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If Engineers solve problems, why are there still so many problems to solve?: Getting beyond technical “solutions” in the classroom

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If engineers solve problems, why are there still so many problems to solve? : Getting beyond technical "solutions" in the classroom

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Abstract

This Evidence-Based Practice Paper describes implementation and assessment of an exercise bringing international perspectives, liberal arts, and the United Nations Sustainable Development Goals into a first-year engineering program - challenging the arbitrary boundary between engineering and the liberal arts. First-year engineering students (Civil, Mechanical, and Electrical) participated in a role-playing game recreating the 2009 United Nations Climate Talks in Copenhagen, Denmark. The exercise is part of a series of published games called *Reacting to the Past* (RTTP), with the purpose of engaging students to enhance their understanding of a given event or topic, while improving their research and communication skills. In this case, the further goal was for students to broaden their understanding of the technical aspects of climate change, as well as the political and social reasons that technological solutions are not always implemented, despite the best intentions and technical knowledge. Students practiced researching a topic, selecting and evaluating resources, proper citation of works used, written and oral communication, and advancing a position in a professional manner. These skills, while crucial for practicing engineers, are often relatively weak in incoming students.

Our initial success integrating international perspectives and traditional liberal arts concepts into a first-year engineering course was supported by several classroom innovations, including a classroom-embedded librarian and gamification.

Benefits of this activity in the first-year classroom include:

- Getting students to interact with each other in a substantive way, strengthening the cohort, and supporting retention.
- Providing structure for learning library, writing, and presentation skills, etc.
- Introducing how professionals handle concepts of politics, tact, and negotiating across boundaries.
- Providing an experiential learning environment to understand how politics, both personal and professional, can interact with technical solutions, leading to improvement or disruption in the lives of all.
- Starting a discussion about United Nations Sustainable Development Goals early in the careers of engineering students.

Certainly, students will see these concepts again; there are multiple group projects and research projects in their time at our school, as well as courses on ethics and professionalism. However, introducing these concepts in their first semester prepares students for future courses, and helps them understand that engineering is not just problem sets and robotics.

Background: The College and the Course

Engineers often do not arrive at college with an appreciation for the importance of professional research and communication skills [1]. These skills are necessary not only for their successful undergraduate career, but also for a successful engineering career. Engineering students are often unaware of the number of reports and presentations they will be expected to deliver, or the amount of teamwork required in the engineering work environment. They do not yet understand that their chosen profession is strongly sociotechnical, involving both social and technical aspects [2]. Many novel approaches have been developed to address these challenges, including problem- and project-based learning [3], entrepreneurship [4], and flipped classrooms [5]. Some students have also demonstrated increased success with increasing awareness of the positive impact engineers can have on communities [6].

Merrimack College is a small, liberal arts college in the Augustinian Catholic tradition, located in North Andover, Massachusetts, northwest of Boston. There are approximately 3,700 undergraduates at the college, and 700 master's students, with no doctoral programs. There are approximately 400 undergraduates specializing in Civil, Mechanical, Electrical, or Computer Engineering. Civil, Mechanical, and Electrical Engineering students interact with one another, especially in the first year, while Computer Engineering has its own curriculum. Of the approximately 100 incoming students, 35% are Mechanical, 30% are Civil, 20% Electrical, and 15% are undecided.

At Merrimack College, all first semester Civil, Mechanical, and undeclared Engineering (CE, ME, and UE respectively) students are required to take "GEN1001: Introduction to Engineering." The course includes a lecture (covering measurements, exposure to basic statics/mechanics, technical writing, basic software skills, guest lectures, presentation skills, etc.), and recitation (including a group project to design and build an operational windmill). The course for incoming engineers includes interdisciplinary hands-on projects, presentations, and writing assignments with the goal of developing a sense of cohort, and "leveling the field" for students with a wide-range of backgrounds and experience.

Electrical Engineering (EE) majors generally take a different introductory course, coming together with the other engineering first-year students on Fridays during a recitation session to design and build the interdisciplinary windmill projects. In Fall 2017, due to sabbaticals, the EE students were enrolled in the same lecture section as the CE and ME students. Enrollment in GEN1001: Introduction to Engineering was 96 students in 2017, 88students in 2018, and 79 in 2019. Table 1 summarizes the enrollment in GEN1001 for the Fall semesters 2017 to 2019.

