Multidisciplinary Approach to the First Year Engineering Design Project

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Introduction

Montgomery College is a minority serving community college in the suburban Washington, D.C. area which is the academic home of several thousand STEM students, many of whom will transfer into baccalaureate degree programs in engineering, computer science, the sciences, and technology fields. In the first two years of college, and particularly under conditions of uncertainty and material problems precipitated by a pandemic, STEM students face barriers to attainment of educational and career goals. First-year STEM students may not feel a sense of "belonging" in their chosen major or may not have even selected a program of study [1]. Second year students face a "critical juncture" as they approach transfer to a 4-year school [2]. At this point, many STEM students change majors or leave higher education altogether [3]. Engineering education research points to feelings of isolation as contributing factors to lack of persistence in the engineering major [4].

One way to promote persistence among students who have selected STEM is to assist individual students in developing a professional identity. Professional identity development is the process of "becoming" a practitioner, including the reconciliation of professional identity with one's other identities (such as gender and cultural identification). An effective path toward assimilating a professional identity is participation in the STEM community and in the performance of work that is authentic to professional practice.

All engineering students and many other STEM majors at Montgomery College take a freshman level course called "Introduction to Engineering Design." Like similar courses in virtually every engineering curriculum, this course features development of fluency in engineering vocabulary, an introduction to some of the technology tools of engineering, and a project-based learning approach featuring a strong teamwork component. The course helps to promote professional identity development by exposing students to authentic engineering practice. It is also a general education course, vetted and certified as providing a broad foundation of knowledge with learning applicable to general settings.

A weakness of such a course is lack of a multidisciplinary presentation of engineering. Rather, engineering is typically presented as the employment of a set of skills centered around technology tools. By incorporating features of liberal education into the first engineering course, the resulting engineering practice demands attention to critical thinking in conjunction with the application of technical skills. This can be done by attending to the general education intent of the course throughout, not just in selected lessons designed to support specific outcomes on the general education rubric. The course fuses engineering literacy with cognitive and affective knowledges and reflexivity and attempts to emulate Heywood's ideal of "a liberal education that enlarges the mind" rather than "the study of a range of disparate subjects that apparently have no connection with one another" [5].

This paper presents the author's experience of incorporating historical, social, political, and economic lenses into the introductory engineering course by assigning team projects to address challenges of COVID-19 in refugee camps.

The project assignment was intended to provoke questions such as:

- Does this make sense?
- How is this going to work?
- What assumptions are embedded in the solution imaginary?
- Who will monitor, collect, and process the data?
- What follow-up actions will be triggered?

The Course

ENGINEERING 101 (Introduction to Engineering Design) builds an engineering practice skill set by exposing first year engineering students to a rich set of topics selected by the instructor as important to engineering practice, including the rudiments of engineering graphics, computer-aided design and solid modeling, analytical exercises using worksheet software, and ancillary topics such as technical communication, project management, risk, reliability, and uncertainty. The learning throughout the course is intended to give the students a toolbox to aid in their performance of a team project authentic to engineering practice.

The course does not use a standard textbook but is built from a common "textbook" of core topic lessons and examples authored by previous instructors, supplemented with materials, lessons, and topics curated by individual instructors, such that the course has common elements, but each instructor offers a different interpretation.

In the Fall of 2020, the course was presented in synchronous remote mode using Blackboard courseware delivered over a Zoom platform. The course allows for class time to perform teamwork as part of a laboratory component, and breakout rooms were used for this purpose, with the advantage of the ability to summon the instructor to join a breakout room for discussion, clarification, and consultation with an individual team. Teams organized additional collaboration outside of class, through modalities of their choosing, which typically included additional video conferencing, email exchange, and chatting.

To convey the flavor of the course, the following panels illustrate the Blackboard content presented in one weekly module for the first topic in the course. Each weekly lesson attempted to engage the students using multiple modalities.

In the beginning of the course, reflection exercises prompted students to consider the role of the engineer, social justice framings of engineering, and each student's self-conception as an engineer. Discussion forum and Wiki exercises provided means to interact with other class members, as a prelude to future collaborations. The introductory topic module sets the pace for the course and a precedent for each succeeding content module to include a theme, provocative questions, a variety of student activities, some requiring collaboration, and one or more assessments.

