understood better just to make it work more predictably, and that process usually results with new areas of engineering, just like hydrodynamics, thermodynamics, all the way to nanophotonics.

Secondly, there is usually a personal (or, rather, societal) touch associated with any engineering accomplishment. Rarely is an engineered concept, device or process, born simply from physical laws or mathematical proofs. A device or process exists because somebody needs it at a particular time or place. Its purpose as well as presence is not dictated by universal principals, but by personal and societal aspirations. This “artistic” side of engineering clearly distinguishes it from hard sciences, even though it is built on hard sciences.

For many high-school seniors, this fundamental difference may be the primary reason for the appeal of engineering over physics, chemistry or biology where “discovery” rules. A seventeen-year old might aspire to build, create, and contribute to society, and “engineering” may permit him or her to realize these ambitions or build functional tools that make life easier. The connection between an individual’s desires and the needs of society is an element in the decision to become an engineer, one that might be characteristic of the profession.

This quest of personal impact is best supported if students understand the impact on and by other engineers to society as they create their own works. While this understanding can be both inspirational and grounding, it is also important that the broader, more global social effects of engineering outside of a classroom are recognized. In the same manner that an art history class would provide context to an art student, an engineering history course helps to anchor the aspirations of engineering students early in their education. Yet, few institutions offer comprehensive engineering philosophy or history courses targeted at freshmen.

The need for a comprehensive approach to engineering education is more than just topical. Traditional age college students (17-23) are more likely to appreciate hands-on or experiential learning than the abstractions of a lecture hall. Students who gravitate to practical fields and solving social problems are more likely to learn well when given practical problems to solve, even if those problems are abstract in nature, than they are in didactic courses. Few first-year courses offer creative opportunities that ask students to question why something might work in the context of how scientists and entrepreneurs have solved problems of the past.

In Fall 2005, we launched a freshmen Honors course at the University of Kentucky (UK) to explore the "Impact of Emerging Technologies on the Society." This was an attempt to explore, with the best and brightest students, what one should expect from any emerging technology. The course focused on whether technologies can or should be embraced easily by society, while considering potential ecological and societal detriments because of their "unknown" nature. A brief glance at the progress of civilization shows that several such emerging technologies had unpredictable short- and long-term impacts on local and global societies. The roman waterways, the compass, the printing press, the steam engine, the airplane, microscopy, and computers are among some of the more significant technologies that opened the doors to more potent developments that irreversibly altered the course of human civilization. Examination of these areas allows students to begin to develop an understanding of technologies' potential impact and encourages them to contemplate precautions and risks.

The objective of our HON101B course was to discuss these engineering developments with a fresh approach, and see their impact on society in a philosophical context. Our ultimate goal was well established: we wanted students to understand the impact of such past developments in order to speculate on the potential and eventual impact of nanotechnology on our lives.

There is no doubt that nanotechnology is a significant "emerging technology" with many potential benefits, along with avoidable, unavoidable and questionable adverse effects. With so many media reports on the promises of nanotechnology, from medicine to entertainment, we find many freshmen students are keenly aware of the arrival and the potential of nanotechnology. Our course was designed as the "foundations" course of the

"Nanotechnology Track" of the Honors Program. The second course focuses on the "Art and Science of Small," whereas in the third course we explore social, cultural, ethical, socioeconomic, financial, and industrial implications of technology, all intertwined with engineering dreams.

The overall objective of HON101B was to give a larger-than-life philosophy of engineering to our freshmen students. Having a course designed around nanotechnology was quite effective for that purpose. Indeed, the course attracted more than just the engineering freshmen, as we had many students from physics, biology, and chemistry as well as from anthropology and physical therapy. In keeping with the Honors Program, the sequence of courses is writing intensive; students receive credit for freshmen composition and three of their general education requirements.

