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ORIGINAL PAPER

Nanoethics and Policy Education: a Case Study of Social Science Coursework and Student Engagement with Emerging Technologies

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Abstract The article analyzes the integration of a module on nanotechnology, ethics, and policy into a required second-year social science course at a technological university. It investigates not simply the effectiveness of student learning about the technical aspects of nanotechnology but about how issues explored in an interdisciplinary social science course might influence student opinions about the potential of nanotechnology to benefit the developing world. The authors find a correlation between student opinions about the risks and benefits of nanotechnology for the developing world with their judgment of whether nanotechnology fits comparative, historical models for development.

Keywords Ethics · Nanotechnology · Policy · Social science · Risk · Ethical issues related to nanotechnology (EIRNT) · Development · Developing countries · Undergraduate education

The concept of the policy entrepreneur [5] as an advocate for policy initiatives is peculiarly relevant to the development of nanotechnology, a growing field whose unique implications for human health and the environment continue to pose novel questions for researchers and policymakers alike. It was leadership from policy entrepreneur and engineer Mihail Roco at the US National Science Foundation in the 1990s that led to the US National Nanotechnology Initiative (NNI), which was formally initiated by President Bill Clinton in 2000. NNI was further institutionalized under President George W. Bush in 2003 with the signing of the 21st Century Nanotechnology Research and Development Act. It is doubtful if any of these developments would have happened as they did without Roco's repeated advocacy.

The four basic goals of NNI are stated as

- To advance world-class nanotechnology research and development;
- To foster the transfer of new technologies into products for commercial and public benefit;
- To develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology;
- To support the responsible development of nanotechnology (http://nano.gov/about-nni/what/vision-goals).

The Nanotechnology Undergraduate Education (NUE) Program established by the National Science Foundation in 2002 addresses the third and fourth goals listed above in its mission "to integrate nanoscale science, engineering, and technology into the undergraduate engineering curricula."

With funding from NSF NUE, an interdisciplinary team at a public engineering and applied science university integrated nanoethics and policy modules into a

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required first-year humanities and a required second-year social science course. For both courses, the general goal of our research project was to infuse learning about nanotechnology into undergraduate applied science and engineering education in such a way that students come to appreciate and are able to articulate its multiple societal, ethical, economic, and environmental aspects. None of the research activities, including the lectures and student assignments, were designed nor intended to produce particular effects in student opinions, for example, to convince them of the safety of nanotechnologies. Rather, students were introduced to the basic technical features of nanotechnologies and a variety of standpoints on the societal, ethical, economic, and environmental dimensions of its applications. The research team consisted of more than 20 members from the disciplines of Africa and African American Studies, Anthropology, Cultural Studies, Communications, Education, English, Geography, History, International Relations, Law, Philosophy, Political Science, and Sociology.

The present article provides a detailed analysis of the second-year effort in a required social science course titled Human Systems. It investigates not simply the effectiveness of student learning about the technical aspects of nanotechnology, but the influence of interdisciplinary social science coursework on student opinions about the potential of nanotechnology to benefit the developing world. The paper begins with a brief history of the research project, including the findings from the first year of integrating nanotechnology modules into the first-year humanities course. It then provides an overview of the second-year social science course, describes the assessment exercise used to gauge changes in student opinions, and concludes with preliminary findings. For the second-year social science course, we find statistically significant evidence that the nanotechnology module affects the way students understand comparable historical situations and weigh the risks and benefits of nanotechnology for the developing world.

Year 1: Integrating Nanotechnology into a Humanities Course

A previous article reported on the first phase of the research project, in which the team introduced nanoethics and policy modules in Nature and Human Values (NHV), a required course for all students at the university [7]. NHV aims to develop students' writing and communication skills in relation to professional ethics for engineers and applied scientists. Each week, students attend a common lecture and then spend 3 hours in smaller discussion seminars.

In the Spring 2012 semester, approximately 125 out of the 400 registered NHV students were given a pre-module survey to measure their attitudes about nanotechnology, especially its ethical and environmental impacts. All NHV students read two articles about nanotechnology [6, 11] and attended a 50-min lecture by the Corinne Packard, the research project's Principal Investigator, who presented information about nanotechnology applications for solar energy research. In their discussion sections, students participated in classroom activities related to the readings and lecture, such as analyzing the rhetoric of nanotechnology in the media and product advertisements, designing an "action plan" to develop an imaginary nanotechnology product with the precautionary principle in mind, and creating a warning label for a real or imaginary nano-product.