Topic 1 - Introduction to Engineering

Welcome to ENGINEERING 101!

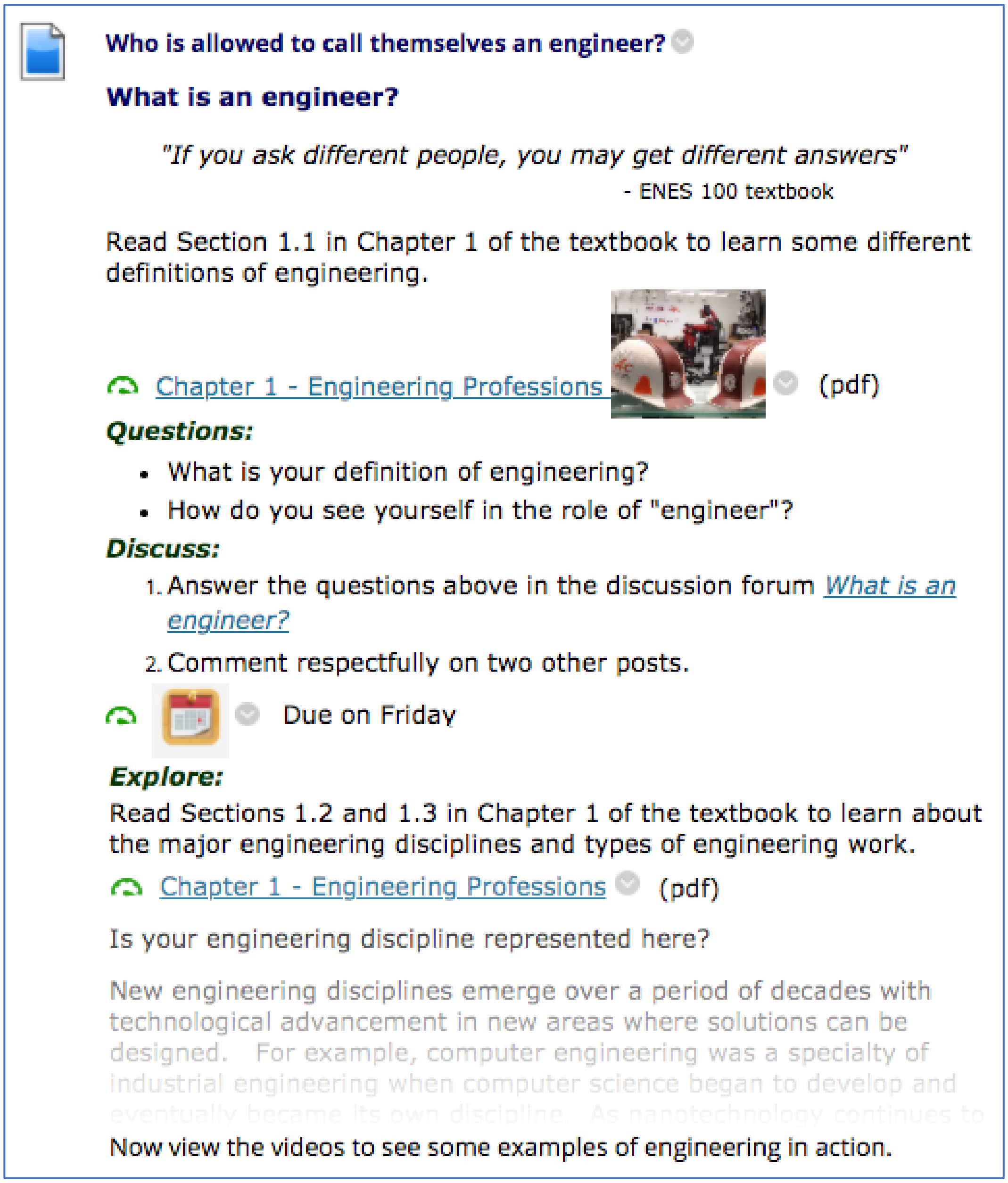
In this module, you will begin to learn what engineering is all about.