Table 1: GEN1001 Course/Semester Summary

Semester	Total number of students enrolled (number each section)	Majors	RTTP?	UN Sust. Goals?
Fall 2017	96 (48, 48)	CE, ME, UE, EE	Yes	No
Fall 2018	88 (45, 43)	CE, ME, UE	No	No
Fall 2019	79 (41, 38)	CE, ME, UE	Yes	Yes

In the last third of the Fall 2017 and 2019 semesters, students were engaged in a number of exercises related to climate change. They were introduced to the mechanics and history of

climate change and investigated the political and economic reasons that have made this a significant issue. To learn more about the involvement of the United Nations in climate change, students engaged in a role-playing exercise recreating the 2009 Climate Talks in Copenhagen, and in Fall 2019, students also reviewed the UN Sustainability Goals, creating a video discussion of how engineering is linked to one of the specific goals.

The Fall 2018 class was the "control" for the activities, providing a method of comparing outcomes of the course with and without the role-playing and video exercises.

Background: The Game

The role-playing exercise is part of a series of published games called *Reacting to the Past* [7], designed to engage students to expand their understanding of a given event or topic. In this case, the goal was to involve students in the technical aspects of climate change, and explore the political and social reasons that technical solutions are not always implemented despite best intentions and technological ability [8]. In addition, the exercise goals included:

- Having students interact with each other in a substantive way, strengthening the cohort, and supporting retention.
- Providing structure for learning library, writing, and presentation skills, etc.
- Introducing how professionals handle concepts of politics, tact, and negotiating across boundaries.
- Creating an experiential learning environment to understand how politics, both personal and professional, can interact with technical solutions, leading to improvement or disruption in the lives of all.
- Initiating discussions about United Nations Sustainable Development Goals early in the careers of engineering students.

As part of the RTTP role-playing game, each student was assigned a unique, historical figure that participated in the Copenhagen Climate Summit [9]. The roles included individuals with various motivations and perspectives associated with their professional position, including Barack Obama, President of the United States, Mohamed Nasheed, President of the Maldives, Rajenda Pachauri, Chairman of the International Panel on Climate Change, and Katie Couric, News Reporter. Rather than "just" researching a topic, students experienced what it might have been like to be involved in climate debates as a participant – with "points" resting on how well they knew the topic, how well they communicated their reasoning, and on the final outcome of the game (was the final game outcome positive for the character's position? (i.e. type of treaty approved)). They experienced why some individuals and groups might want a stronger agreement and transparency, while others push for weaker agreements or less transparency, all believing they are acting in the best interest of their country or industry. This provided students the ability to appreciate multiple viewpoints on data and policies, and how each perspective was seen as legitimate for a specific population.

Students worked individually and in groups to select appropriate sources, properly cite the works they used, and communicate through writing, discussion, and presentation to professionally articulate a position. This exercise illuminated the need to find valid sources, understand what others might say in reaction or support of a given viewpoint, and to clearly communicate

technical topics both in written and oral form. These are skills that are important in all engineering fields.

The embedded librarian offered students feedback from someone other than the instructor, to provide a different perspective on their own work, and to more clearly understand the broader impact of the work done by engineers. The librarian offered extended office hours and movie nights related to topics covered in the class. In addition, the "teamwork" atmosphere made the class more enjoyable for the instructor, which made it more enjoyable for the students. The librarian and instructor worked together to prompt discussion, and more fully engage students in all aspects of the course.

After two class periods on climate change science, and one class period introducing the game, students were given their role. The students then had one week to prepare to meet with their "factions," and then one week to prepare for the start of the game. The game lasted over two entire class periods, and a third class period was used for debrief discussion.

Background: Sustainability Goals

After the RTTP game, in the Fall of 2019, the students were asked to become familiar with the United Nations Sustainable Development Goals [10], select one goal and one target of interest to them, and create a video that describes how two different engineering fields might impact the goal and target. The aim was to show students how engineers impact sustainability, quality of life, and social and environmental issues globally. Students were provided a rubric for the project (Table 2).

Table 2: Video Rubric

Metric	Description	Possible Points
Clarity of goal & target	Picked a goal & at least one target. Clearly gave details.	5
Production Value	Clean. Clever. Put thought into it.	5
Length	2.5-5 minutes.	5
Clever connection to 2 branches of engineering	Makes the connection from target to your future careers.	5
Entertaining	Interesting, Funny, Good	5

Students were introduced to specific types of resources earlier in the semester so that they could be applied towards the video project, and submitted as a component of the final submission and were given a rubric to help them prepare the project and use the sources previously introduced (Table 3).

Table 3: Video Resource List Rubric

Metric	Description	Possible Points
Two governmental or UN websites	For all sources: - Sources are the type requested. - References are properly formatted in APA - References are relevant to the work in your video.	5
Two academic journals		5
Two resources from "Access Science" database		5
Two resources from "Access Engineering"		5
Two popular magazines		5

Students in teams of 3 or 4 selected a variety of targets on which to create a video, including:

- Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.
- Target 7.3: By 2030, double the global rate of improvement in energy efficiency.
- Target 15.2: By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.