After the module, the students who participated in the original survey responded to a post-module survey that both revisited the initial questions and asked new questions measuring changes in attitude or engagement. A small number of student volunteers from that sample also participated in one-on-one interviews designed to elicit more detailed information related to any concerns they had about nanotechnology for society at large and for their particular careers.

The surveys, interviews, and instructor reports revealed two primary findings.[1] First, students generally considered the nanotechnology module to be informative and engaging. The NHV instructors trace the module's popularity to the relative novelty of nanotechnology, which they believe captured the students' imaginations and precluded discussions from settling into polarized debates, as was common with the better known ethical controversies surrounding issues such as nuclear energy, genetically modified foods, and climate change.

Second, the module slightly increased student beliefs that the benefits of nanotechnology do or will outweigh the risks. Before the module, slightly over half of the 125 students (51 %) reported believing that the benefits outweigh the risks. After the module, that number increased to 60 %, with the number of students reporting that they were unsure about the relationship between

[1] For a more detailed analysis of this phase of the research and its results, see Mitcham et al. [7].

benefits and risks decreasing from 31 to 16 % and the number of students believing that benefits and risks were about equal increasing slightly from 16 to 22 %. The NHV instructors attributed these patterns to a more general positive attitude about technology among CSM students as a whole [7].

Year 2: Integrating Nanotechnology into a Social Science Course

Human Systems (HS) is a required, three-semester credit, second-year social science core course that surveys the development of political, economic, social, and cultural institutions as they have emerged since 1500 to create the contemporary global world. Often the class is summarized more simply as a study of the rise of globalization. HS classes of 70 students are taught each semester as lectures with readings and a spectrum of writing assignments by instructors with disciplinary backgrounds in history, political science, sociology, anthropology, geography, and philosophy. Although there are common objectives with partial common readings, all instructors are free to allow their individual perspectives to exercise some influence on the content.

To prepare to integrate a nanotechnology module into the HS course, the research team developed and hosted a workshop for HS faculty before the term began. Faculty members read key texts on nanotechnology, including varying assessments of its potential role in developing countries (e.g., [3, 4, 10, 15]). Together, this set of readings reviewed the problems nanotechnology was often presented as being able to solve and asked critical questions about the feasibility and social implications of such uses. The research team made presentations on the background of the NNI; the fundamentals of nanotechnology; the concept of the precautionary principle; the nanotechnology policy context in the USA, Europe, and China; and the initial findings from the NHV surveys. The research team and faculty members collectively brainstormed ideas for integrating nanotechnology into the HS course and assessing student opinions and engagement with the module.

As a result of this workshop, nanotechnology was introduced into the class as a 1-day module near the end of the Spring 2013 semester as a case study in science, technology, and globalization. Individual instructors were free to tailor the module to complement their own course content, though everyone used a common set of PowerPoint slides. The promotion of nanotechnology research programs in the USA and other countries were presented as an example of the increasing attention politics and economics pay to scientific and technological research, of global scientific collaboration, and of international scientific competition. The focus was on the various factors influencing nanotechnology policy development, as a complement to NHV work on the ethics of nanotechnology. Two of the four instructors also assigned their students readings [3, 15] that specifically examined nanotechnology in the developing world.

An Assessment Exercise

Prior to the nanotechnology module (in the first week of classes) and again at the end of the semester (in the final week of classes), students were given a writing prompt describing a fictional scenario involving globalization and nanotechnology (see Appendix 1).[2] In the scenario, a US company, NanoCoat, uses nanotechnology to give paint self-cleaning and water-resistant properties. The product was described as not yet approved for manufacture or sale in the European Union, although NanoCoat was said to anticipate an emerging market in developing regions of Latin America, Asia, and Africa. As a result, NanoCoat was seeking to build an industrial plant for its products in the African nation of Mchana. The imaginary Republic of Mchana was characterized as having below-average life expectancy and a high proportion of people living in poverty. Mchanan President Akili was said to fully support the plan, seeing the industrial plant as an opportunity to advance Mchana economically and technologically.

