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Exposing Students to the Interactions of Science, Engineering and Public Policy through an Interdisciplinary Course

Dr. Lianne Cartee, North Carolina State University and University of North Carolina at Chapel Hill

Lianne Cartee is an NC State Alumni Distinguished Undergraduate Professor. She serves as Associate Chair for Education and Director of Undergraduate Studies in the Joint Department of Biomedical Engineering at the Univ. of North Carolina at Chapel Hill and North Carolina State University.

Clifford E. Griffin, North Carolina State University at Raleigh

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Abstract

Anecdotal evidence suggests that science and engineering students are not as conversant about the policy process as they should be, and that policy students are similarly not conversant about the process by which science and engineering solutions are approached. To address this issue, an interdisciplinary perspectives course—Interactions of Science, Engineering and Public Policy—was developed and taught in an effort to achieve the following interrelated goals: convincing engineering students of the importance of familiarizing themselves with the ways policy making decisions impact engineering solutions; exposing policy students to contemporary technological issues and the importance of understanding technology in the policy creation process; and promoting and increasing future involvement of the students, generally, and engineering and science students, particularly, in the policy making process.

Introduction

The present wisdom holds that as technology becomes increasingly important in society, there is a simultaneously increasing need for a well-trained workforce comprising leaders and decision makers who understand technical issues and problems associated with our economic, social and environmental well-being, including those related to clean water, environmental sustainability, information security, energy production, nonproliferation, food security, medical advancements and, increasingly so, issues associated with global climate change. The development of this workforce, we contend, requires that we increase our students' exposure to the interdisciplinarity and diversity of perspectives on these and other important technical policy issues. In that regard, we hypothesize that courses that bring together students from different disciplinary backgrounds—in this case, students from engineering, science and policy—to engage with and learn from one another about the types of questions that decision makers in these different areas ask, the ways in which solutions are pursued and produced, as well as the societal impacts of those solutions—will not only provide that corpus of broadly informed leaders and decision makers, but will also provide a future workforce that recognizes that its opportunity set is not constrained by discipline.

In this regard, students in either the technical or social sciences, who are interested in pursuing a career in public service, not only need an ability to understand and communicate ideas related to modern technology and their policy impacts, but, equally important, need to be confident in that ability. We contend, therefore, that to make an impact on the range of issues listed above, engineering students and engineers need to understand policy issues and how to engage and positively influence policy and decision making. Simultaneously, policy students and policy makers need to understand technology and how to harness it to inform meaningful policy programs and outcomes. In the process, our broader goal is to introduce and encourage students to begin to think in systems, because our traditional mode of problem solving doesn't allow us to understand and engage with the modern world's complexity, given that our policy interventions are often ineffective, inefficient, or have an array of unintended, perverse outcomes. [1] A key goal of this course was to get students to begin thinking in systems to better understand this complexity and to develop meaningful, strategic, and lasting solutions.

Our Approach

In the spring of 2019, we offered the course, Interactions of Science, Engineering and Public Policy, to students in the University Honors Program at North Carolina State University with the aim of introducing them to the different approaches that engineers, scientists and policy makers bring to problem solving in order to promote a more methodical approach to the creation of public policy and a more comprehensive consideration of constraints to engineering implementation in solving societal problems.

In designing a course that would contribute to the development of leaders and decision makers for a technology-driven future, we determined that, a dynamic learning environment consisting of lectures, group projects and discussions, guest speakers (practitioners from the different fields), and experiential learning to inform the final project, was critical. This type of learning environment would be conducive to learning outcomes whereby students would be able to:

1. Distinguish the approaches used by engineering and public policy to produce public policy outcomes;
2. Compare the dynamic, complex and interactive processes of engineering and public policy through which public problems are identified;
3. Examine case studies of public policy in response to engineering solutions to identify strengths and weaknesses;
4. Work in interdisciplinary teams to develop and articulate possible strategies for obtaining public policy outcomes; and
5. Generate a unique solution to a current problem using both the political science and the engineering approach to problem solving.

Methods

To achieve these outcomes, we designed the course to engage students in three phases. Phase I—Decision Making in American Politics; Phase II—Decision Making in Engineering and Science; Phase III—Ethical Issues in Engineering and Policy. Interspersed throughout these three phases would be the laboratory component whereby students would meet with legislators and heads of state government agencies, such as transportation, environment and water, at the State Legislative Building and government offices in surrounding areas.

