Introducing Engineering as an Altruistic STEM Career

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For years engineering educators and researchers have tried to get more students from underrepresented groups interested in engineering as a career field and college major. Many interventions designed for high school students assume that students do not know about engineering careers and just need opportunities to learn about the field. As a result, intervention programs may have touted the strong employment rate for engineering graduates or the high salaries.

The key may not be lack of awareness but instead a narrow conception of engineering. Research has shown that girls, first-generation college students, and students from racial and ethnic minority groups tend to have more interest in *altruistic* careers and want to work collaboratively to help others (Allen et al. 2015; Belanger, Diekman, and Steinberg 2017; Belanger et al. 2020; Lakin, Davis, and Davis 2019; Wade 2012). To them, these values are more important than salary. The stereotypical view of engineering is that the field is filled with people who want to make money and prefer to work alone; this perception is reinforced by many outreach programs. This perception of engineering reduces its attractiveness as a career to those that are interested in "making a difference" in our world. But what if the common perception of engineering is off-base? Many practicing engineers would argue that this perception is wrong (Faulkner 2007); they see engineering as a way to work in teams to solve some of society's most pressing issues (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine 2010). Highlighting this view of engineering may help engage more underrepresented groups in thinking about engineering as a career path.

The National Academy of Engineering's (NAE) *Grand Challenges for Engineering* (NAE 2008) is a list of 14 critical challenges that society faces and can be addressed by engineers. These challenges highlight how important engineering is in helping others and also emphasize the collaborative, creative, and interdisciplinary work that engineers do. The challenges are intended to help the public understand more concretely how engineering innovations contribute to advancing society and to provide real-world examples of how an engineering career meets communal and altruistic goals (Figure 1).

The Grand Challenges are an effective way to engage students' curiosity about engineering because they appeal to students who are interested in serving their community and solving important societal challenges. In this article, we share a few of the activities we have developed to introduce the Grand Challenges to students to demonstrate the impacts that engineering has on society and their own lives. Our work has primarily focused on summer camp experiences, where junior high and high school students come to the university campus, but these activities have also been used in formal spaces (e.g., high school and university classrooms) as well as informal spaces (e.g., community outreach events and school-based STEM events). We have found that, as a result of these activities, students' interest in engineering is enhanced, and all students better recognize the huge impacts that engineering has on society and their own lives.

Example Activity #1: What's the challenge?

This class discussion activity is designed to help students think about challenges they or their community face that could be addressed by engineering. The activity mirrors the methods by which the NAE developed the Grand Challenges. By developing a list of the challenges they see in their own communities, students gain an understanding of the direct impact engineering has on their health and happiness. This activity has been used many times by the authors in various settings, including STEM camps for high school students, junior and high school classrooms, and college-level courses. While the sophistication of the language used by the participants varies, the types of problems identified by the participants often mirror those in the Grand Challenges. For younger and older students alike, the activity engages brainstorming skills, active listening to build on others' ideas, discussion, and developing and applying criteria for selecting engineering solutions.

The activity begins with a brainstorming session conducted in groups of three to five students. Students are asked:

> Think about your life, your family, your school, your community, etc. Identify a task that could be accomplished in a

FIGURE 1

NAE's 14 Grand Challenges for Engineering.

Engineer better medicines	**Provide access to clean water**	**Create tools that advance scientific discovery**	**Enhance virtual reality**
Prevent nuclear terror	**Advance personalized learning** (Extended to "Advance personalized learning (online or other education formats)")	**Reverse-engineer the brain** (Rephrased to "Study how the brain works to make better artificial intelligence")	**Secure cyberspace** (Extended to "Secure cyberspace and fight cyber warfare")
Provide energy from fusion	**Restore and improve urban infrastructure** (Rephrased to "Repair and improve urban infrastructure (roads, water treatment, bridges)"	**Make solar energy economical** (Rephrased to "Make solar energy less expensive")	**Advance health informatics** (Rephrased to "Advance health data to improve medical treatments"
	Manage the nitrogen cycle (Rephrased to "Manage the impact of farming and industry on the nitrogen cycle and the environment")	**Develop carbon sequestration methods** (Rephrased to "Manage carbon emissions to protect the environment")	

more economical way, a difficulty that you encounter that if eliminated would make life better, or another issue that you think could be resolved by new technology.