Statistical Analysis of Outcomes

At the end each of the three semesters, the Student Assessment of Learning Goals (SALG) from the organization Science Education for New Civic Engagements and Responsibilities (SENCER) was used to survey students. Through the SALG, students rate themselves on their improvement in a variety of outcome metrics. The results are summarized in Table 4, which assumes equal difference between each of the Likert scale options

Table 4: Student responses to the question: "As a result of your work in this class, what GAINS DID YOU MAKE in your UNDERSTANDING of each of the following?"
- Standard Deviations are given in parentheses.
- Scale: 1: no gains; 2: a little gain; 3: moderate gain; 4: good gain; 5: great gain.

Prompt	2017 (n= 71)	2018 (n=74)	2019 (n=64)
The role of the engineer in society	3.8 (1.14)	4.1 (0.93)	4.1 (0.93)
The importance of units in engineering calculations	4.0 (1.13)	4.2 (0.92)	3.9 (1.03)
The usage of units	3.9 (1.16)	4.1 (0.97)	3.9 (1.00)
The importance of interdisciplinary work & teams in engineering	4.1 (1.11)	4.3 (0.93)	4.2 (0.98)
The role of all engineers in environmental issues, such as climate change & mitigation	N/A	4.0 (0.97)	N/A
The science behind climate change	4.0 (1.01)	N/A	3.8 (1.12)
The politics behind climate action	3.9 (1.09)	N/A	3.9 (1.15)
The role of engineers in climate mitigation	4.0 (1.14)	N/A	4.0 (1.10)
How ideas from this class relate to ideas that you might encounter in other technical classes.	3.7 (1.27)	3.9 (1.04)	3.8 (1.19)
How ideas from this class relate to ideas that you might encounter in other NON-technical classes.	3.5 (1.24)	3.7 (0.98)	3.8 (1.16)
How studying engineering area helps people address real-world issues	4.1 (1.14)	4.1 (1.05)	4.0 (1.06)

On average, the students in 2017 and 2019, with the RTTP role-playing game, felt that they made slightly fewer gains in many of the key aspects of the course than seen in 2018 without the game. Few of the metrics show significant differences; self-assessed gains related to

understanding of the role of the engineer in society between years 2017 and 2018 was significant (r=0.047). The gains made were on average "good" for the majority of the metrics.

Table 5 summarizes student assessment of their own gains in particular skills practiced in the course. The summary assumes equal difference between each of the Likert scale options.

Table 5: Student responses to the question: "As a result of your work in this class, what GAINS DID YOU MAKE in the following SKILLS?"
- Standard Deviations are given in parentheses.
- Scale: 1: no gains; 2: a little gain; 3: moderate gain; 4: good gain; 5: great gain.

Prompt	2017 (n= 71)	2018 (n=74)	2019 (n=64)
Finding articles relevant to a particular problem in professional journals or elsewhere	3.5 (1.09)	3.9 (0.98)	3.9 (1.09)
Critically reading articles about issues raised in class	3.6 (1.14)	3.7 (1.12)	3.8 (0.98)
Identifying patterns in data	3.4 (1.33)	3.8 (0.97)	3.8 (1.18)
Recognizing a sound argument and appropriate use of evidence	3.7 (1.22)	3.7 (1.05)	4.0 (0.99)
Developing a logical argument	3.8 (1.15)	3.7 (1.08)	3.9 (1.12)
Writing documents in discipline-appropriate style and format	3.6 (1.18)	3.5 (1.18)	3.9 (0.99)
Citing references appropriately	3.8 (1.15)	3.9 (1.08)	3.9 (1.23)
Understanding how to determine the academic quality of sources.	3.7 (1.18)	4.0 (1.08)	3.8 (1.13)
Using the library resources available for Merrimack students.	3.7 (1.19)	4.1 (0.94)	4.0 (1.11)
Working effectively with others	3.9 (1.22)	4.1 (1.08)	4.0 (1.07)
Preparing and giving oral presentations	3.6 (1.26)	3.7 (1.13)	3.6 (1.16)
Having a good idea of what you want to do after college.	3.7 (1.28)	4.0 (1.09)	3.8 (1.19)
Being comfortable that you know either (1) you are in the correct major, or (2) you should change majors.	3.8 (1.27)	4.0 (1.03)	3.8 (1.18)

On average, students believed that they achieved "good" gains in the majority of the outcomes on the SALG survey, regardless of the inclusion of the game and Sustainability Development Goals activity. This is encouraging, as first-semester engineering students may not be expecting to do non-technical work as part of their engineering education. They report equal impact from an entirely technical semester and from learning the social impacts of engineering and the political/economic complexities of the field.