In their writing assignment, students were first asked to speculate about the interests of various stakeholders in the situation: the economic, societal, cultural, and political motivations of the company; the motivations of the president of Mchana; and the reactions of civil society groups such as Western economic planners, human rights organizations, and organized labor. After this initial analysis, students were prompted to extend their analysis by being asked whether the situation fits with how other countries, historically, have become

[2] This timing was used to assess how the course as a whole, rather than simply the nanotechnology lecture, affected student thinking about nanotechnology.

developed; whether they shared the president of Mchana's enthusiasm for the project; and what they would want to know about the situation if they were Mchanan citizens who had taken Human Systems (see Appendix 1 for specific questions).

All 434 student participants were given a randomized ID number, and their pre- and post-module responses coded as such were uploaded into Dedoose, a mixed-methods software. In Dedoose, responses were further coded by student gender and instructor. A random 10 % of the responses were read to identify common themes. Eighty-five different themes, such as "Comparative Historical Perspective," "Mistrust of Politicians," and "Labor Conditions" were identified by a social science professor and an undergraduate researcher, along with a weighting system of each theme. For example, the code "Corporate Performance" was applied when students identified the specific behavior of NanoCoat as a company as an influencing factor in the scenario, and the code Human Health (and subcodes of consumers, communities, and workers) was applied to essays mentioning health in their assessment of the scenario. If essays expressed an opinion on the balance of risks and benefits of the nanotechnology plant for the fictionalized country, they were coded as either risks outweighing benefits or benefits outweighing risks. Essays that did not express an opinion on this balance or made the case for both interpretations were coded as neutral, while essays that explicitly expressed uncertainty in assessing risks and benefits were coded as unsure. These codes were given a variable weight of 1 or 2, with 1 signifying mention only and 2 deeper exploration of the factor. After the social scientist and undergraduate student researcher normalized their application of codes in the initial random sample of essays, ensuring that they assigned the same codes and weighted score to each essay, all essays were read and coded for each theme by the undergraduate researcher.

Results

Following the coding, the results were analyzed for changes in student opinions as a result of the Human Systems course and the nanotechnology module. There were no significant trends associated with student gender. This article analyzes three main areas that were significant to the overall research project and relevant to the course under question. Two produced statistically significant results, and a third failed to produce statistically significant results where they otherwise might have been expected:

(1) Understanding of comparable historical situations
(2) Risk/benefit analysis
(3) Complexity of thought

Understanding of Comparable Historical Situations

With respect to (1), there is evidence that the nanotechnology module affects the way students understand comparable historical situations (Fig. 1). For example, before the nanotechnology module, 37 % of students surveyed stated that the fictional scenario did not fit typical historical scenarios of development; after the nanotechnology module, that percentage rose to 58.8 %. Similarly, before the nanotechnology module, 11 % of students surveyed stated that the fictional scenario "both did and did not fit" the historical scenarios of development; that percentage rose to 19 %. Since the surveys gathered are samples of the HS student population, it is possible that these increases were due to random sampling error and not due to the module's affect on student understanding. Formal statistical tests were used to study the likely cause of the increases.[3] Under the assumptions that students were randomly selected for each survey[4] and that no major confounding factors were present, the statistical tests suggest that the HS coursework has impacted student understanding of historical scenarios of development. HS coursework includes several examples of globalization scenarios similar to that described in the prompt, and as a result of this information, students are developing both a more nuanced perspective and a more critical attitude toward the role foreign companies play in developing nations.

[3] In both cases, the statistical test used was a z test for the difference between two proportions. The null hypothesis—that there is no difference between the pre-module and post-module proportions—is implausible, since the calculated p values (1.62×10^{-6} and 1.84×10^{-2}, respectively) were small.

[4] The essay was a required assignment for the course, and the points assigned to its completion were included in the students' final scores. Like other class assignments, however, not all students completed it. Therefore, since participation in the response exercise was in a sense voluntary, it is likely that these samples, as well as the samples collected in subsequent analyses, are not truly random.