For younger students, examples are provided such as, "I do not like to cut my grass." Each group is encouraged to develop a long list with about 10 minutes to brainstorm. In a recent summer camp, this initial brainstorming resulted in a wide range of topics, from no jobs available, drug abuse, animal cruelty, homophobia, failing schools, water pollution, and lack of food. All contributions are accepted for the compiled brainstorming list.

Next, the teams identify a technological solution to the problems they have identified. Technology is defined as anything created by humans to solve a problem. Students are encouraged to think creatively about potential solutions. Some examples of problems are provided, such as developing grass that can be "programmed" to grow only to a specific height. Students often propose solutions that are not achievable given the current level of technology, but the goal is to identify a technological solution to each. As the examples show, students have a deep understanding of systemic issues and those problems do not always immediately translate to technological solutions. Teachers should help student groups differentiate "technological solutions." Some examples include:

- **Animal cruelty**: A non-technological solution may be to pass new laws**.** A technological solution is to invent an app to report animal abuse when it is observed and allow adoption agencies to access records when someone applies to adopt an animal.
- **Water pollution**: A non-technological solution offered was to "give everyone a water filter for their home." Since this is existing technology and thus a policy decision, the students decided to invent more economical water filters that are easily distributed.

FIGURE 2

Students use a multimeter to test solar panels for energy efficiency.

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FIGURE 3

Students test their newly made solar cell.

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It is important to recognize that some issues may not lend themselves to an obvious technological solution. Teachers should help students brainstorm how technology could be used to address the challenge. For example, a student group identified bullying as an issue in their school system. While a technology to eliminate bullying was not identified, the students suggested that an app could be developed that would allow a bullied student to "call for help." Other students could then respond with encouragement or offer a seat for lunch.

The rest of the activity centers on discussing each group's list and narrowing all topics to a core list of three to five top challenges for the class. First, we combine similar ideas into a smaller set of broad issues. Then, students select the most important to address. During the discussion, teachers help the students think about the scale of the issue (i.e., a local, national, or worldwide problem). There is often a passionate debate as students discuss why a particular problem is important to address. Often, we use a group vote to finalize the list. In our summer 2020 camp, our top five issues were:

1. Police brutality / racism
2. Lack of education, failing students
3. Poverty / access to high-paying jobs
4. Illness/healthcare/cost
5. Animal cruelty

After the class has agreed on the top three to five issues, the teacher can introduce the NAE Grand Challenges. The teacher explains how they were developed using a similar process that involved input from scientists, engineers, researchers, politicians, and others across the globe. The group then discusses the similarities and differences between the NAE list and the list the class developed. The students often identify many of the same themes. The teacher should reinforce that the ultimate solutions to these problems have not been identified but engineers and other STEM professionals can work to solve the problems.

For some students, this activity may be the first time they have thought about how society could be improved; others may already have developed a passion for addressing these kinds of issues. Regardless, recognizing that they will ultimately bear the burden of solving or living with the issue can motivate students. Linking the issue with technology helps students understand the role of STEM in improving society. A complete facilitator's guide is available in Online Resources as part of the "Access to clean water" lesson.

Attitude surveys were administered regarding class activities (see Online Resources, "Access to clean water"). In a sample of high school summer camp participants, we found that 93% rated this lesson as "somewhat" or "very" interesting. All of the students (100%) reported they learned "some" or "a lot" from that activity.

Example Activity #2: Making solar energy economical

The goal of this unit was to demonstrate how chemical and materials engineers are contributing to creating cheaper and more efficient solar energy. Our unit on solar energy allows students to gain fundamental knowledge on current and developing solar cell technology, observe the environmental factors that affect solar cell performance, and produce a working dye-sensitized solar cell. Dye-sensitized solar cells use organic dyes to absorb sunlight and produce electricity in a method inspired by photosynthesis. The complete activity description can be found online (see Online Resources). The activity is derived from the technique shown in the video *A Delicious New Solar Cell Technology* (Farrow 2009). This video demonstrates building a dye-sensitized solar cell using the powdered sugar from powdered doughnuts sensitized (i.e., better able to absorb sunlight) with purple Passion Tea from Starbucks.