Phase I

Students were introduced to some of the fundamentals of the policy process from the social science perspective through an exploration of various decision-making models. We drew upon Brower and Abolafia's "Bureaucratic Politics: The View from Below," [1] which builds upon the social science gold standard—Graham Allison's *Conceptual Models and the Cuban Missile Crisis* [2], and *Essence of Decision Making: Explaining the Cuban Missile Crisis* [3].

Complementing this approach to decision making was Charles Lindblom's *The Science of Muddling Through* [4].

Phase II

Students were introduced to the engineering approach to design and problem solving by having them read Henry Petroski's *To Engineer is Human: The Role of Failure in Successful Design.* [5] This was followed by an exposure to the DMADV (Define, Measure, Analyze, Design and Verify) design strategy [6]. Complementing this perspective were discussions of Stanford Biodesign Case Studies that students reviewed in preparation for class discussion. Following the introduction to the DMADV approach, students were presented with a Stanford Biodesign case study, "Glooko, Inc." and given assignments in writing needs statements. [7]

Phase III

During the semester, several classes were devoted to guest speakers from science and engineering fields as well as from policy. These lectures included the process by which nuclear energy is developed as well as the processing stages that lead to the development of nuclear weapons; the process by which the North Carolina Legislature works; the different roles that a congressional staffer might play while working on Capitol Hill; and Complex Systems and a Systems Engineering approach to engineering and policy. Students were then introduced to concepts such as individual and corporate personhood and the nature, importance and difference between obligations and responsibility–professional responsibility and official responsibility–among scientists, engineers and policy makers. These discussions included differentiating between legal and moral responsibility as well as between official and professional responsibility, and were drawn upon to demonstrate a Venn diagram relationship between the practice of science, the scientific community, and society.

A critical module focused on the various factors underlying public views about science, particularly the role of political party (views) and ideology, religious affiliation, educational attainment, age and generational differences, gender, and race/ethnicity. Survey data were used to inform how these factors influenced public views toward global climate change and power plant emissions; attitudes toward energy policy (offshore drilling, hydraulic fracturing, nuclear power, and alternative energy sources); the role of government spending in ensuring scientific progress. Data driven discussions also interrogated adults' views toward scientific procedures depending on their level of scientific knowledge, including attitudes regarding the use of bioengineered organs for human transplant; whether or not it is safe to eat genetically modified foods; whether or not it is safe to eat foods grown with pesticides; whether access to drug treatments should be provided before testing is fully completed; whether or not government funding of engineering and technology pays off; whether or not government funding of basic science pays off; and whether or not humans have evolved due to natural processes.

These lectures and presentations laid the groundwork for the deeper discussion of a number of engineering-informed, ethically-based issues, including the Boeing Super Max aircraft, the Volkswagen Emissions Scandal, the blowout of the Deepwater Horizon oil rig, the final voyage of the Space Shuttle Challenger, the Crash of Healthcare.gov, Bits and Atoms: Artificial

Intelligence (AI) Policy and Governance, Free Internet Initiative in La Grange, Georgia, and Whistleblowing City. We elaborate on the Boeing Supermax aircraft, the Volkswagen Emissions Scandal, and the Deepwater Horizon Blowout. We provide the contours and contexts of three of these issues.

The Boeing Supermax Aircraft. The near crashes and subsequent crashes of Lion Air Flight 610 and Ethiopian Airlines Flight 302 underscore the issue of opportunities and challenges of engineering redesign, which seeks to improve functionality without increasing cost. In this case, Boeing, acting on the belief that it must keep up with its main competitor, Airbus, elected to modify the latest generation of the 737 family, the 737NG, rather than design an entirely new aircraft. This became a significant engineering challenge because mounting larger, more fuel-efficient engines, similar to those employed on the A320neo, on the existing 737 airframe posed a serious design problem because the 737 family was built closer to the ground than the Airbus A320. To provide appropriate ground clearance, the larger engines had to be mounted higher and farther forward on the wings than previous models of the 737 [8]. Moreover, this redesign required the development and implementation of the Maneuvering Characteristics Augmentation System (MCAS). Financial decisions making the MCAS system optional ultimately led to the grounding of the Boeing 737 Super Max airplane [9]. The learning objective was to reconcile Boeing's decision with the software engineering code of ethics. This code states that software engineers "shall act consistently with the public interest," and that ethics, integrity and professional reputation are integral to the engineer's relationship with client and employer, product, judgment, management, profession, colleagues, and self [10].