Open the module and study each content item. Your assignments are:

- Read the syllabus and take Quiz 0
- Read textbook Chapter 1
- "What is an engineer?" discussion post and comments
- Watch 2 videos and take the video quiz
- Contribute engineering vocabulary terms to the Class Group Wiki

Due on Friday

Figure 1 – Welcome page for the Topic 1 - "Introduction to Engineering"



Who is allowed to call themselves an engineer?

What is an engineer?

"If you ask different people, you may get different answers"

- ENES 100 textbook

Read Section 1.1 in Chapter 1 of the textbook to learn some different definitions of engineering.

Chapter 1 - Engineering Professions (pdf)

Questions:

- What is your definition of engineering?
- How do you see yourself in the role of "engineer"?

Discuss:

1. Answer the questions above in the discussion forum *What is an engineer?*
2. Comment respectfully on two other posts.

Due on Friday

Explore:

Read Sections 1.2 and 1.3 in Chapter 1 of the textbook to learn about the major engineering disciplines and types of engineering work.

Chapter 1 - Engineering Professions (pdf)

Is your engineering discipline represented here?

New engineering disciplines emerge over a period of decades with technological advancement in new areas where solutions can be designed. For example, computer engineering was a specialty of industrial engineering when computer science began to develop and eventually became its own discipline. As nanotechnology continues to

Now view the videos to see some examples of engineering in action.

Figure 2 - Preliminary assignment prompts for Topic 1

Video content was featured throughout the course, as part of individual instructional modules, and as extra credit exercises. The videos allowed class members to reflect on and discuss aspects of engineering identity as modeled in popular and social media. For example, the movie *Temple Grandin* [6] portrays an autistic individual who is not named as an engineer but who is seen doing self-taught engineering work. These videos provoke questions such as “Who gets to be called an engineer?” and allow students to see themselves as engineers. The short film *Dream Big: Engineering Our World* [7] was selected for the first instructional module to prepare the class for the team project assignment. *Dream Big* features engineers engaged in humanitarian volunteer roles, and it highlights the exchange of engineering knowledge between specialists and local engineers.

Video

Begin with this very short and humorous video which illustrates the slightly arrogant pride that engineers often display in their profession and their work.

Is Becoming an Engineer Worth all the Hard Work?

(streaming video, 2.5 minutes)

Next, on a more serious note, look at what happens when engineers are driven by curiosity, pride, and inspiration to change the world.

> *"Keeping people safe has always been the heart and soul of engineering"*

This documentary highlights engineers from various backgrounds — many of whom are women — and the projects they're designing, from earthquake-proof structures to footbridges in developing countries.

While you are watching the video,

1. make a list of engineering vocabulary terms that you hear, and
2. ponder these questions:
   - What engineering skills are being modeled?
   - Who is doing "engineering"?
   - Why does the narrator keep referring to "us" and "they"?

Dream Big: Engineering Our World

(streaming video, 42 minutes)

Assignment: Define the engineering terms you wrote while watching the video and record your terms and definitions in the class Wiki, which you can find in the "Class Group" area, which you can access from the "My Groups" link in the left side menu.

Due on Friday

Next: Take the video quiz

Figure 3 - Video content provokes questions and discussion

Theoretical Perspectives

Engineering students arrive at their Introduction course while still forming expectations of what engineering is and what they themselves might do upon earning an engineering diploma. Some students form their nascent impression of engineering from courses that they took in high school, which, according to student reports, typically center around computer aided design using popular software tools, and sometimes computer programming. The structure, presentation, and delivery of ENGINEERING 101 attempts to convey the richness of what constitutes engineering across disciplinary praxes, societal impact, and practitioner identity dimensions. Students come to realize that engineering is more than just computer aided design; "engineering" comprises a multidisciplinary set of practices conducted in diverse settings by individuals who came to engineering knowledge in different ways through lifelong reciprocal processes of acquisition and synthesis.