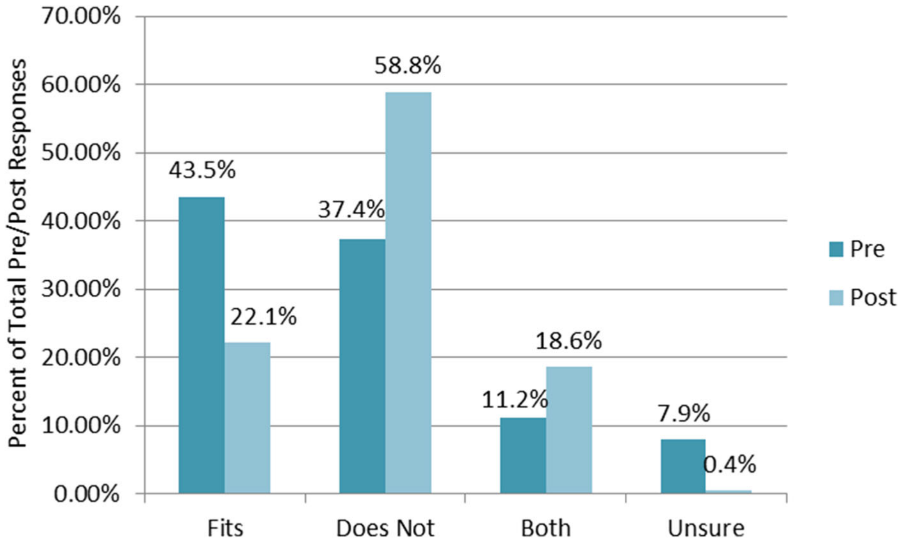


Fig. 1 Student opinions about nanotechnology development in relation to comparable historical situations

Additionally, more students responded that the scenario "both did and did not fit" historical models of development after taking the course, an improvement from 31 to 42, which in conjunction with the shift away from "unsure" indicates a development of greater complexity in student thought.

Risk/Benefit Analysis

How students evaluated the overall weight of risks and benefits also changed as a result of Human Systems (Fig. 2). Before HS, 56 % of students overall supported building the plant, and 44 % did not. After Human Systems, a similar split occurred, but with 59 % believing that the risks outweighed the benefits, and only 41 % showing support for the plant. A formal test was used to assess these changes. Under the assumption that no major confounding factors were present, the test reveals that there is good reason to believe that HS coursework had an impact on student support for the plant.[5] Students' risk/benefit analysis showed a correlation with their evaluation of comparative historical development:[6] if students said that the situation fits the historical model, then they also overwhelmingly thought the benefits were worth the risks; the same correlation occurred with students reporting that the scenario did not fit historical models of development and that the risks outweighed the benefits (Fig. 3). Figure 3 suggests that student appraisals of nanotechnology not fitting with historical models for other countries' development may be a primary contributor to their opinion that the risks of nanotechnology outweigh the benefits for developing countries.

Variability in students' assessment of risks and benefits did, however, exist between the four different instructors. On one extreme, one instructor ended the semester with 50 % of his students arguing that risks outweighed benefits, 31 % arguing that benefits outweighed risks, and 19 % taking a neutral stance. On the other extreme, another instructor ended the semester with 50 % of his students arguing that benefits outweighed the risks, 24 % arguing that risks outweighed benefits, and 26 % taking a neutral stance. Both instructors started the semester with similar distributions of the risk/benefit assessment (roughly a third in each category), assigned the same readings during the semester, and used the same PowerPoint slides for their lecture on nanotechnology. The lectures and readings in the rest of the course must account for the dramatic differences in student opinion at the end.

It is prudent to note, however, that that the increased negative assessment found in the second-year students related to the risks and benefits of nanotechnology was

[5] The statistical test used was a z-test for the difference between two proportions. The null hypothesis—that there is no difference between the pre-module and post-module support for building the plant—is implausible, since the calculated p value (1.87×10^{-3}) was small.

[6] To assess the correlation between these variables, the *phi coefficient* was calculated. The phi coefficient measures the strength of the correlation between two binary variables and, in this case, has a range from 0 to 1. Since the value for this data, 0.68, was close to one, these variables are correlated.