The Volkswagen Emissions Scandal The problem emerged from the incompatibility of the Environmental Protection Agency's (EPA) remit to protect people's health by reducing the amount of pollution produced by emissions from automobiles, especially in large cities, and Volkswagen's (VW) goal of becoming the world's largest producer of "clean diesel" fueled automobiles. Acting upon President Obama's energy policy, which included an endorsement of so-called "clean-diesel," VW undertook a huge marketing campaign trumpeting its cars' low emissions. However, US authorities performed required testing before admitting the cars to the market, and the vehicles that VW sold in the American market between 2008 and 2015 did not meet the EPA's emissions standards. Volkswagen installed a special software in the cars that altered the results of the emissions test by a factor of about 40. [11]

In September 2015, the EPA confronted VW, claiming that its cars sold in America were outfitted with a "defeat device" (or software) in diesel engines that could detect the testing apparatus and change the performance to improve results. VW admitted to the cheating. However, while the EPA claimed that some 482,000 cars in the US only, including the VW-manufactured Audi A3, and the VW models Jetta, Beetle, Golf and Passat, were fitted with this software, VW admitted equipping about 11 million cars worldwide with this software. Similar to the Boeing case, the learning objective here centered on the students' ability to discern and reconcile VW's profit-driven decision with the software engineering code of ethics. [10]

The Deepwater Horizon Blowout. Managing risk for low-probability, high-impact events is quite challenging. The Deepwater Horizon Blowout represents such a challenge because the root cause of these types of events is usually difficult to precisely determine and thus eliminate because they occur so infrequently, and measuring success requires large data samples over an extended period. The management of the risk requires improvements in standards, procedures, human factors, materials, controls, inspection, improved regulations and maintenance as well as sharing of best practices among/within the oil and gas industry and the government; taken together, these actions can be grouped as continued improvement in the safety culture. [12] One key issue that is not properly addressed in the risk management of this enterprise is the issue of interoperability, which is systemic. The uncomfortable reality is that while the rigs are operated by a contractor, they are staffed by people from different companies with specialist jobs and, quite often, there is no one on the rig who understands the entire scope of the operation. The learning objective here was to have students recognize that while specialization in one area is important, one's specialty is a component of a much more complex operation. Therefore, an understanding of complex systems is important. A related lesson is that there is tremendous pressure in the corporate and scientific worlds to convert uncertainty to risk. This calls upon one to take an uncertainty, assign it a probability and simulate the probability of failure. As Lehigh Professor John Kenny Smith notes, the problem, is that "999 times, people get away with doing unsafe things, and it's only the 1,000th time that something horrible happens." [13]

Final Project

For their final project, teams of students applied the DMADV approach to one of three controversial bills passed by the state legislature. Students were encouraged to use their acquired skills in identifying motivating factors to develop a needs statement free of hidden motivations. Finally, students developed and evaluated possible alternative solutions to address the true need.

Results

Sixteen students, 15 first year students and one junior enrolled in the course. Student majors were widely distributed as shown in Table 1.

Number of students	**Major**
7	Engineering (civil, electrical, material science, mechanical, nuclear)
5	Biology
1	Computer Science
1	Fashion and Textile Management
1	Physics
1	Psychology

Table 1: Breakdown of plans of academic study for students enrolled in the course

Students were given a pre and post survey at the beginning and end of the course. Survey questions were divided into three broad categories, self-evaluation of prior knowledge, opinions on the importance of the interaction of science, engineering and public policy, and likelihood of involvement in the policy forming process. Survey responses were on a Likert scale.

Prior knowledge
1 – no knowledge; 5 – very knowledgeable

- My knowledge of the public policy process is best described as:
- My knowledge of the engineering design process is best described as:
- My knowledge of current political and policy issues on a national level is best described as:
- My knowledge of current political and policy issues on a state level is best described as:

Importance of the interaction of science, engineering and public policy
1 – not important; 5 very important

- I think knowledge of science and engineering to the public policy making process is:
- I think knowledge of public policy issues to the engineering design process is:

Important of involvement in policy forming process
1 – not likely; 5 very likely

- My likelihood of speaking out in public about a cause I support is:
- My likelihood of contacting my federal or local representative is:
- My likelihood of assuming a leadership role in an organization is:
- My likelihood of becoming involved in the legislative process in the future is:
- My likelihood of volunteering for a political group or candidate I support is:
- My likelihood of promoting a cause I support via social media is:

Results on the importance of a knowledge of science and engineering to the policy making process and a knowledge of public policy issues to the engineering design process were confounded because not all students completed the survey before the first class. After introduction to the goals of the course, their opinions may have been altered. This alteration could have reduced the significance of differences pre and post survey. Results of the pre and post survey compared for each question asked are shown in Figure 1. Asterisks indicate results that were significant based on a 2-sided, paired t-test with a significance of $p=0.05$.