Engineering knowledge and what counts as engineering are somewhat malleable concepts. Downey and Lucena [8] argue that the knowledge content of engineering is closely related to engineering identity management and invoke the metaphor "code-switching" to link professional knowledge with quest for legitimacy. In ENGINEERING 101, the concept of "code-switching" has been taken literally: to become an engineer is to assimilate an engineering vocabulary. The harnessing of engineering knowledge is accomplished through the dual objectives of "knowing what engineers know" and "doing what engineers do." Each instructional module was organized with the intent to provide a new set of vocabulary in parallel with new opportunities for praxis.

Engineering educators are positioned to nurture professional identity development, and indeed, the process of "identifying with a community of practice" is central to learning itself [9]. Godwin [10] identifies several components of engineering identity development: individual interest and affinity, self-efficacy, performance, recognition. In ENGINEERING 101, each student produced a course portfolio in which the student curated showcase examples of their course production and narrated individual reflections on the assignments and methods employed therein, their learning, and a statement of who they are across identities that hold meaning for the student. While guiding students in the creation of the portfolio, the instructor emphasized that each student's agency in selecting assignment pieces, deciding what to include or exclude, composing layouts, and intermingling these components with reflections in the student's own voice, is essential in the production of a unique, living document. Thus, students were empowered to harness their learning exercises across a diverse set of content toward their own unique engineering identity development.

Project-based learning is a time-honored educational model that is flexible enough to accommodate a wide variety of engineering practice exercises. As with authentic engineering practice, project-based learning ideally features "open-ended, ill-structured" problems and "work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators" [11]. Kolmos and de Graaff [12] propose a hybrid model of project-based learning and problem-based learning which supports a learner-centered approach. This hybrid model, called simply PBL, is ideal for a course such as ENGINEERING 101, which presents "problem solving" as a diverse core skill set to be honed by every engineer. The course was organized around a team project which gave students and teams opportunities to apply the knowledge and skills they acquired throughout the course toward an open-ended challenge intended to reflect authentic engineering practice.

The aim of "liberal education," which is also called "general education," is to "help students acquire the knowledge and skills necessary to enlarge their minds" [5]. ENGINEERING 101 conveys to students the importance of the engineering norm of continuing disciplinary education. The course prepares students for a lifetime of teaching themselves engineering knowledge. However, engineering literacy is not the only kind of literacy needed to function as an engineer in society. The organization of the course around a humanitarian project required student teams to attend to issues outside of engineering and fuse a plethora of considerations through critical thinking into their engineering production.

The Assignment

Small team assignments provided a forum to acclimate to teamwork, then a large team project assignment was assigned. In a typical semester, students are allowed to form teams of 4 to 6 members on their own, and they will often choose to remain with students that they met in the small team assignments. In the Fall 2020 semester, sixteen student teams in four ENGINEERING 101 sections were given the same open-ended assignment. The first team task was to use the brainstorming skills already practiced in the course to decide on an approach to the assignment.

Background
At any given time, there are on the order of 100 million refugees worldwide. Refugees are persons temporarily or permanently displaced from their homes, and especially their home country, usually due to violence, war, persecution, human rights violations, or natural disasters. Refugees typically live in settlements with improvised housing, such as tent cities. In times of pandemic, refugee camps may not meet the needs of societies and of individuals in terms of public health, specifically, protection from and response to communicable disease. The reality for many refugee settlements is daily life in close quarters, often without running water, electricity, and sanitation.

Assignment
Your task is to brainstorm the problem of protection from communicable disease in refugee settlements. The goals are to reduce the transmission of diseases such as COVID-19 in refugee camps and to promote personal health for every person, defined as being in a state free of communicable disease. Different scales are possible with a task such as this. Your solution may involve some type of personal protective or wearable gear, a device used in an individual dwelling unit, or something that is deployed in the community.

As with all engineering solutions, your solution will involve trade-offs. Keep this in mind throughout the project. What are you optimizing? What will get worse? From whose point of view is this project designed? Who are the stakeholders, and what stake do they have in the project? What features will your solution offer? What is the extra cost to add a new feature? Consider not only monetary costs, but possible consequences of making changes to the design in terms of—desirability, ease of use, runtime between charges, maintenance requirements, interchangeability of parts, universal fitment, effectiveness of other features, etc. What is the cost of leaving out features? How will the design's effectiveness be impaired?