We first presented the "Nanotechnology Track" proposal to the UK Honors Program during the Fall 2004 semester, and received approval from the Honors Program Steering Committee and the Senate Council. The University invites academically talented students and their parents to attend special two-day advising conferences in March called Merit Weekend. To attend a Merit Weekend, students must have been admitted with at least a 28 composite score on the ACT Assessment (or 1240 on the SAT). Participating students eligible for admission into the Honors Program were given the privilege of early registration for their Fall courses, and our foundations course was the first to fill up, even before we made the presentation in the second Merit Weekend. We had 21 enthusiastic students, and all twenty-one eventually completed the course.

The class was primarily taught by M. Pinar Mengüç, Professor of Mechanical Engineering, and by a dedicated TA, Eleanor Hawes. Hawes provided students with individual attention on written assignments. Jane Jensen, an Associate Professor from the College of Education, attended the majority of the lectures and served as a sounding board in and outside the class. Ingrid St. Omer, Assistant Professor of Electrical and Computer Engineering, joined us from time to time and established the bridge to the next class, which she will be teaching. The third class in the series will be primarily Jane Jensen's responsibility, with input from Drs. Mengüç and St. Omer, and Hawes will remain the TA for all courses. Hawes is a PhD candidate in the College of Engineering, whose research focuses on nanoscale engineering.

Structure of the Course:

We wanted to structure the course around themes that would resonate universally. While "computers" would have been a natural choice to discuss the impact of emerging technologies, today's college freshmen have no memory of the days before computers, just as older generations have little or no recollection of times without electricity or running water. On the other hand, our generation's experience with computers can be considered a juxtaposition of "before- and after-personal computers" experience. We have observed a significant change in society since the early 1980's when the first PC was introduced. The widespread impact of e-commerce, e-mail, and digital music is undeniable and still growing. Although a typical freshman has not experienced such a drastic difference in their life, they still experience a slow metamorphosis every day because of new and clever uses of computers. Instead of exploring the ever-changing impact of computers using a few sources, we spread the discussion throughout the semester, and based it on our personal experiences, as everybody is likely to have a story to tell. We preferred to use other engineering marvels for the purpose of more structured discussions, so that we would not put our students, or us, for that matter, at a disadvantage.

We wanted to primarily explore the engineering accomplishments associated with power, water, and world trade. We decided to start from the discovery of the steam engine, then to discuss the impact of the compass on widespread maritime trade, and eventually to discuss the Roman aqueducts. We wanted students to understand how drastically the world changed with the impact of each of these major ideas. We left some other key technologies, such as print and the microscope, to be explored in the future. Finally, using these historical observations as an arsenal, we focused on nanotechnology and speculated on its potential impact as it appears to rise on the horizon.

The story of James Watt is a wonderful one to re-enact for a course like ours. The steam engine is a significant engineering achievement and its impact on society has been phenomenal, both in the short- and long-term (even after two centuries.) Its potential adverse effect on our existence, particularly global warming, is still a hot topic of research and discussion. In addition, there are compelling parallels between the research, engineering, and venture capitalist circles of the late 1700s in England and today's America. These similarities allow the students to find direct connections between the development of nanotechnology and the steam engine.

The text used for this part of the course was Bill Marsden's *Watt's Perfect Engine: Steam and the Age of Invention.* It was a relatively short, information-laden book about James Watt, the man, the engineer, and the businessperson. Marsden was not necessarily painting a glorious picture of James Watt, as, at the end of the book, only a few students wanted to be associated with him. Yet all of them admired his cleverness, pervasiveness, attention to detail and ambition.

The book details all the attempts regarding the development of the steam engine. The information in the book is not limited to the life of Watt, but also discusses his surroundings, the industrial and academic settings he faced, his interactions with scientists and bankers, his struggles in developing and marketing his ideas, and his frustration with the "pirates" of patents and government agencies. The students were able to relate to Watt and his times. Understanding him and his focus on his ideals helped them to visualize what could happen if they find themselves in Watt's shoes with a concept related to nanotechnology. This understanding was crucial in their later articulations about the future of nanotechnology in their final paper.