Results show that students evaluated their knowledge of public policy, the engineering design process and political and policy issues on both the state and national level were greater as a result of completing the course. They also increased their opinion of the importance of engineering to policy making. They did not indicate that they placed additional value on the public policy process to engineering design. The introduction of the importance of public policy to the engineering design process in the first lecture, before most students completed the survey, could have elevated the pre-survey results, reducing the significance of the change. The final project also focused on application of the engineering design project to policy making, but there was no corresponding project to apply policy to an engineering design project that might have increased student opinions on the importance of a knowledge of policy to the engineering design process.

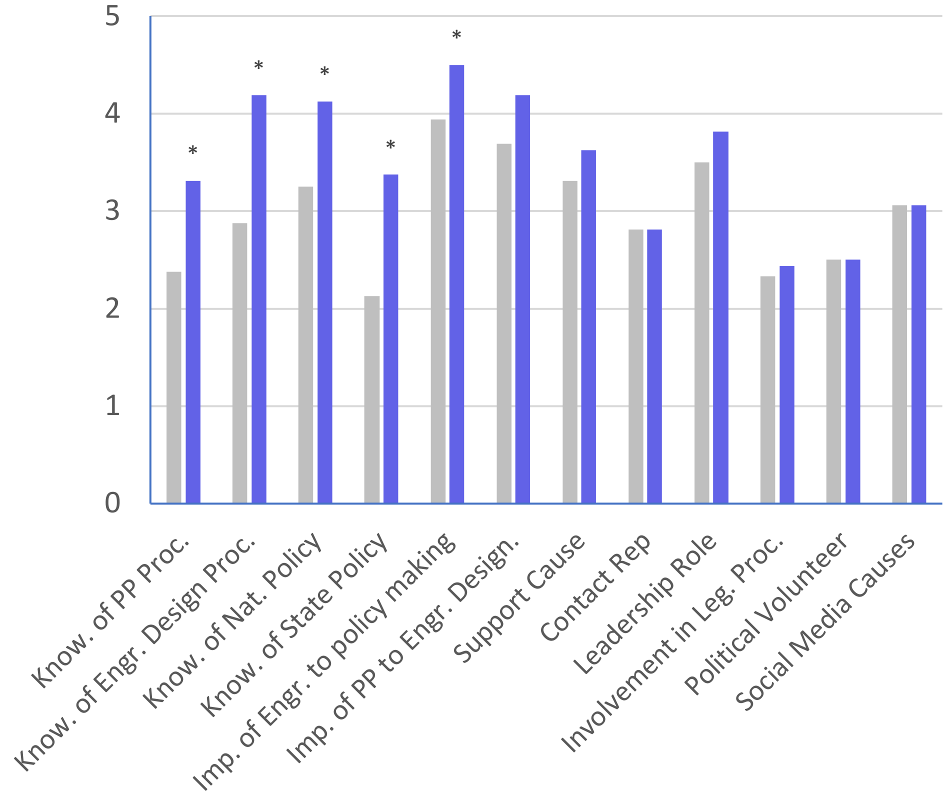

Figure 1: Pre (grey) and post (purple) survey results of student opinions on class topics.

Midterm Exam

For their midterm exam, students were required to answer question 1 and either question 2 or question 3 from the following three questions. These questions were designed to assess their ability to discern and reflect upon the tensions surrounding the technical/technological, economic and ethical imperatives relating to several major policy issues and events:

1. The concepts of Moral responsibility, Official Responsibility, Professional Responsibility, and Role Responsibility are important not only in the political, economic, social and religious spheres but also in the fields of science and engineering. Briefly define these concepts and: a) Discuss and define whistleblowing, including its four elements; b) Discuss and define the Categorical Imperative, and how it should inform decisions to engage in whistleblowing.

2. Many thinkers strongly advocate a focus on Systems Thinking and have advanced an approach to this way of thinking called Complex Systems Theory. a) What is Systems Thinking? b) What are the properties of Complex Systems Theory, including its four elements? c) Discuss how this mode of thinking and analysis differs from the traditional approach.

3. The federal legislation known as Citizens United underscores the concept of Corporate Personhood. This piece of legislation sparked great controversy, especially regarding corporations and free speech, particularly in the area of election campaign contributions. However, there are other important aspects of this legislation that are not often discussed.
   a) Define Corporate Personhood and list the main arguments both in support of and against Corporate Personhood.
   b) Discuss one example where Corporate Personhood has been or can be effective in holding corporations liable for damages that result from their business activities.