Anecdotal Analysis of Outcomes

There were some students that did not enjoy the game activity or the climate change discussions, while others found the activities to be quite interesting and helpful. As a group, they saw the benefits of the more technical semester (2018) quite similar to the benefits of the semester which

introduced the social, environmental, political, and economic impact of engineering. This is encouraging, and perhaps will lead to more inclusion of these important aspects of engineering through the curriculum.

Student comments included:

- *I now realize the different ways engineers/ engineering skills can be used in fields inside and out of engineering.*
- *This class has shown me that there is more that goes into engineering than previous classes have taught me.*
- *I LEARNED HOW DIFFERENT TYPES OF ENGINEERS* [capitalization is student's] *Can work on one project and have different roles. Also, I learned of how important engineers are to every global issue.*
- *This class has taught be both the breadth and depth of being an engineer. I didn't realize how dimensional they can be.*
- *My understanding of engineering changed by this class showing me that politics play a huge role in engineering*
- *My understanding of engineering has not changed.... I feel like I did not gain any further understanding of engineering from this course.*
- *My understanding of engineering has not changed much, I pretty much know everything I knew coming into this. And know I just know a lot about climate change and a Copenhagen debate that didn't solve any issues*
- *The teacher used easy terms for us to understand the key ideas and how we can relate it to our life which helped us connect engineering to our lives.*
- *My understanding of engineering has not changed because of this class because the professor only talked about climate change. Climate change has nothing to do with engineering.*
- *Climate change has a lot to do with engineering.*

The self-reflections show that there were very different ways in which the students absorbed and/or interacted with the course. Note in particular, the last two contrasting comments above, showing that even sitting in the same classroom, students can have very different perspectives on an activity. One factor that may impact the perspectives of students is the background of the student, for instance, math skills. In the SALG survey, students were asked to self-report what level of math they were taking. Responses to this question and to the gains in understanding question were cross-tabulated, and the results summarized (Table 6) for the 2019 section, assuming equal difference between each of the Likert scale options. Students without a math course and students in Calculus 3 are not shown in table due to the small sample sizes.

While not definitive, the data seems to show that the students in Algebra got more out of the lessons than the students in other math sections. Presenting the course for a smaller group of students, perhaps sorting by math course, may have improved the outcomes, and, we expect, would have improved the quality of discussion and debrief of the activity.

Table 6: 2019 student responses to the question: "As a result of your work in this class, what GAINS DID YOU MAKE in your UNDERSTANDING of each of the following?" sorted by math course. Standard Deviations are given in parentheses. Scale: 1: no gains; 2: a little gain; 3: moderate gain; 4: good gain; 5: great gain.					
Prompt	2019 (n=64)	Algebra (n=4)	PreCalc (n=29)	Calc1 (n=21)	Calc2 (n=6)
The role of the engineer in society	4.1 (0.93)	4.75 (0.50)	4.07 (0.80)	4.05 (1.12)	4.33 (0.82)
The science behind climate change	3.8 (1.12)	4.50 (0.58)	3.86 (1.04)	3.62 (1.36)	4.00 (1.10)
The politics behind climate action	3.9 (1.15)	5.00 (0)	3.97 (1.02)	3.57 (1.40)	4.0 (1.10)
The role of engineers in climate mitigation	4.0 (1.10)	4.75 (0.50)	4.17 (0.97)	4.00 (1.21)	3.33 (1.03)
How ideas from this class relate to ideas that you might encounter in other technical classes.	3.8 (1.19)	4.25 (1.5)	3.90 (1.14)	3.48 (1.33)	4.00 (0.89)

Longer-Term Impact

In Spring 2020, many of the civil engineering majors who had been enrolled in the Fall 2017 Introduction to Engineering course were reunited in a required junior-level course, taught by one of the Introduction to Engineering professors. These students were asked to complete a survey regarding how they now feel about the activity from their freshman year (Table 7).