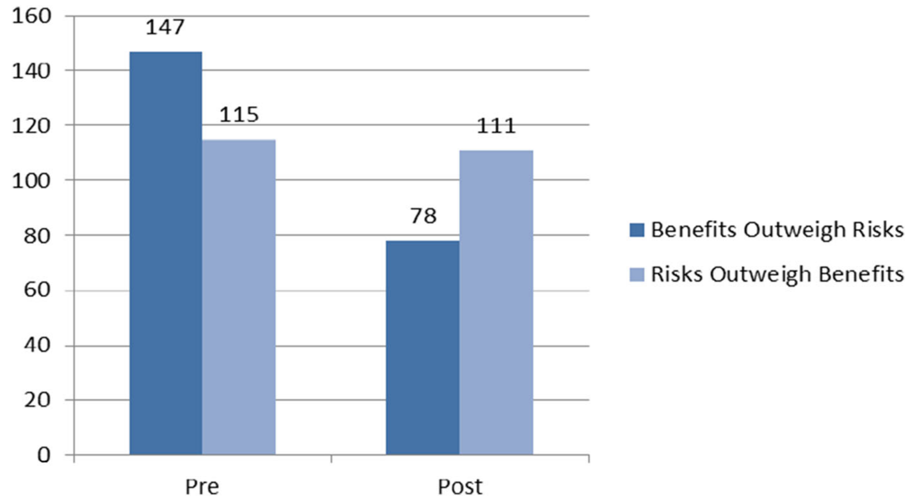


Fig. 2 Student assessments of risk/benefit analysis of nanotechnology development

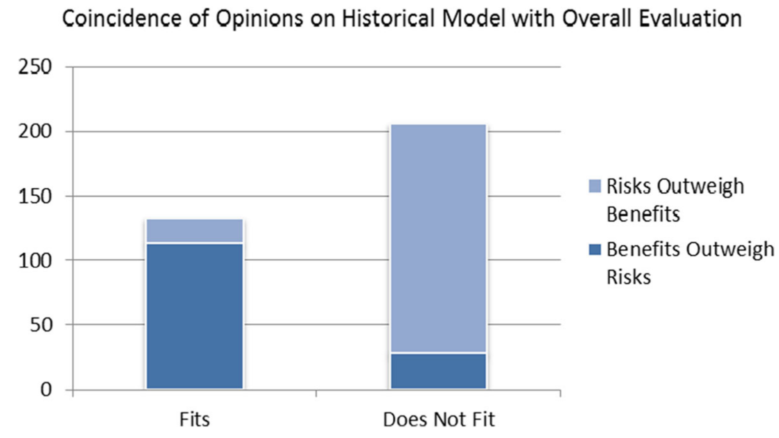
largely due to student opinions in one instructor's section, in which half of all students ended the course by arguing that the risks of nanotechnology outweighed the benefits after only a third of them held that opinion at the beginning of the semester. In two other instructor's sections, student opinion shifted in the opposite direction, with about half of the students believing that the benefits outweighed the risks. For the fourth instructor, student opinions were virtually evenly split among those believing that risks outweighed benefits, those believing that benefits outweighed risks, and those expressing a neutral opinion. The overall results were skewed toward the risks outweighing the benefits because more of that particular instructor's students elected to participate in the research.

It is difficult to determine precisely why the instructors ended up with such varying results in student opinions, especially since the instructors themselves state that they did not express strong personal opinions about nanotechnology in either the workshop or their lectures. We would note that the instructor whose students ended up with the markedly pessimistic evaluations assigned students readings that specifically debated the possibilities for nanotechnology to benefit the developing world [4, 10]. Further research might focus on how specific coursework and articles specific to NT influence student opinions.

Complexity

The degree of complexity evident in student responses improved from the beginning to the end of the semester. Essays were assigned a 1 for mentioning a code theme and 2 for demonstrating critical thought about the theme. The average weight per essay increased from 1.11 to 1.20 (s=0.09) over the semester. The number

Fig. 3 Coincidence of student opinions on historical model with overall evaluation



of codes applied represents the number of themes evident in the writing. The mean number of codes applied to each essay also increased from 13.39 to 16.05. A formal test suggests that this is a statistically significant increase.[7] The change is also evident qualitatively. For example, one student began the semester by pointing to the market rationale motivating both NanoCoat and the president of Mchana and arguing that "this technological advancement may also encourage other companies to invest in the Republic of Mchana, thus helping industrialize the country and speeding its growth to catch up to the modern standards." The student ended the semester on a more skeptical note by writing that nanotechnology was not a "silver bullet" and would likely result in a similarly unequal distribution of wealth as was evident in previous economic development projects. Moreover, this student reconsidered the relationship between technology and society: "When it comes to nanotechnology, many scholars do not take into account that the relationship between science and society is much more complex than simply identifying a technology and its benefits… technology is important, but it isn't everything."