Overall performance on the Midterm exams was excellent with students scoring an average of 92%. We remain cautiously optimistic about their understanding of and facility to deal with morally charged issues. This is not a comment on their ethics; instead, it is a recognition of their limited exposure to these types of questions and issues is reflected in a less sophisticated treatment of the Whistleblowing, Corporate Responsibility and Categorical Imperative questions than might be expected of someone with significant professional experience. It should not be a surprise, then, that all students chose to answer the Complex Systems question. This suggests to us that a future course should incorporate more of a focus on Complex Systems, while demonstrating that issues like environmental sustainability, health care, economic well-being, climate change and the like are subsystems that are all part of a Complex Adaptive System.

Final Project

For their final project, teams were assigned one of three pieces of legislation previously passed by the local state legislature: 1) the Coal Ash Management Act of 2014; 2) the NC Farm Act of 2013; and 3) House Bill 2 ACT (*aka* the bathroom bill).

Students were given the following assignment:

1. Identify the stated objectives of the legislation and write a Needs Statement identifying the actual problem requiring a solution without an embedded solution.
2. Identify the Key Stakeholders including 1) the individuals proposing the legislation, the constituencies impacted by the legislation and the interest groups promoting the legislation together with their objectives.
3. Write a problem definition including a statement of the problem, the affected population and a measurable outcome.
4. Develop an alternative solution and apply a decision matrix to choose between solutions including the solution in the bill and alternate solutions.
5. Create a Failure Mode and Effects Analysis (FMEA) for the chosen solution and use the results to improve the chosen solution.

Two teams of three students were assigned to apply the engineering design process to each bill. When rated on the following scale, 1 = requirements not met; 2 = requirements met with some shortcomings; 3 = requirements met, student teams received the average scores shown in Table 2.

Task	Score
Needs Statement	1.83
Stakeholders	3
Problem Definition	2
Alternate Solutions	3
FMEA	2.7

Table 2: Average scores on individual project components rated on a scale from 1-3.

Writing a needs statement was the most challenging portion of the project for students. Students tended to repeat the objective stated in the bill without looking for a broader perspective of the actual problem that needed a solution. Students did an excellent job of identifying stakeholders and alternate solutions. On the other hand, many problem definitions lacked quantifiable targets. Their FMEA analysis on the whole was well executed with only one group failing to conduct the analysis on their selected solution but rather analyzing one particular failure for each project. In all projects, students identified one of their alternative solutions as a better solution than the solution chosen by the North Carolina legislature. This may indicate that an engineering approach to problem solving can generate better solutions, but it may also be that students felt the "correct answer" would be an alternative solution, given that all the bills chosen for the analysis were controversial.

Challenges

Our goal was facilitated by our access to a group of top-tier students from the NC State Honors Program, whose remit strongly encourages students to step out of their comfort zone and explore areas that broaden their experiences and stretch their intellect. One shortcoming was that none of the students who chose to enroll in our course was from the College of Humanities and Social Sciences; all were from the engineering, science, and technology fields. Consequently, while we gleaned insights into their understanding and appreciation of the ethical issues associated with scientific discovery and engineering decisions and products, the cross-disciplinary interactions that we had envisaged did not necessarily occur. Most of the students' responses were anchored largely in their disciplines. For example, none of the students knew that most of the funding for engineering and science comes from the Government, generally, and specifically, the Department of Defense (DOD). Those who viewed themselves as future "disrupters" thought that funding for their respective innovations would be obtained through crowdsourcing or venture capital. Those who considered big tech firms as their prospective places of employment were unaware that companies such as Microsoft, Apple, Amazon and Alphabet (Google) are the recipients of some large DOD contracts.

A major challenge was our inability to have our students meet with legislators and heads of state government agencies (transportation, environment and water, for example) at the State

Legislative Building and government offices in surrounding areas. This was due to both university scheduling and our inability to sync the semester schedule with the state legislative calendar. If students had been given the opportunity to interact with local legislators, their pre and post survey results related to their personal likelihood of becoming involved in the public policy making process may have shown greater difference. Without that involvement, there was no significant change in any of the survey measures in that area. If the course were offered in the future, we would recommend facilitating those connections perhaps through teleconferencing.

We, nonetheless, considered this course a success in that we achieved a number of our goals. However, the real test would be to follow the careers of this cohort of students for the next 10 years, surveying them about their professional decisions and the extent to which the course has been material to those decisions.

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