Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #45864

Exploring Engineering Majors Through Engaging Synthetic Scenarios

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Introduction

This complete research paper explores the depth and breadth of student engagement with engineering disciplines in a first-year, general engineering course. First-year engineering courses are often one of the first steps that engineering students take on their journey to selecting an engineering discipline that aligns with their interests and aptitudes. Often, first year students do not have a strong grasp of the different tasks, duties, and knowledge that distinguish engineering disciplines from one another. Students tend to lean on preconceptions of engineering disciplines rather than exploring the breadth of the field. Traditional course-based approaches like product dissection enable students to reinforce the popularity of familiar disciplines like mechanical engineering or electrical engineering. These interventions fail to engender engagement with lesser-known disciplines or even a more nuanced view of the more common majors. This study presents a scenario-based learning intervention designed to increase a sense of relatedness and motivation, encouraging students to broaden their understanding of engineering roles using authentic, real-world engineering scenarios.

Students in a first-year General Engineering course worked in teams to analyze open-ended engineering scenarios synthesized by their instructor. Teams were tasked with expanding on the overall scenario context, identifying stakeholders, and developing job postings for related engineering disciplines. Using qualitative content analysis, we examined 35 team submissions across six simulated scenarios to examine the breadth of engineering disciplines students mentioned, the depth of engagement with stakeholder interests, and the quality of task alignment with the engineering roles. Our results show that the scenario-based approach results in a more diverse representation of engineering disciplines as compared to other interventions. Notably, students demonstrated deep engagement with stakeholders and their interconnectedness.

Context

Course Description

The scenarios were administered during the first semester of a two-course sequence in the first-year general engineering (GE) program housed in the Engineering Education Department within the College of Engineering Virginia Tech called Foundations of Engineering. The program outcomes for the GE program are to equip students to

1. select a major that aligns with their interests and goals,
2. have the foundational academic, technical, and professional knowledge and skills needed to succeed in a degree-granting major, and
3. develop a sense of belonging and identification with engineering to support long-term persistence toward a degree.

The Foundations of Engineering I course was designed to introduce students to engineering by exploring data collection and analysis, engineering problem-solving, systems thinking, contemporary software tools, professional practices and expectations, and the diversity of fields and majors within engineering. The course learning outcomes are:

1. Compare and contrast the contributions of different types of engineers in the development of a product, process, or system
2. Articulate holistic and ethical issues that impact engineering solutions
3. Solve problems using systematic engineering approaches and tools
4. Model an engineering system
5. Communicate solutions and arguments clearly
6. Develop teamwork skills

Discussions with the degree-granting programs within the College of Engineering have continually brought focus to the objective of serving the students in their mission to select from one of the 34 engineering majors offered by 12 degree-granting departments [1]. Specific aspects of these outcomes that are continually under development are encouraging students to challenge their preconceptions of the more well-known majors and encouraging them to engage with exploration of some of the lesser-known majors in the program. So, while the innovative learning activity described in this paper contributes to all the course learning outcomes, it is particularly tailored to the first and second learning outcomes associated with developing a broad and accurate understanding of the breadth and depth of the engineering field.

Traditional Activity

Under the premise of "Consistency with Autonomy" the multiple instructors of Foundations of Engineering I at the study institution have some latitude to tailor the learning experiences in their classrooms, provided they align with the previously established learning outcomes and fulfill programmatic assessment requirements (ABET and general education) [2]. However, a common approach they use to helping students learn about different engineering disciplines and their contributions to existing technology has been the *Product Exploration* or *Product Take-apart* activity.

In this activity, students are encouraged to bring small objects to the classroom that they feel comfortable disassembling, even if they may not be able to reassemble them. Commonly brought items include pocket calculators, cell phones, computer mice, and toys. Instructors provide simple toolsets, including various screwdrivers, Allen keys, and pliers. During the class period, students work in teams to disassemble the objects while reflecting on several prompts such as:

- What parts can they identify?
- What is the intended purpose or function of these parts?
- How do the materials, shapes, and design aspects of the parts align with their purpose?

Students are also encouraged to take multiple pictures of the process, capturing the product in its fully assembled state and documenting each stage of disassembly down to the individual components. General safety precautions are emphasized, such as handling tools with care, unplugging or removing batteries from electrically powered devices and avoiding the disassembly of batteries.

After the in-class activity, teams are tasked with writing a report and creating a presentation that highlights the contributions of four engineering disciplines to the creation of the object they disassembled. Prompts guiding this analysis typically include revisiting the function or purpose of the various parts and describing a design choice informed by the expertise of each discipline.

The hands-on nature of this activity makes it highly engaging, particularly when student teams have multiple products to take apart and can choose one for their assignment. However, the limited variety of items brought to class often leads to certain disciplines being consistently selected, which reduces the representation of the full diversity of engineering majors. Disciplines such as Mechanical, Electrical, Industrial, Materials, and Chemical Engineering, as well as Computer Science, are those most students readily associate with the fabrication of the objects they usually take apart. Additionally, the description of the connections between these disciplines and the objects are often straightforward, failing to capture the nuances of different roles within or across disciplines. For example, students might state, “Material engineers chose a durable plastic for the case of the mouse to withstand thousands of clicking cycles” or “Computer scientists wrote the code for this ethernet switch to control outputs to connected devices”.

