Exploring Students' Perceptions of Complex Problems and Stakeholders

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Exploring Students' Perceptions of Complex Problems and Stakeholders in a Social Entrepreneurship Course

Abstract

Studies have shown that engineering students are typically not exposed to what they will encounter as practicing professionals: problems that are hard to define, have multiple stakeholders, and involve non-engineering constraints. There is therefore a need to expose engineering students to real, complex problems. Various publications in engineering education, including ABET outcomes, have also emphasized the importance of preparing students to work in multidisciplinary teams and to be knowledgeable of current issues.

In 2013, the University of Pittsburgh implemented a course (ENGR 1060/2060) on social entrepreneurship that targets these concerns. The course, titled "Social Entrepreneurship: Engineering for Humanity", discusses social entrepreneurship through the lens of sustainability and "wicked", or complex, problems. It is taught as part of Engineers for a Sustainable World's (ESW) Wicked Problems in Sustainability Initiative, in which ESW provides the participating schools with a different wicked problem every year. The course is open to all majors, and to both undergraduate and graduate students. While the majority of the students thus far have been mostly undergraduates from different engineering majors, there have been undergraduate students from non-engineering majors as well as graduate students from both engineering and non-engineering majors, providing a multidisciplinary environment for students to discuss and learn about wicked problems.

Although the semester-long project is a group project, students work on individual writing assignments that they submit throughout the semester. They are given prompts related to wicked problems, sustainability, and social entrepreneurship, and they then write 600-1000 words in response to these prompts. These writing assignments require that students find appropriate references to provide facts and support their statements, but they also require some personal reflection, and convey each individual's perspectives about the different topics. The purpose of this study is to explore how students' perceptions of and engagement with complex problems and stakeholders change as a result of participating in this course. Students' individual writing assignments from 2015 and 2016 were qualitatively analyzed to answer the following research questions:

- In what ways do students describe complex problems, and how does this change from the beginning to the end of the semester?
- In what ways do students characterize stakeholders, and how does this change from the beginning to the end of the semester?

Data were analyzed using open coding. No predetermined themes were used as part of the data analysis; the resulting themes emerged from the data. Findings from this study can provide information regarding how students begin to think about complex problems, current issues, and

stakeholders – problems such as those they will encounter as engineering professionals – and how these thoughts evolve throughout the semester.

Introduction and Background

Engineering is usually characterized as a field that focuses on problem solving. For example, the Engineer of 2020, as described by the National Academy of Engineering (NAE), will have the ingenuity needed to "identify problems and find solutions"[1]. A great focus of engineering education has been to prepare students to be effective problem solvers. However, research has shown that the problems students encounter as part of their engineering education often differ significantly from the ones they encounter in the workplace[2]. Jonassen et al.[2] write that the common types of problems students are exposed to are word problems "for which the parameters … are specified in the problem statement." In contrast, the problems encountered in the engineering workplace are "ill-structured and complex"[2]. Additional research has found that engineering students also recognize this difference: they describe the problems they see in their courses as "closed-ended, contrived, and focused on mathematics", while problems encountered in the workplace are described as "complex, open-ended, and requiring the consideration of diverse criteria"[3]. The mismatch in what students are prepared for and what they actually encounter suggests a need to revise the types of problems that are incorporated into undergraduate programs.

The descriptions of the engineering problems encountered in the workplace suggest that engineers are dealing with "wicked" problems. Wicked problems are unresolvable problems with values-driven solutions[4]. The complete list of attributes, as listed in Rittel and Webber[4], can be found in Table 1. The Engineer of 2020 will be working on problems related to "climate change, the environment, and the intersections between technology and social/public policies"[1] – all considered examples of wicked problems. As such, it would benefit students to be exposed to wicked problems as part of their undergraduate curriculum.