Table 7: Spring 2020 Retrospective Survey of Fall 2017 Intro Students "Copenhagen … 2 years later!" n=16 Likert Scale Responses				
Question Prompt	Low Likert Labeled as:	High Likert Labeled as:	Median (mode)	Count 1 (count 4)
1. Did you LIKE the activity at the time?	1 = I hated it back then.	4 = I loved it!	3 (3)	0 (3)
2. Did you see the VALUE in the activity at the time?	1 = I had no clue why we were doing that.	4 = I was getting a lot out of it.	3 (3)	0 (5)
3. What do you think NOW?	1= In retrospect, I hate that we did that.	4 = I look back fondly	3 (3)	0 (4)
4. Do you see the VALUE NOW?	1= I don't get why we did that.	4 = I think it enriched my education.	3 (3)	0 (5)
5. Did the activity change the way you THINK about climate change?	1 = not at all	4 = VERY much	3 (3)	0 (4)
6. Did the activity change the way you FEEL about climate change?	1 = not at all	4 = VERY much	3 (3)	0 (4)

As juniors, 16 students from the Fall 2017 Introduction to Engineering course completed the survey in Spring 2020. All of these students reported that the activity changed both how they think and how they feel about climate change, with no students answering "not at all" to questions 5 and 6.

Responses varied, but indicate that students appreciated and learned from the opportunity to see the topic of climate change from different points of view (Table 8) as indicated from the responses to the open-ended prompt "Please comment on anything you remember about YOUR experience. Especially anything you remember about changes in how you thought or felt about climate change, engineering, college, etc..." from the Spring 2020 survey.

Table 8 : Spring 2020 Retrospective Survey of Fall 2017 Intro Students "Copenhagen … 2 years later!" n=16 Open Ended Responses
1. I remember having to play the oil corporations and it was difficult to fight for something I didn't in reality believe in but it was interesting looking at it from a different point of view
2. Climate change is becoming a greater issue in government's throughout various countries. We need to work together to change our unforeseen future
3. Shows how climate change applies to science and how politics and science overlap
4. The debate was the most interesting part because you needed to either defend, fight, or provide the facts in order to state your opinion and I liked that.
5. It was very interesting understanding all of the different parts associated with climate change. I think what I liked most about the activity was having to consider all options cost, environmental affects ect when making decisions.
6. The idea of developing nations being hurt economically by environmental regulations was a concept I didn't think about before hand and it was interesting to learn about what those nations wanted and how the regulations would affected them.
7. In retrospect the activity taught me a lot. At the time it was cool to see that in real life people don't agree about something so big like climate change and even with research students were able to defend the points which were brought up in Copenhagen. I do believe this did influenced my interest in the environmental aspect of engineering and solidifying my decision to minor in environmental studies.
8. It made me realize how there are different solutions and simple ways that could would help our environment a better place.
9. I remember I felt very strongly about climate change and during the exercise I had to represent China and try to convince people that the biggest producer of CO2 was going to cut down. It was very eye opening and only made me more interested and educated about climate change. You get to see how it effects big countries as well as small, and how it effects companies of different sizes. It was interesting to see everyone's arguments for or against, and what was their driving factor in making that decision such as profit, public safety, world preservation, etc. It was an awesome experience for people to debate

Discussion and Summary

First-year engineering students come from a variety of backgrounds with different levels of college preparedness. Some are well aware of the role that engineers play in society, including supporting global efforts to improve lives, such as the UN Sustainability Goals and addressing climate change. Some students are well prepared for and show strengths in their technical courses, while others have more experience in communication, including presentations and technical writing.

An introductory course for first-year engineers is typical at many engineering schools. Instructors in these courses want to achieve many goals, including strengthening the cohort and supporting retention, developing communication skills, outlining political barriers to technical solutions, and understanding the importance of global issues. Concepts encountered during the first year may not make an immediate impression on students, but may instead form the basis for more mature interaction with diverse ideas, perspectives, and people later in the college career and later in life.

Meeting learning outcomes and goals with gamification has become relatively prevalent in fields, such as business, computing, and marketing [11], [12]. However, in a course with students with varied backgrounds, it can be challenging to develop their understanding of the links between the game and the lessons or skills. Additionally, if class size is relatively large, discussions and debriefs may suffer.

Including a *Reacting to the Past* game, or research around the UN Sustainability Goals, appears to be able to achieve similar goals and outcomes as a traditional lecture- and activity-based course. RTTP and covering Sustainability goals may be more amenable in smaller class sizes, and with students who are more homogenous in their course preparation. While the boundary between the liberal arts and engineering may be arbitrary, first-year engineering students do not always see it as so, and need some detailed discussion and debrief.

Next Steps

- Develop additional ways to introduce sustainability and environmental goals to first-year students.
- Encourage the college to reduce the class size of GEN1001, and sort students by math course.
- Close the semester with more technical activities, so students “remember” that they did cover these types of activities, reinforcing the sociotechnical aspect of all engineering fields.
- Look for ways to deepen student understanding of connections between engineering and sustainability, community, and public/environmental health.

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