The procedures used in the video have been modified so that the activity is suitable for a high school lab setting. All safety protocols described in the lesson plans should be reviewed and followed. Some examples include:

- Plastic pipettes and glass stirring rods.
- Chemicals including titanium dioxide (TiO_2) nanopowder, acetic acid, and Lugol's solution.
- ITO glass slides.

Other materials required include traditional solar cells and a multimeter.

We begin with a short discussion of the importance of solar power and the current limitations on efficiency and cost. Depending on the level of the students, material related to the science of silicon-based vs. dye-sensitized solar cell technologies is discussed. Regardless of the level of technical discussion, two important points are made. First, processing silicon-based solar cells is costly and requires very expensive equipment compared to dye-sensitized solar cells. Second, the efficiency of solar cells is critical in determining how cost-effective they are. We conclude the introduction with a screening of the inspiration video (Farrow 2009).

There are two parts to the hands-on activities. In the first part, students evaluate a traditional silicon-based solar cell. These solar cells are available from many sources, and we often use several different types. Students get a brief lesson on calculating power, given voltage and current based on measurements from the multimeter. Students then evaluate the voltage and current output of the solar cells under different lighting conditions, such as direct sunlight, shade, inside light; when placed 0°, 45°, and 90° to the sun. These measurements can be performed in small groups or by individual students if a sufficient number of multimeters and solar cells are available (Figure 2).

In the second part of the activity, students build a dye-sensitized solar cell. In this activity, students mix chemicals, prepare glass surfaces, and assemble the final cell. The cell can then be tested using the same conditions and multimeter that were used in the first part of the activity. A dye-sensitized cell consists of two exterior pieces of glass (each coated with indium tin oxide (ITO)) with inside layers of TiO_2, a photosensitive organic dye (such as raspberry juice), and an electrolyte mixture. When the cell is exposed to sunlight, electrons are excited in the photosensitive dye, which creates a charge between the semiconductor material (including the TiO_2 layer) and the electrolyte layer. This activity develops skills in

- the use of scientific tools such as the multimeter,
- how to take and record data,
- general lab safety and PPE,
- how lab chemicals can be derived from food,

FIGURE 4

We used dry erase boards and vinyl cling to create reusable and easily revised city blocks.