Methodology

As with a typical "Introduction" course project, students apply disciplinary learning throughout the course toward developing a solution to the problem assigned to their team. To achieve the pedagogical goal of promoting critical thinking skills, the project assignment is deliberately vastly open-ended. Students are prompted in the initial assignment narrative and with subsequent task assignments to consider the project and possible solutions from stakeholder points of view. The use of engineering methods such as computation and the production of specifications is secondary to the task of thinking through the proposed solution and how it will impact users. Thus, the use of engineering tools is not the primary focus of the project; instead, engineering tools are employed in the service of project goals and in anticipation of benefits (and possible harms) to constituents. To motivate continuous team progress toward completion and to provoke thinking about the project from multiple viewpoints, the project assignment was organized around a series of milestones, which are presented in Table 1. By unfolding the project this way, the project became a team effort in thinking deeply about a multivalent issue, with consideration of the impacts of the problem and the proposed solution on stakeholders, especially the intended clients.

Table 1 - Team Project Milestones, Deliverables, and Outcomes

Milestone	Deliverable	Outcomes
Initial presentation	Brief summary of brainstorming results	Team must coalesce quickly around a project direction Articulation of team's shared vision Practicing presenting together
Conceptual design	Hand-drawn sketch illustrating how technology resource will be used in project solution	Conceptualization Emphasizes the multi-step process leading to solution products
Project charter	Document articulating project purpose, objective, scope, and plan	Team must commit to a proposed scope Mutual understanding between team members and professor
Simulated review	Questions and answers from simulated discussion with project client	Team assumes client's point of view Potentially uncover weaknesses in solution Preparation for questions that may arise during presentation
The "curveball"	Document response in final project proposal	Incorporate consideration of risks into project planning Deeper consideration of stakeholder viewpoints Contemplation of social impacts
Project presentation	Oral presentation to class	Building team presenting skills Assessment skills (peer-grading)
Project proposal	Proposal document	Writing skills Modeling a request for proposal (RFP) response
Team member evaluation	Evaluation grid and written comments	Evaluation skills Self-assessment and reflection

Results

Each milestone task challenged the teams to incorporate external viewpoints when thinking and writing about the project and the team's proposed solution approach. As a result, the project effort went far beyond the production of engineering specifications. The task that seemed to confound students the most was the conceptual design. At the point in the course in which students were introduced to Microsoft Excel software as a computational and analytical tool and assigned to practice with Excel by calculating and graphing beam deflection or projectile motion, the team project assignment regarding Excel was to *draw a sketch* of how Excel might be used in the project solution.

Many teams submitted an Excel workbook with calculations, and some were quite elaborate, as if attempting to produce a finished solution to the entire problem. The rationale for such an assignment, as this instructor explained numerous times, is that one cannot implement a solution, especially with software, without preliminary steps of conceptualization and planning. Before typing formulas and text into worksheet cells, one must consider questions of what purpose the worksheet will serve, where input data and calculations will be stored, how results will be illustrated, and who is envisioned as the "user," the worksheet's designer, or another stakeholder. The conceptual design exercise asks students to contemplate at least the second and third questions. Much like the design of computer code follows construction of a flowchart, design of a worksheet may follow a sketch of how the worksheet is to be laid out and what information it will display. Moreover, sketching is a core skill set for engineers. Even when instructions were clarified explicitly, students seemed to struggle with believing that they were being asked to submit a hand-drawn sketch.

The simulated review challenged each team to interrogate their proposed solution thoroughly from the client's position, then to answer the client's anticipated questions. Many of the questions were of a technical nature or directly addressed product specifications, but some revealed degrees of abstraction and concern about the condition of people or the environment. Others incorporated life cycle thinking, one of the topics taught in the course. These are examples of some of the questions that the teams generated:

> *What technology will be used to help refugees through these tough times in COVID-19?*
> *What happens with all the trash generated from the supplies?*
> *How will the refugees communicate with your team if they have an issue?*
> *Will there be any counseling or therapy sessions to help refugees deal with trauma?*
> *Do refugees get an income so they can have a way to start their lives after leaving the camps?*
> *What type of environmental effects would you expect to cause by creating this product?*
> *What are some potential environmental or personal impacts on the surrounding area?*
> *Will refugees have anything to do other than stay in place all day?*