Table 1: Characteristics of wicked problems, as listed in Rittel & Webber[4]

1. There is no definitive formulation of a wicked problem
2. Wicked problems have no stopping rule
3. Solutions to wicked problems are not true-or-false, but good-or-bad
4. There is no immediate and no ultimate test of a solution to a wicked problem
5. Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial-and-error, every attempt counts significantly
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan
7. Every wicked problem is essentially unique
8. Every wicked problem can be considered to be a symptom of another problem
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution
10. The planner has no right to be wrong

In 2013, the University of Pittsburgh implemented an elective course (ENGR 1060/2060) on social entrepreneurship to address these concerns. The course, titled "Social Entrepreneurship: Engineering for Humanity", discusses social entrepreneurship through the lens of sustainability and wicked problems. It is taught as part of Engineers for a Sustainable World's (ESW) Wicked Problems in Sustainability Initiative (WPSI)[5]. WPSI supports several institutions with diverse courses that all focus on the same wicked problem each year, with WPSI providing a different wicked problem every year along with shared guest lecturers and infrastructure for inter-institutional peer review and faculty support. (See Hess et al. [6,7] for more information on WPSI).

ENGR 1060/2060 centers around three main topics throughout the semester: social entrepreneurship, sustainability, and wicked problems. In addition to learning about these topics, students complete a semester-long group project to write a business plan for a social enterprise that will address that year's specific wicked problem (provided by WPSI). Students also work on five individual writing assignments that they submit throughout the semester. Prompts relate to questions and intersections of wicked problems, sustainability, and social entrepreneurship, and students write 600-1000 words in response to each prompt.

ENGR 1060/2060, though housed in engineering and taught by an engineering faculty member, is open to all majors, and to both undergraduate and graduate students. While the majority of the students thus far have been undergraduates from different engineering majors, there have been undergraduate students from non-engineering majors as well as graduate students from both engineering and non-engineering majors, providing a multidisciplinary environment for students to discuss and learn about wicked problems.

A major strength of ENGR 1060/2060 is that it helps prepare students for many skills. The writing assignments, presentations, and in-class discussions help strengthen their communication skills. The group project, with students of different majors and levels, develops their teamwork skills. The course topics and readings focus on the types of complex problems they will encounter as professional engineers, and the process of writing a business plan strengthens their knowledge of business principles. All of these skills will be necessary to the success of the Engineer of 2020[1], and will give them a breadth in addition to the technical depth they usually possess (see Tranquillo[8] for more on the importance of the "T-shaped" engineer, and Hess et al. [6-7] for more on the skills students develop as part of WPSI). The specific ABET outcomes targeted by this course are (c) "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability", (f) "an understanding of professional and ethical responsibility", (h) "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context", and (j) "a knowledge of contemporary issues"[9].

The purpose of this study is to begin to assess the effectiveness of the course and course structure in helping students learn the course topics. This first study will focus on two topics in particular. Because engineers need to be prepared to work on wicked problems, our first research question

is (1) In what ways do ENGR 1060/2060 students describe complex problems, and how does this change from the beginning to the end of the semester? Because engineering is a discipline that by nature involves numerous stakeholders[1], and the involvement of various stakeholders is a requirement for addressing wicked problems, our second research question is (2) In what ways do students characterize stakeholders, and how does this change from the beginning to the end of the semester?

Data Collection and Data Analysis

To answer the research questions, students' individual writing assignments were analyzed. As previously mentioned, students are given prompts throughout the semester that are related to wicked problems, sustainability, and social entrepreneurship, and they write 600-1000 words in response to these prompts. These writing assignments require that students find appropriate references to provide facts to support their statements, but they also require some personal reflection, and convey each individual's perspectives about the different topics. Two writing prompts were analyzed for this study:

- The first prompt (referred to as Prompt1): "Pick a problem that you believe to be wicked. Sustainability-related problems are good, though not required. Explain why this problem is important, why you believe it to be wicked, who some of the major stakeholders are, and why the problem matters to you personally. You should include at least 3 non-class sources to back up factual statements or statistics."
- The last prompt (referred to as Prompt2): "Write an essay/editorial (for publication in a newspaper) around the need for new social enterprises in the market, or a restructuring of the market (for example, a tax on X or an approval process for Y), to effectively respond to a specific wicked problem. You do not necessarily have to suggest a particular solution, but rather identify a particular point in the system and ask for change (if you have a solution in mind, you can suggest it). Be specific about facts (when necessary), and be convincing to someone who has never heard of these concepts before."

These two prompts were selected because the first one was assigned towards the beginning of the semester, and the second one towards the end of the semester, which would allow us to see if there were any changes in students' perceptions.