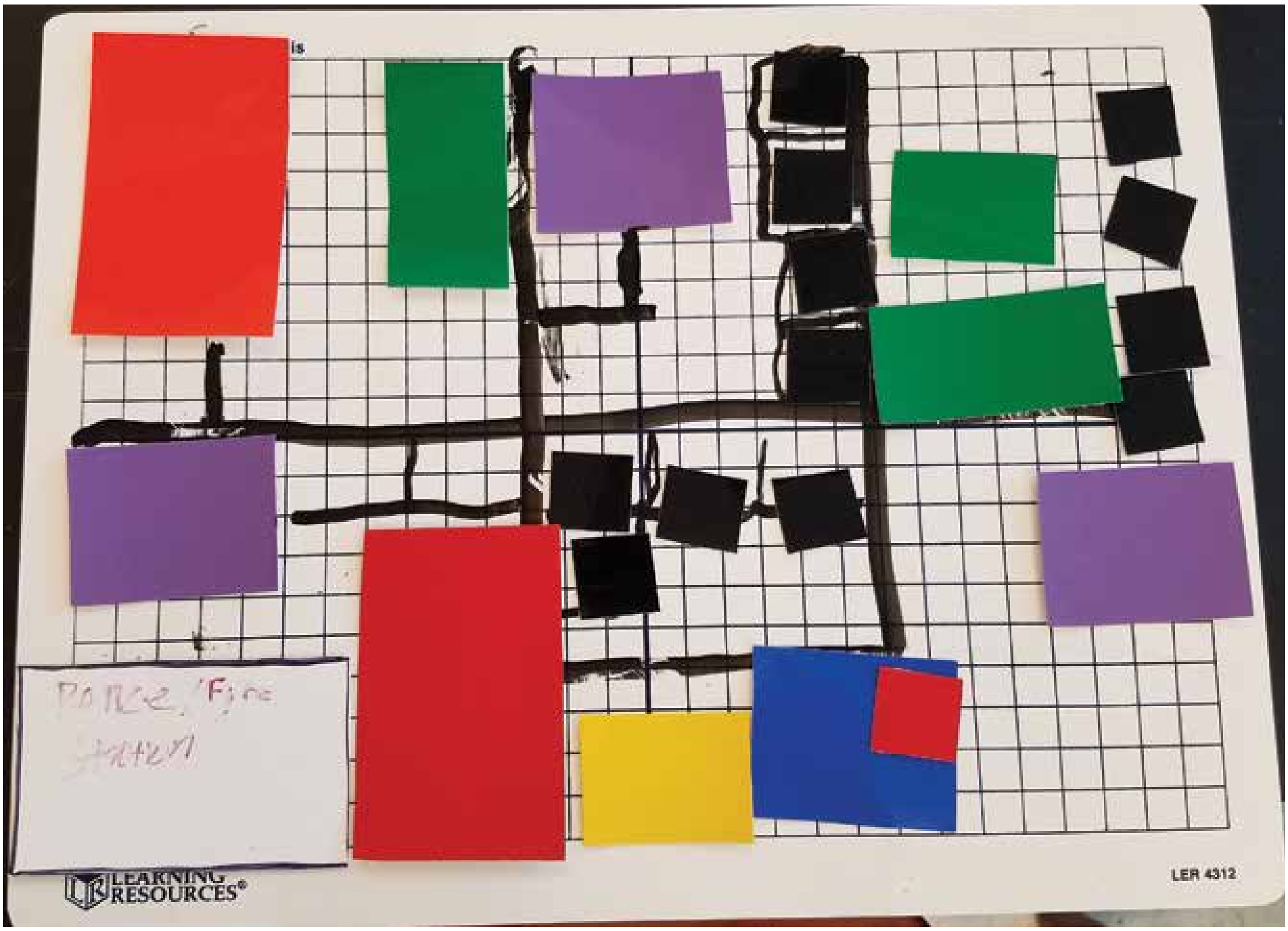

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FIGURE 5

Students interview the "mayor" about his priorities for development. Each role comes with a guide on their values and priorities for the block.

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- the parts of a dye-sensitized solar cell,
- how different chemicals affect cell performance, and
- working together in a small teams.

The first part of the lab takes about 30 minutes. Depending on grade level, students could be asked to calculate averages or prepare graphs and charts showing differences and ranges between their measurements. Students can do the calculations and graphs before they build their own solar cell in part two; however, we have found that this activity fits well during the break required to cure the coating created during the second activity. The second part of the lab takes about 40 minutes plus the coat-curing time on the hot plate. We suggest that teachers speed up the lab by preparing the solutions in advance. More advanced students might prepare the necessary solutions as part of the lab activity (Figure 3).

A pre- and post-assessment for this lesson is provided in Online Resources. In a sample of freshman engineering students, the percent correct for the assessment questions rose from 48% before the module to 69% after the module. High school summer camp participants rated the lesson very well with 98% saying that making a solar panel was "somewhat" or "very interesting." Similarly, 96% reported learning "some" or "a lot" from that part of the lesson. In a later summer camp, 85% of high school students rated it as "somewhat" or "very" interesting. When asked if this kind of engineering would help others, 95% agreed that it was clear how it helped others.

Example Activity #3: Improving Urban Infrastructure

The goal of this lesson was to demonstrate how civil engineers affect our everyday lives through infrastructure design. Our unit on urban infrastructure was based on a lesson plan developed by the Foresite Group (2014) for teaching students about civil engineering. Students are given a blank "city block" on which they must place different buildings (e.g., schools, grocery stores, homes) with different costs and land requirements (Figure 4). Each student on a team is assigned a role to play in negotiations (e.g., mayor, economic developer). Budget and space are the primary constraints.