The second text used was about the compass, by Amir Aczel, titled *The Riddle of the Compass.* In this book, there was no hero in sight, though Flavio Gioia of Amalfi is historically claimed to be the inventor of the compass. Because there was no convincing evidence that there was a single person behind this idea, or any detailed account of Gioia for that matter, we did not explore the impact of the compass on society from an individualistic point of view. Through this book the students examined the big picture and realized how an anonymous discovery could make a city-state and alter the world at large significantly.

The story of the compass is a compelling one for understanding the extent of the impact of a technological advancement on society. The discovery of the compass in China did not necessarily influence the trade there as much as it did around the Mediterranean shores. There is no hard evidence that the compass used in Amalfi for navigational purposes is based on the Chinese version, yet there are many anecdotal stories that it may be the case. Regardless, the compass box of Amalfi incorporated centuries of know-how gathered about the winds of the Mediterranean Sea, and then helped the traders to sail year-round instead of waiting for calmer weather. This technological marvel helped Amalfi to flourish, although briefly.

Venice struck gold with the compass, and became a formidable maritime power for three centuries. Through this book, we could clearly observe how the clever use of an instrument impacted a city-nation. We could then extrapolate this speculation on a nanotechnology-based discovery and discuss its potential impact to the U.S. or to other countries.

The third book, *Pompeii*, by Robert Harris, was a light-hearted historical novel, yet it was an appropriate choice to explore how the technology was ingrained in society during the height of the Roman Empire. In studying *Pompeii*, we observed the importance of an engineer, as well as the impact of engineering as related to aqueducts, which are considered as one of the most important structural concepts of all time. This time there was no single inventor, no scientific circles, no venture capitalists or patent issues to explore. Yet, there was the impact of an engineer who put his heart out to his profession. This book, we felt, may have resonated with the students more; after all how many of our students were potential inventors or entrepreneurs?

Pompeii gave the students an opportunity to view the effects of engineering from a predominantly social standpoint. The action in the book revolves around politics and personalities, which shape the outcome of the novel, and the hero's life. *Pompeii* allowed the students insight into the variables, including politics and whims, which have, do and will alter engineering, and the focus of engineering. In addition, the terrible destruction of Pompeii opened discussions about the effects of nature on man-made structures, which in turn led to discussions of the reverse scenario.

The final segment of the course concentrated on several chapters from *Nanocosm* by William Atkinson. The concepts in the chapters were speculative and were supposed to be viewed with the insight gained from the previous three books. Reading these new ideas, which have not yet hit the main-stream media, the students were able to sense the potential impact of nanotechnology both in the short- and long-term. In addition, they were able to speculate on potential adverse effects and ethical questions. One particular subject, that we discussed several times due to the high level of student interest, was about "playing god." If mankind can master the principles of nanotechnology, and build structures at an atomic scale, they can manipulate matter and genes and control the progress of cells. The students pondered on both the feasibility of this notion and the ethical questions surrounding the idea.

With *Nanocosm*, we practiced using the new concepts through virtual companies. The students were divided into six groups of three- or four-persons. They chose their own focus areas and established companies in nano-medicine, entertainment, defensive military concepts, energy, arms, and novel materials. Then they explored how they could impact society within their choice of a nanotechnology company. They thought about the new ideas and developments, in a similar vein to James Watt. They considered the potential impact of the ideas beyond the obvious, reflecting on what the compass achieved. They considered the long-term impact on common people, as was the case in *Pompeii*. Finally, they ventured into the question of "playing god!" We are sure that they gained a solid insight into a new world where nanotechnology may be a key player.

Class Discussions

The class was built on a "seminar" concept. Although there were a few traditional lectures which lasted the entire class duration, most of the time we had class discussions after a ten- to fifteen-minute introduction lecture. One of the most important practices we implemented through out the semester was the face-to-face discussions. Students formed almost a complete circle in the classroom so that each person could have direct eye contact with each other. This practice enhanced the discussions and established a common bond between the students. They were expected to participate in the discussions as often as possible, but not less than once every two class hours. After a while, we were familiar with the personalities of the students, beyond just their names and interests; using this additional insight, we were able to include all of them in discussions at different levels.