To remind teams that their projects are situated in the messiness of the real world, where risk and uncertainty are the rule, each team was dealt a "curveball" late in the project:

A new problem has arisen this week. Incidents of vandalism have been reported in the camp. It appears that the culprits are children, whose schooling was interrupted; the children have not attended school for eight months. The most common issue is that children are using pencils from the intake station to poke holes in masks and in plastic barriers. There are also reports that children are using gloves as balloons, but it is not known whether the gloves are new or used, which raises the possibility of introducing infection from the camp waste stream.

The teams responded to the challenge by writing additional content in the Results and Recommendation section of the project proposal, which was the final deliverable of the project. From the simulated review task, one team had already considered that refugees must have something to do "other than stay in place all day." The "curveball" assignment reinforced notions of project clients as real people whose days are occupied with cares and concerns. Some teams suggested that children resident in the camp must be schooled to prepare them for assimilation in a future home community. Another suggestion was educating youth about COVID-19 and the importance of the integrity of barriers. A few teams regarded camp residents antagonistically throughout the project and organized the safety of the camp around punitive enforcement measures. One team thoughtfully considered how technology could be inappropriate, ruling out the use of drones for contactless delivery:

Drones could potentially be intercepted or perceived by refugees as containing lethal equipment. Drones would actually exacerbate an already hazardous situation. The dust from the drones would pose a risk to COVID-19 patients already suffering from respiratory symptoms. Children make up the majority of the camp, and drones would pose a safety risk upon arrival.

At the end of the term, each student was given a short exit interview with an open-ended invitation to comment on the most important take-aways from the course. Most students mentioned either teamwork skills or software skill development, or both. Many students expressed surprise and pleasure—and a few regret—that the course included a rich diversity of topics. A few students mentioned the movies assigned in the course. Some students spoke about having been called "engineers" throughout the course. The following sample of student exit interview responses conveys a sense of the course having helped students feel comfortable in their engineering skin, which is an aspect of one's engineering identity.

Table 2 - Selected Excerpts from Student Exit Interviews

How to be even more skeptical and optimistic in everything I see and as an engineer in the making that I always have to ask a lot of questions and to be confident in what I do […] What I saw is that I'm capable of great things, especially from learning new aspects of engineering which I never tried before and I really enjoyed it.
This class kind of made me value things that I felt like are often overlooked in STEM. It focused on your technical skills, but it also on your interpersonal skills, especially with the team project.

It kind of made me realize the importance of being able to speak up.
All of us came from such different lifestyles with a lot of different skills, and we were able to work together to create something that was completely amazing.
Realizing the importance of what you're doing, how it affects other people and the ways that you can use engineering to better society. I think those were really strong themes in the class, and that's what I liked about the class.
I'm learning how to be comfortable with not knowing things.
I felt it kind of gave me hope in a way, because I don't feel like I would be the stereotypical engineer—I feel like I'm more of a humanities person.
Doing more independent thinking and independent learning.
It would definitely have to be the assumptions. That part was a little shocking to be honest. Just taking the time to really think about all the assumptions that are in literally everything you do.
I realize engineering really isn't just about calculations; it's more about the impact that engineers do to society.
Learning how to cooperate with groups and to figure out different methods to work with them.
Learning more of like the deeper meaning of engineering. Collaborating with my teammates who have other insights than I did.
The way you approach a problem, learning how to work as a team and brainstorming. I think that I can apply that to other classes.
I got a lot more of the professional side of engineering instead of just very technical aspects.
I feel like I'm very good at talking to people but I never realized how important having another person to help you think can be.
Where a lot of the learning really happened was having to learn for ourselves, and it's a good thing because it's independence and it's more of a real-world type environment.
The extra credit book that I read actually gave me a new perspective towards life. Also, I used to hate writing, but when I came to this class, I've actually learned how to write, for example, the essay about *The Martian* movie. I've learned how to write long essays and move with the flow.
This is kind of the first team project I've had where I had so much freedom.
I've always been afraid of math, however I actually started to get a little bit more excited about math again. So the biggest thing I took away from this class was the confidence. I have a positive feeling that I can do this, not just engineering math but engineering as well.