Students were able to offer more specific suggestions for improving the impact of nanotechnology manufacturing for a developing country. At the end of the semester, one student wrote, "Providing schools to teach children, providing roads for public transport, investing in the education of teachers to minimize the effects of any brain drain occurring all could have lasting effects without any hazards that a factory may offer." A different student ended the semester by writing, "Though Nano-Coats and President Alkili think that it is a good idea to bring the production of this technology to the Republic of Mchana, historically new technologies like this do not help a country to develop." He or she then cited a study of genetically modified organisms as an example of emerging technologies benefitting the developed world. The same student began the semester with a much more general critique of cheap labor and the likelihood of profits going to a "small percentage of wealthy people" leaving "next to nothing" for the poor, using factories in China as an example. A third student began the semester by writing about the economic incentives as the primary drivers of NanoCoat's desired move to Mchana, arguing that opposition from workers' rights organizations and human rights advocates "wouldn't matter" because of the strong economic pressure. At the end of the semester, the student wrote, "The international society should work on making sure that technology would be used to help poor and developing countries and not be buried in the graves of patents and private companies."

Although the overall depth of student understanding in society, culture, economics, and politics improved, the relative importance they assigned each of these categories did not significantly change. Student responses to the question on the economic, political, social, and cultural motivations of NanoCoat were analyzed for the frequency of actually addressing each of these four categories. The relative frequency of each of these categories in student responses provides a general indicator for how students perceive their relative importance. No significant change was observed as indicated by raw quantitative mention of topics; essentially, students' relative understanding of economic, political, social, and cultural systems remains the same before and after the course (Figs. 4 and 5).[8]

Conclusion

Student opinions about the risks and benefits of nanotechnology in first-year NHV humanities course and the second-year HS social science course are strikingly different. In the first-year humanities course, the module on nanotechnology slightly increased student perceptions of the potential benefits of nanotechnology. In contrast, the module on nanotechnology significantly increased student awareness about the risks of nanotechnology, especially for the developing world. The core of both modules were developed by the same research team, though the first-year module focused more on the technical elements of nanotechnology within the broader context of ethics, nature, and human activities, and the second-year module gave more attention to the policy context within the broader frame of globalization and development.

[7] The statistical test used was Welch's t test for the difference between two means. The null hypothesis—that there is no difference between the pre-module and post-module mean number of codes—is implausible, since the calculated p value (5.74×10^{-10}) was small.

[8] The statistical test used was a two-sample chi-squared test. For this test, the null hypothesis was that the pre-module relative frequencies are the same (and differ in the collected data because of random sampling error). The p value for this test was 0.89.

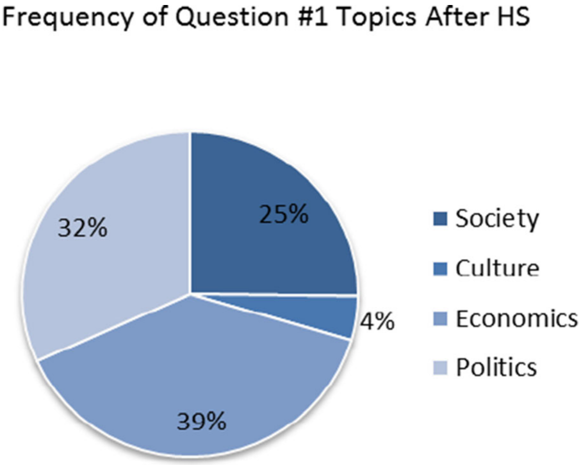


Fig. 4 Frequency of topics represented in pre-module responses

The differing results of the two activities could be partially explained by the development of student thought. At least some of the second-year HS students were encountering the topic for at least the second time since they were enrolled in one of the first-year humanities courses featuring the research team's nanotechnology module. Because students do not cycle through the two classes in a standard schedule or timeframe, not all of the HS students had taken the NHV course during the semester that incorporated the nanotechnology module. Though students were not asked if they had taken the NHV nanotechnology module, ten out of 434 students explicitly mentioned NHV as influencing their thoughts during the HS exercise. Given a lack of data, changes in student opinion cannot be primarily or solely attributed to greater exposure to the topic at this time.