To enhance student participation and to encourage critical thinking, we introduced two other activities into the class. The first was a regular one-page essay in which the student could express any ideas and opinions about the current discussion topic. The short essays allowed the students to voice ideas which they might be timid about expressing in class, encouraged them to think about the subjects outside of the classroom, and gave us insight into how the students were thinking about the subjects and discussions. The second activity was in-class group work. The students were given an invention that we had not studied, and were asked, in their groups, to discuss how these inventions might have been formed. For these activities we used a simple mechanical system, the water clock, and a complex mechanical system, the Enigma machine. These in-class activities allowed the student to practice their critical thinking in line with encouraging them to speculate on nanotechnology. The activities also allowed us to understand the level of speculative and critical thinking of the students.

Lectures by Experts

During the semester, the students were exposed to two different types of lectures beyond those presented and discussed in the class. The Honors track, along with the Nano-scale Engineering Certificate Program (NECP) make up the Umbrella Program on Nano-Scale Engineering (*UPoN*). All members of the UPoN community, including upper-classmen, graduate students, and faculty were expected to participate in a Colloquium series organized within *UPoN.* The series included lectures by three prominent researchers on nanotechnology; 1) energy and carbon-nanotubes (Tim Fisher, Purdue), 2) thin-films (Z. Zhang, Georgia Tech), and 3) advanced materials (William Nix, Stanford). At the beginning of the semester, we devoted one colloquium to the nanotechnology-related laboratories at the University of Kentucky. After a social gathering of pizza and drinks, we visited several laboratories in small groups, including nano-fabrication facilities, nano-characterizations labs where advanced microscopy units are located, and nano-machining labs. The students in the Honors track met the faculty and graduate students who actually work on the cutting edge nanotechnology research. It was an eye-opening day for many.

Another eye-opener was the "Creativity Colloquium" which took place at the studio of Professor Gary Bibbs, a faculty member in the College of Fine Arts. His slide show about his creativity, his thought process, and his actual implementation of ideas to construct large metal sculptures was quite well received. He resonated with the students who already knew about the efforts and frustrations of James Watt in building different versions of his engine and the contrasts and similarities between his sculpture studio located in a warehouse on the edge of campus and the laboratories of the Engineering faculty were striking.

In addition to these Colloquia, we had discussions of major nanotechnology concepts from time to time. Early in the semester, Mengüç discussed the Richard Feynman's famous article, *There is Plenty of Room at the Bottom*, which was originally delivered in December, 1959, and is considered to be the starting point of the nanotechnology. Later, Hawes discussed the principles of "self-assembly," one of the ultimate objectives of nanotechnology. Professor Bruce Hinds delivered a lecture on carbon-nanotube based membranes, an idea he published in *Nature.* In addition, St. Omer discussed the National Nanotechnology Initiative to show the extent of national interest in nanotechnology and Jensen discussed federal interest in exploring the societal implications of nanotechnology.

Observations from Final Papers:

The final paper topic for the students was to speculate on the future of nanotechnology. The students were encouraged to explore ideas that were both central to the class and important to the individual. The result is a collection of papers that covers a broad range of ideas and philosophies. All of the papers espoused a philosophical belief. Many of the papers focused on what nanotechnology will tell us about the nature of how things work. The topics chosen by the students varied greatly and ranged from discussions about whether nanotechnology can be considered ‘playing god’, how nanotechnology can revolutionize medicine, creation of biological systems using nanotechnology, a revolution in computer technology, and a theological discussion about nanotechnology among others.

Each student explored the potential good that can be achieved through nanotechnology. Fewer students chose to explore negative impacts thoroughly, although most mentioned some potential hazards. The students generally chose to focus on the benefits of a particular branch of science that nanotechnology might influence. They veered away from discussing ecological and broader societal impacts. In class discussions, the students allowed themselves to speculate with more imagination, but on paper the subjects conveyed a more conservative outlook. This does not imply that the papers were not interesting, they were, and some of the ideas presented showed depth and breadth of thought. Rather, the students demonstrated an even broader outlook in conversation than they allowed themselves on paper.