Data were collected from the 2015 and 2016 semesters the class was taught. During these semesters, the class was taught by the same engineering faculty member; different instructors taught the course the prior semesters. The class composition for 2015 and 2016 is in Table 2. The class composition varies by year, and in prior years has been different.

Table 2: Class composition for 2015 and 2015

	Gender	**Level**	**Major**
Fall 2015 semester	7 male 5 female	9 undergraduate 3 graduate	10 engineering 2 non-engineering
Fall 2016 semester	7 male 5 female	12 undergraduate 0 graduate	12 engineering 0 non-engineering

The Prompt1 and Prompt2 assignments were collected from each group. In order to have a more homogeneous group, only the assignments submitted by undergraduate students were kept for analysis; assignments submitted by graduate students were not used. In addition, only Prompt2 assignments that did focus on a wicked problem were kept for analysis (some students mentioned but did not describe the wicked problem they were referring to, thus not providing much analyzable data about their perceptions of wicked problems), and in order to have more comparable samples, when a student's Prompt2 was removed, that student's Prompt1 was also removed. The resulting data set consisted of 11 students (six from 2015 and 5 from 2016), with a Prompt1 and Prompt2 assignment from each.

Data were analyzed using open coding, in which categories and subcategories emerged from the data itself[10], and text was grouped according to these categories. Themes were then generated from these categories and used to answer the research questions.

Results

The wicked problems students chose to write about were varied and diverse, and included poverty, clean water, famine, and healthcare. For the most part, students were unique in their selections, but there were some wicked problems that were selected by 2-3 students (for example, food waste and clean energy). The complete list of wicked problems, as selected by the students in this sample is:

- Childcare
- Clean energy
- Clean water
- Drug trafficking
- Famine
- Food waste
- Gender
- Global warming
- Healthcare
- Homelessness
- Natural disasters
- Poverty
- Public school system
- Waste
- Water waste
- Work automation

The data then revealed how students describe wicked problems. These themes represent the ways students most consistently described wicked problems; different descriptions of wicked

problems were not commonly used by the students. Students described wicked problems as having the following characteristics:

- They are complex and difficult to define, and it is often difficult to understand the causes
- They are difficult to approach and difficult to solve
- They affect and are affected by other (often wicked) problems

Examples from students' writings include:
- "…the very nature of wicked problems [is that] they are difficult and complex"
- "The simple answer to [the clean water access issue] is [that it is] a wicked problem. Unfortunately, this simple answer does not come with a simple solution."
- "…wicked problems commonly have no perfect solution and proposed solutions will have unintended consequences that can improve or worsen the situation"
- "Another issue in dealing with wicked problems is that solving one cause of the problem may cause another cause or another problem to arise"

Regarding how to address wicked problems, students' writing assignments revealed these themes:

- They require education, awareness, and/or a change of perspective in order be effectively addressed
- Collaboration is necessary to effectively address the problem
- There is a need to focus on long-term and sustainable solutions (though this was only mentioned in Prompt2, by two students)

Examples from students' writings include:
- "Educating and changing the mindset of individuals is the first step in solving this wicked problem"
- "[There is a need to provide] a sustainable solution for the future by targeting the main cause of homelessness"
- "[To address global warming] …negotiation between countries will become even more important."
- "We should work together to solve the famine problem now…"

The different ways students describe wicked problems, both in Prompt1 and Prompt2, and the percent of students who mentioned each one, is summarized in Table 3.

Table 3: Descriptions of wicked problems, and percent of students who mentioned each

	Prompt1	**Prompt2**
Characteristics of wicked problems:		
Complex and difficult to define; often difficult to understand the causes	27%	9%
Difficult to approach and difficult to solve	55%	27%
Affect and are affected by other (often wicked) problems	73%	45%
Requirements to effectively address wicked problems		
Education, awareness, and/or a change of perspective	18%	36%
Collaboration	9%	18%
Focus on long-term and sustainable solutions	0%	18%

Finally, the data revealed who the students considered to be stakeholders in the problems they selected. Stakeholders ranged from the people or industries directly affected (coded as "primary industry" or "primary individuals"), to government, to the environment and future generations. The different codes are below:

- Primary industry (Specific industry most directly affected by the problem)
- Secondary industry
- Primary individuals (Specific individuals most directly affected by the problem)
- Secondary individuals
- Consumers/the average person/the community/the public (Used when no specific group of people and no specific industry were mentioned, but rather the more generic "us" as consumers and "average" people were mentioned as stakeholders)
- Future generations
- Relevant charities and nonprofits
- Policy makers
- Local, state, and/or federal government
- The environment

One last thing that students mentioned was that there is a need for social enterprises, and other business structures, to address wicked problems. 45% of the students mentioned this in Prompt2 (none in Prompt1). This is not surprising, as the course focused on how social entrepreneurship can be effective at addressing wicked problems, and social entrepreneurship was a topic included as part of the prompt.