We made several modifications to the original lesson to enhance the connection to Grand Challenges and create a local connection for students (see Online Resources for the lesson plan). First, we found articles in the local paper about a new Amazon distribution center that was being built in their area. We framed the activity as a $35 million investment that Amazon was making to develop a city block near the new center. This gave students real-world connections to the problem of urban infrastructure, thinking about how new roads and buildings would affect employment, traffic, and pollution in their own community. Second, we had camp mentors serve as the different stakeholder roles of mayor, economic developer, etc., with guides for their roles that included priorities and values (Figure 5). This put the students in the role of a team of civil engineers. They interviewed each stakeholder before designing their city block based on this input, and space and money constraints. Finally, each group presented their city block to stakeholders, justifying their choices based on the priorities they learned from the stakeholder interviews. The following includes some questions we asked student teams along with their responses:

- Why did you decide to place all of these houses near each other? *Well, people don't like a lot of traffic and noise, so we put the shops all over here and the houses together.*
- Where do you think you'll have the most traffic and noise in this block? *Over here by the shopping and school. We put the school near the houses because it's only noisy during the day and people need to drop their kids off easily.*
- Why did you decide to put the school right by the mall? *Well, we needed a big open space."* Do you think that might make traffic worse? *"Yeah, I guess during drop off and pick up, you couldn't get to the mall…*

We have found this activity successful for a number of formal and informal spaces. During this activity, students learn about constraints in the engineering design process, consider social and technical limitations to engineered solutions, work in teams, and learn about the impact of engineers on their daily lives through infrastructure (Figures 4 and 5).

A post-lesson attitude survey similar to that for the other lessons was administered to another sample of high school students participating in a summer camp. We found that 89% of students rated this lesson as "somewhat" or "very" interesting. When asked if this kind of engineering would help others, 95% agreed that it was clear how it helped others.

Key takeaways

Engineering lessons can be made more powerful by connecting design challenges to real-world concerns students observe in the news or in their community. This can also engage the interest of students from groups underrepresented in engineering. Here are some suggestions based on our experiences with introducing engineering as an *altruistic* career path.

Make the societal challenge AND engineering solutions salient

One pitfall in using activities based on the Grand Challenges is to focus only on the steps of the activities or only on a technological innovation. A vital part of engaging students' altruistic interests is to introduce both the societal challenge that is being addressed (e.g., talk about the Flint water contamination crisis or a local incident) and the technological solutions that engineers provide (e.g., engaging in our Access to Clean Water lab—see Online Resources).

Make the challenge local as well as global

The *NGSS* engineering standards suggest that "global challenges also may have manifestations in local communities." (NGSS Lead States 2013, p. 129) Students are more engaged if they feel they have a personal connection to what they are learning. In our camp, taking an abstract problem of urban development and challenging students to think about how *their* neighborhoods would be impacted by a new manufacturing center, which had been recently announced, added authenticity to the activity.

Have fun

In our experience working with high school science teachers, the most successful are willing to try and fail with a new activity. Engineering is all about prototyping and improving a design. Treat your lessons the same way. If you do not have the confidence or flexibility to bring engineering to your formal classroom, try afterschool or weekend events where the stakes are lower and the energy is higher for everyone.

Conclusion

Engineering has an image problem. Many students and teachers have a narrow view of engineering, emphasizing the economic opportunities, prestige, or technical focus of the field. Engineering is all these things but is also a collaborative and entrepreneurial field where interdisciplinary experts work together to solve important societal challenges. Students who want to help others and work in teams can find productive and fulfilling careers in engineering. Demonstrating the societal value of engineering also creates greater appreciation of the field even if students do not follow that path. Consider planning engineering lessons that highlight the altruistic opportunities that engineering provides. ■

ONLINE RESOURCES

Access all of our Grand Challenge lesson plans:

- Reverse engineering the brain: *https://nanohub.org/resources/27050*
- Restore and improve urban infrastructure: *https://nanohub.org/resources/27312*
- Access to clean water: *https://nanohub.org/resources/27268*
- Making solar energy economical: *https://nanohub.org/resources/24553*
- Connections between Internet of Things and solar energy, clean water, and engineering the tools of discovery: *https://sharepoint.eng.auburn.edu/sites/CS4ALL/RFE/CS/_layouts/15/start.aspx#/*

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