Similarly, in the reports the identification of stakeholders is often superficial and limited to the producer/retailer/consumer triad. Although students are encouraged to consider the full lifecycle of the product, including the sourcing of its materials and its final disposition, they usually focus on the users of the product, the retailers that sell it, or the companies that manufacture it. Investors holding stocks in those companies are often mentioned as well. While valid, these connections represent just the surface of the many layers of interactions we would like them to explore.

With this context in mind, the research question guiding this study is as follows: How does an open-ended scenario-based learning approach influence the breadth of discipline exploration and stakeholder identification among first-year engineering students?

Conceptual Framework

Literature

Scenario-Based Learning (SBL) uses realistic scenarios as a framework for teaching and learning, enabling students to acquire and apply their knowledge to practical, real-world situations [3]. These scenarios can take various forms, such as specific circumstances, critical incidents, or narratives, and are designed to immerse students in meaningful contexts [4].

Properly crafted scenario-based learning contexts enhance students' sense of relatedness by positioning engineering tasks and knowledge within real-world scenarios that students find relevant to their social contexts. According to self-determination theory, relatedness is one of the key drivers of intrinsic motivation [5]. Intrinsic motivation encourages students to engage more deeply in learning, increasing the likelihood of engaging in help-seeking behaviors, proactively exploring additional resources to expand their understanding. Aligning tasks as directly related to their intended careers or interests is a technique that students sometimes use to self-moderate their motivation, an aspect of self-regulated learning [6]. This suggests that scenario-based learning not only drives engagement with engineering concepts but also encourages self-directed exploration of the disciplines.

Scenarios can range from simple conditions and circumstances to complex sequences of events with well-defined plots, roles, and team dynamics. Students may navigate these scenarios through multiple pathways, leading to a variety of potential outcomes. By integrating these features, SBL provides a flexible and dynamic platform for addressing specific learning objectives while leveraging student motivation and providing them with a sense of autonomy about their learning experience [3].

SBL has been widely implemented in business-related courses and is also used in engineering education. While still grounded on realistic situations and circumstances, SBL implementation in foundational engineering courses has adopted a particular approach, featuring dynamic scenarios that evolve based on the decisions students make [7]. This approach is argued to be more effective for reinforcing existing knowledge rather than fostering the acquisition of new concepts. However, it remains rooted in the principles of active learning, requiring students to engage actively in the learning process.

For the purpose of this study, we did not use the sophisticated dynamic scenarios described earlier. Instead, the scenarios were crafted in a static yet open-ended manner, allowing students to freely explore the situations presented and research additional information as they see fit. In this way, we argue that SBL can address the shortcomings of the traditional product take-apart activity by immersing students in narratives that necessarily involve diverse engineering disciplines and stakeholder interactions beyond the production and use of a common retail product. In addition, the open-ended nature of the scenarios provides students with a sense of agency, which is key to fostering engagement and motivation [5].

Design of a new assignment

As discussed in the traditional assignment section above, students often demonstrate at least a surface familiarity with the more traditional Engineering disciplines such as Electrical, Mechanical, or Civil Engineering. We have termed the less well-known majors as Discovery majors. These include Materials Science and Engineering, Biological Systems Engineering, and Building Construction, among others. When tasked with exploring the contributions of different majors to the development of a product or process of the students' choosing, often the roles of these discovery majors are either not apparent, oversimplified, or are not necessary at all. The end effect is that students tend to reinforce pre-existing conceptions about the more broadly understood majors.

The new assignment structure was developed to specifically address certain perceived shortcomings in the traditional assignment, to align with course and program learning outcomes, and to facilitate and encourage opportunities for peer-to-peer feedback. Each scenario was designed to naturally involve at least one of these discovery majors in our program. For instance, addressing environmental contamination might require expertise in biological systems engineering, while developing infrastructure for remote areas might necessitate mining or construction engineering expertise.

To ensure scenarios authentically incorporated the Discovery majors and implied realistic ethical dilemmas, generative AI was employed in scenario development. Prompt instructions explicitly required each generated scenario to suggest the contributions of Discovery majors available at Virginia Tech and implicitly incorporate an ethical dilemma suitable for exploration by students.

The scenarios were designed as open-ended, ill-structured problems to simulate the ambiguity and complexity of real-world engineering challenges. The scenarios were designed to center around situations that are relevant to students' lived experiences such as addressing climate change, supporting a Mars colony, or solving infrastructure challenges in natural disaster recovery. The real-world, ill structured nature of each scenario implied ethical dilemmas to lay the groundwork for later coursework on Engineering Ethics. For example, a scenario on disaster recovery could involve questions about resource allocation or the prioritization of vulnerable populations. These ethical dilemmas were not provided to the students but were implied in the context of the scenario.