The different stakeholders that appeared in the students' writings, both in Prompt1 and Prompt2, and the percent of students who mentioned each one, is summarized in Table 4.

Table 4: Stakeholders, and percent of students who mentioned each

	Prompt1	**Prompt2**
Primary industry	45%	64%
Secondary industry	9%	18%
Primary individuals	73%	64%
Secondary individuals	27%	9%
Consumers/the average person/the community/the public	64%	91%
Future generations	0%	9%
Relevant charities and nonprofits	18%	27%
Policy makers	18%	64%
Local, state, and/or federal government	64%	73%
Environment	27%	36%
Social enterprises	0%	45%

Stakeholder examples from students' writing include:

- "The people who have the biggest stake in the problem [of famine] are the people experiencing it." → example of primary individuals as stakeholders
- "Environmental disasters affect us and the environment" → example of the environment and the public as stakeholders
- "… the approach from government incentives can be an important tool to speed up with development, as well as reduce costs for clean energy technologies. With fair and stable federal tax policy for renewable energy […]" → example of the government and policy makers as stakeholders
- "We should work together to solve the famine problem now, so that nobody has to suffer from famine in future generations." → example of future generations as stakeholders
- "Quicker solutions [to the problem of food waste] can even be social enterprises similar to [names of social enterprises] that take 'ugly' foods from farms to more useful locations than the trash." → example of social enterprises as stakeholders

Discussion

The students in this sample wrote about societal and sustainability-related wicked problems of their own choosing. The benefit of their conducting research on and writing about these problems is that it is preparing them to begin to think about the types of problems they will need to address as professional engineers, problems that are, in fact, of an environmental and societal nature[1].

The writing samples provided information on how students describe wicked problems. The results indicate that students' understanding of wicked problems is accurate to a degree: they described wicked problems as complex and hard to define, as difficult to solve, and as affecting and being affected by other problems, which they are[4]. However, their characterization of wicked problems is still somewhat incomplete. They fail to acknowledge some of the additional characteristics of wicked problems, as defined by Rittel and Webber[4], such as the uniqueness of each wicked problem, and the possibility of many possible responses. They often focus on physical or technical solutions, without acknowledging that complex problems can be addressed by many different possible methods. This is an important aspect of wicked problems to emphasize more strongly in future offerings of the course so that students are better prepared for the problems they will encounter as professional engineers: problems that are complex, as they described, but that are also subject to numerous possible solutions[2].

However, the lack of writing containing certain characteristics of wicked problems does not necessarily mean that students are unaware of these characteristics. The writing prompts and word count restrictions may be limiting how they write about wicked problems. This leads to some questions for the course instructor: How should students' knowledge of wicked problems be assessed? What kinds of descriptions of wicked problems would demonstrate that students effectively understood the concept? The answers to these questions will determine whether these writing prompts should remain as is or whether they should be modified to allow for deeper descriptions from the students.

While the data provided information on how students describe wicked problems (the first part of the first research question), it was not able to provide much information on the second part of the research question: whether there were any changes from the beginning to the end of the semester. Table 3 showed the comparisons in percentages between Prompt1, which was submitted towards the beginning of the semester, and Prompt2, which was submitted towards the end of the semester. The percent of students who mentioned the main characteristics of wicked problems actually dropped from Prompt1 to Prompt2. Because it is very unlikely that students no longer thought of wicked problems as (for example) being difficult to solve, the drop in percentage is likely due to the nature of the second prompt, as well as students' likely perception that they didn't need to re-describe certain aspects of wicked problems, and that we were by that point in the semester, all familiar with what constitutes a wicked problem.