This instructor is encouraged that an open-ended engineering design team assignment can be used to reinforce learning in the large variety of topics relevant to engineering while also contributing to professional identity development in students. While the students did appear to have adopted a degree of critical thinking practice in their project work, the effect was not as strong as the instructor had expected, and some teams clung to a somewhat paternalistic approach in implanting their solutions. Future implementations might be improved by providing an introduction to the client, either in person, as in a nursing home visit to interview clients about their needs and preferences, or perhaps through readings or films that will help engineering practitioners understand how the client experiences the world. Supportive general education courses will be useful in reinforcing critical thinking across the curriculum.

Conclusion

Situating an open-ended introductory engineering design assignment in a real-world setting featuring elements of risk and uncertainty across multiple dimensions can be a valuable way to immerse students in authentic engineering practice. The assignment promoted development of a mindset to deal with the messiness of complex contemporary problems and contributed to engineering identity formation by demanding the integration of a diverse skill set in which conventional engineering activity such as writing specifications and making calculations are only components. Students were challenged to consider more than just the mechanical or electronic design aspects of their project; they must also think about how technologies would be used in a particular social and cultural setting, and how their solution would scale up to a population of many thousands of people. Individuals learned to function as team members and to learn from one another. The success of this approach in honing critical thinking skills will no doubt be strengthened by a supportive curriculum. Adaptations such as pairing “Introduction to Engineering Design” directly with a general education humanities course should be considered.

References

[1] B. W. Packard, J. L. Gagnon, O. LaBelle, K. Jeffers, K., & E. Lynn, “Women's experiences in the STEM community college transfer pathway,” *Journal of Women and Minorities in Science and Engineering*, vol. 17, no. 2, 2011.

[2] G. Lichtenstein, H. L. Chen, K. A. Smith, & T. A. Maldonado, “Retention and persistence of women and minorities along the engineering pathway in the United States,” in *Cambridge Handbook of Engineering Education Research,* A. Johri & B. M. Olds, Eds. Cambridge University Press, 2014, pp.311-334.

[3] M. J. Johnson and S. D. Sheppard, "Relationships Between Engineering Student and Faculty Demographics and Stakeholders Working to Affect Change*," *Journal of Engineering Education*, vol 93, no. 2, 2004, pp.139-151.

[4] M. E. Reyes, “Unique challenges for women of color in STEM transferring from community colleges to universities,” *Harvard Educational Review*, vol. 81, no. 2, 2011, pp. 241-263.

[5] J. Heywood, “Engineering at the Crossroads: Implications for Educational Policy Makers,” in *Cambridge Handbook of Engineering Education Research*, A. Johri & B. M. Olds, Eds. Cambridge University Press, 2014, pp. 731-748.

[6] M. Jackson (Director), *Temple Grandin*, HBO Films, 2010. [Film]

[7] G. MacGillivray (Director), *Dream Big: Engineering Our World*, MacGillivray Freedom Films, 2017. [Film]

[8] G. L. Downey and J. C. Lucena, “Knowledge and professional identity in engineering: code-switching and the metrics of progress,” *History and Technology*, vol. 20, no. 4, 2004, pp. 393-420.

[9] K. Tonso, “Engineering Identity,” in *Cambridge Handbook of Engineering Education Research*, A. Johri & B. M. Olds, Eds. Cambridge University Press, 2014, pp.267-282.

[10] A. Godwin, “The development of a measure of engineering identity,” *ASEE Annual Conference & Exposition*, January 2016.

[11] M. J. Prince and R. M. Felder, “Inductive teaching and learning methods: Definitions, comparisons, and research bases,” *Journal of engineering education*, vol. 95, no. 2, 2006, pp. 123-138.

[12] A. Kolmos and E. de Graaff, “Problem-Based and Project-Based Learning in Engineering Education,” in *Cambridge Handbook of Engineering Education Research*, A. Johri & B. M. Olds, Eds. Cambridge University Press, 2014, pp. 141-160.