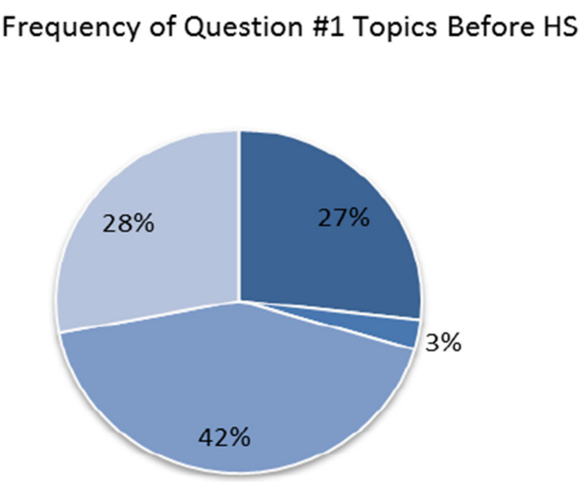


Fig. 5 Frequency of topics represented in post-module responses

The opinions of the first-year NHV students correspond more closely with general American attitudes about nanotechnology than do the second-year HS students. In polls given in the USA, people express generally positive views about nanotechnology [2]. In fact, one study found that those who argue that the benefits of nanotechnology outweigh the risks outnumber those who perceive the opposite by a ratio of three to one [12]. The opinions of NHV students also confirm other students demonstrating that increased knowledge of nanotechnology, especially among scientists, is correlated with higher levels of support [1, 13, 14].

The question then is what the social science course data suggests for understanding both American and scientific attitudes about nanotechnology. The preliminary results suggest that social science coursework dedicated to understanding the social, economic, and historical dimensions of globalization and development, paired with readings that specifically apply those perspectives to analyzing nanotechnology in the developing world, introduces nuances and introspection into students' concern for the risks and benefits of nanotechnology. This intellectual rigor and curiosity may spill over into students' later work as engineers in fields unrelated to nanotechnology or perhaps even as policy entrepreneurs themselves, ready to bring the societal, ethical, economic, and environmental dimensions of science and engineering to bear on new policies that grapple with emerging technologies.

This research and the greater research project aimed to infuse societal, ethical, economic, and environmental issues into engineering education so as to enhance its social relevance and increase sensitivities to the complexities of innovation, thereby graduating more effective contributors to 21st century engineering practice in accord with an ideal proposed by the National Academy of Engineering in its reports on "The Engineer of 2020" [8, 9]. The nanotechnology exercise provides a useful case for integrating ethics and policy education into an undergraduate engineering curriculum. The social science course is effective in educating students to become critical thinkers in terms of comparative historical perspectives, and changes some opinions on issues of globalization, but it does not change the relative importance placed on economics, politics, society, and culture.

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Appendix: Essay Prompt

NanoCoat is a US-based corporation that is becoming a leader in the manufacture of specialized paints and other surface coatings. These paints and coatings, developed from techniques utilizing nanoscience and nanotechnology, exhibit distinctive features (e.g., self-cleaning and highly water resistant). But many products have not yet been fully approved for manufacture and sale in several European countries. Furthermore, the company projects the emergence of a vast market in the developing worlds of Latin America, Asia, and Africa. After surveying investment opportunities in all three regions, Nano-Coat has chosen to site a new industrial plant in the Republic of Mchana, a gold-exporting African country with below-average life expectancy and a high proportion of poor people. The leader of the Republic of Mchana, President Akili, is excited about the NanoCoat decision, which he thinks will put his country on the technological map and uplift his people economically. He finds it puzzling that some Western and Asian countries have rejected investment approaches from NanoCoat.

1. What economic, political, social, and cultural factors might be encouraging NanoCoat executives to consider constructing a plant in the Republic of Mchana?
2. What calculations or considerations might have led President Akili to welcome NanoCoat despite resistance elsewhere?
3. What kinds of responses or reactions might be expected from worker organizations, human rights advocates, and economic planners in Western countries regarding the NanoCoat decision?
4. Does this investment fit with historical scenarios of how countries become economically and technologically capable? Do you share President Akili's enthusiasm?
5. If you were a concerned citizen of the Republic of Mchana who had also taken NHV and/or Human Systems, what information might you want to collect in order to be assured that President Akili has made a reasonable decision?

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