While it was hoped that there would be evidence of change between Prompt1 and Prompt2, the fact is that the prompts are different and do not represent a true pre-post assessment. A true pre-post assessment would include a writing assignment where students would describe their perceptions of wicked problems prior to discussing the topic in the course. Although Prompt1 was submitted towards the beginning of the semester, the concept of wicked problems had already been discussed multiple times in class. Also, Prompt1 and Prompt2 are different, so the writing responses necessarily focused on different topics – both on wicked problems, but in different ways. In spite of the different prompts, because of the amount of time spent discussing wicked problems throughout the semester, it had been hoped that their end-of-semester writings would have demonstrated a deeper understanding of what constitutes a wicked problem, as compared to their writings from the beginning of the semester.

Regarding stakeholders, while the list of stakeholders the students wrote about is broad and does consider a variety of stakeholders, this list is a representation of the entire sample. As a group they were able to provide a broad list of stakeholders, but as individuals, they tended to focus on only a subset of all the possible stakeholders. As Table 5 below shows, most students identified 3-4 stakeholders in Prompt1, out of the entire list of 10. In Prompt2, most students identified either 3-4 or 5-6 stakeholders. There was an increase in the number of students who identified 5-6 stakeholders, and a decrease in the number of students who identified two or fewer stakeholders. This is a positive change, and could suggest that students learned to identify stakeholders beyond those that they first think about. This is important, as the manner in which a wicked problem is approached will depend on who the stakeholders are[6]. However, while the number of stakeholders identified did increase, no individual listed more than six stakeholders, and most still recognized only 3-4. Given the word count restrictions, this may be an adequate number of stakeholders to include, but future offerings of the course can focus on discussing the various stakeholders in more detail, so that students more readily acknowledge more, and more diverse, stakeholders.

Table 5: Number of stakeholders identified, and percent of students who did so

	Prompt1	**Prompt2**
0-2 stakeholders	18%	0%
3-4 stakeholders	64%	55%
5-6 stakeholders	18%	45%
7-8 stakeholders	0%	0%
9-10 stakeholders	0%	0%

An additional change worth noting in terms of the stakeholders identified by the students is the increase in how many students consider policy makers to be stakeholders – 18% of students mentioned policy makers in Prompt1, while 64% of the students did so in Prompt2. This is a

positive change, since it is expected that in the coming years, "the convergence between engineering and public policy" will increase, and engineers will have to "develop a stronger sense of how technology and public policy interact"[1].

Conclusion

The purpose of this paper was to learn about how students think about and describe wicked problems and the corresponding stakeholders. Two writing assignments from a social entrepreneurship course housed within engineering were analyzed using open coding to determine the themes that emerged. The data indicated that students have an accurate, though somewhat incomplete understanding of wicked problems. The data also indicated that as a group they were able to identify a broad list of stakeholders, but their individual writings mentioned only a subset of the stakeholders.

The purpose of this study was also to determine whether there were any changes in students' characterizations of wicked problems and/or stakeholders from the beginning to the end of the semester. It was not possible to determine any changes in their descriptions of wicked problems, possibly due to the fact that the two writing prompts analyzed were different, and also that students may have felt that extensive descriptions of what a wicked problem is were not necessary at the end of the semester, especially when this was not specifically required in the second writing prompt. However, some changes were observed in the number and types of stakeholders that were included in the first and second prompts. A larger number of students included more stakeholders in Prompt2, and there was an increase in how many of them now considered policy makers as stakeholders.

There were some limitations to this study. First, the sample size was small: writing samples from 11 students were collected. Thus, the findings are specific to this group and not generalizable. Second, the data collected was not a true pre and post assessment. In the future, students will be asked to write about their perceptions of wicked problems and stakeholders prior to discussing the topics in class, and writing prompts that are more similar to each other, and thus more comparable, will be assigned at the beginning and end of this semester. This change will provide a more accurate representation of how students' perceptions of these topics evolve throughout the semester.

The writing assignments indicated that students did in fact learn about wicked problems and stakeholders. Their awareness of the characteristics of wicked problems is likely well-retained throughout the course, given that they still referenced them in Prompt2, even though it was not a part of the assignment requirements. As professional engineers, they will be working on complex problems, and the traditional classroom problems they typically work on are not necessarily preparing them for the problems they will encounter in the future[2]. Courses that expose students to wicked problems and stakeholders are therefore important in preparing students for their future careers.

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