The overall tone of the papers exhibited an enthusiastic and interested outlook, which is echoed in the students themselves. The writing abilities of the students improved throughout the semester. The majority of the students had basic writing abilities, and perhaps a fifth of them demonstrated a definite sophistication and style. The majority of the writers were encouraged to show more voice in their work, and to bring their ideas to the forefront with confidence: there was a tendency of the students to write without strength, although the final papers do not reflect this as much. The course was designed for the students to explore their own, and a global, philosophy of engineering, and as the semester progressed, this appeared to occur. We anticipate further development in this exploration as the sequence continues.

Student Comments

After the semester ended, we gathered students’ opinions and suggestions about the course. Independent discussions with the students were quite revealing in terms of what they felt they learned, what they thought should change about the class, and their general observations about the course, the colloquia, and the subject matter. Their overall impression was very positive, and the majority felt they left the class with a deeper understanding of nanotechnology.

For example, one student commented “I didn’t know anything about nanotechnology before I took the class. I feel now like I know the direction it is going and its possible applications.” A second student noted about the reading assignments as “I had never thought about technology like that before critically. In reading Pompeii, the dynamics between the engineers and the people they serve, I’d never really thought about it before, and now I see it all the time.” A third one was quite candid about what he learned about James Watt: “I don’t care for the James Watt book: I don’t care for him. The book led me to believe that he wasn’t a good scientist, but he was a good businessman.” Personal preferences were also playing role in their opinions about the class, as one student said: “The class appealed to everybody because you could make your own opinions without mentioning the science at all." Yet, there was a counter opinion addressed by another one: "You could have more of a social background in the course, but being focused on science helped putting things together." It seems that we hit a different chord in each and every student, and that made the class quite appealing to most, including us.

Next Steps

In the next course of the sequence the students will continue to attend colloquia, meet faculty in the college, and deepen their knowledge of nanoscale science. 19 of the original 21 students have registered for this course. Until now, participants in the course sequence have not been expected to know the science behind nanoscale discoveries. This course will provide an introduction to that science, setting a base for the students' eventual coursework in physics, chemistry, and biology as they pursue their majors. As freshmen, the students will have access to understanding ideas as well as interacting with actual researchers; they will expand their knowledge of the technical language of nanotechnology, while simultaneously researching current nanotechnology trends and being exposed to on-campus research.

In the Fall 2006, the third course of the Honors sequence will explore the societal implications of nanotechnology. The course will begin with the examination of social constructions of the field of science itself and what it means to "practice" science through the empirical work of sociologists and anthropologists. Students will be required to think critically about the role of science and technology in their own lives and as part of an undergraduate curriculum. They will be challenged to examine current debates in the ethics and political ecology of technological development focusing upon questions of use and viability. The course will conclude with discussions of the challenges involved in moving from basic science to engineering applications, and the role of failure in the development process.

Summary:

As a foundations course, HON101B not only served as an introductory seminar in the history of emerging technologies, but also as the first step in a diagonal curriculum that we hope students will follow into graduate school. Beginning with the three courses that make up the Honors Track we hope to help our students understand the impact on and by other engineers to society through discussion and the creation of their own works. Following this sequence, students will be encouraged to continue to participate in *UPoN* through the Nano-scale Engineering Certificate Program offered through the College of Engineering.

We have begun a longitudinal evaluation study of *UPoN*, beginning with the honors sequence, to measure student development in the areas of a) epistemological beliefs regarding the nature of knowledge construction and learning, b) critical reasoning as expressed in oral and written communication, and c) sense of purpose and self-efficacy regarding academic choices and career aspirations. These three areas of student development are interrelated in complex ways and measurable change occurs slowly, thus we are implementing an extended case study model of evaluation that will follow the students through their college careers.

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