Over the course of the semester, students were tasked to engage with their team's engineering scenario in each of the three major components of the course: Engineering Opportunities, Coding and Data, and Unpacking Ill-Structured Problems. For each of the different modules, teams would engage with structured assignments that revolved around their given scenario. Teams acted as consultants in the first module to lay out three engineering job descriptions that would be necessary to engage with their problem. In the second module, teams identified a data set relevant to their scenario and developed MATLAB-based algorithms to inform decisions relative to addressing their scenario. Finally, in the third module, teams began the Engineering design process, researcher stakeholders, ethical considerations, and systems maps to identify an aspect of their problem to address and propose a nominal solution to pursue.

Methodology

The Human Research Protection Program at the study institution determined this study is not research involving human subjects as defined by HHS and FDA regulations, therefore not requiring further review and approval by the institution's IRB. For this study, data were collected from submitted assignments of 207 students enrolled in three sections of the course led by one of the authors of this paper. The students were divided into 35 teams for the duration of the semester.

These data were drawn from a team report assignment in the first module focused on exploring engineering opportunities. This assignment was structured as a consulting report with each team acting as a consulting firm tasked with analyzing the problem, identifying key stakeholders, recommending necessary engineering roles, and anticipating potential ethical challenges. Student teams submitted a report consisting of four sections: (1) an introduction to the scenario and its significance, (2) stakeholder identification, (3) three recommended job postings, and (4) conclusions (see Appendix A).

Our data consists of a semi-random selection of submissions, focusing on Parts 2 and 3, stakeholder identification and job descriptions. A total of 12 assignments were selected from 35 submissions, ensuring equal representation from each of the three course sections and coverage of all six provided engineering scenarios. In Part 2 of the assignment, students were asked to identify all stakeholders involved in or affected by the scenario and to discuss their interests, roles, and potential conflicts associated with the scenario. In Part 3, students were tasked creating detailed job postings for engineering roles to address challenges inherent in the scenario. Each posting was to seek a different type of engineer, to provide a suggested engineering major, and to outline the duties associated with the position.

Deductive content analysis was employed to examine the selected assignments and sections for themes related to the authors' expectations regarding the breadth and depth of descriptions, or the lack thereof. Specifically, the analysis focused on the existing content within the text, rather than any new text generated during the analysis process. [8, p. 25]. Content analysis was chosen because it enables both the quantification of the predominance of specific themes and the provision of rich qualitative descriptions to elaborate on those themes [8].

Using the software NVivo, the two coauthors collaboratively coded two assignments. In addition to coding for the expected themes, open coding was employed to allow the emergence of potentially related themes not initially considered [9]. Based on the codes generated during this process, the co-authors developed an initial codebook to guide further analysis. Four additional assignments were coded collaboratively, providing an opportunity to discuss and resolve the few differences that arose and to update the codebook as necessary. One coauthor then finalized the coding of the remaining six assignments using the refined codebook, which is presented in the next section along with the counts generated by NVivo.

Results

Table 1 presents the study's codebook, including the counts for each code. The codes have been reordered for logical presentation, with those focusing on disciplines and duties listed first, followed by those emphasizing stakeholders. Note that multiple instances of the same code (references) in one assignment (sample) were coded separately.

Table 1. Codebook with code counts.

Code	Explanation	Number of samples	Total references
Diversity of discipline	Nuanced explanations of the dimensions of the engineering role are provided highlighting subsets of the field.	11 (92%)	24
Depth of duty	Discussion of duty goes beyond superficial and common-knowledge arguments.	6 (50%)	12
Cross-functionality	Students discussed interactions between multiple disciplines involved.	3 (25%)	5
Overly general	Description of the duties is too broad and does not have explicit connections to the specific scenario.	7 (58%)	20
Misidentification of discipline	The duties described by the team do not align well with the knowledge and skills associated with the discipline.	6 (50%)	6
Diversity of stakeholders	Stakeholders discussed go beyond the usual investor/producer/consumer including, for example, governmental entities, etc.	11 (92%)	38
Deep stakeholder connection	Discussion of stakeholders' involvement with other parts of the system is rich and meaningful.	10 (83%)	28
Stakeholder dilemma	A conflict or potential conflict between the duties or interests of stakeholders is present.	3 (25%)	5
Superficial stakeholder	Stakeholder presented is obvious to the scenario and does not require a depth of understanding of the system.	4 (33%)	9

The remainder of this section elaborates on the codes described above, now refined as themes after grouping, nesting, and discarding codes as necessary. Selected excerpts expressed in the students' own words are also included to support and help convey the significance of each theme.

Diversity of Disciplines and Depth of Duty

Consistent with the open-ended nature of the engineering scenarios, we expected to see larger breadth and depth in the descriptions of disciplines and job descriptions provided by students than with the product exploration approach.

We did see a broad diversity of engineering disciplines in the data set, with 11 of the 12 submissions containing 24 instances of diverse engineering disciplines. For example, one of the

Mars Colony submissions called for a joint Biological System Engineering/Chemical Engineering role to serve as an "Oxygen and Agricultural Planner and Engineer". Among the engineering majors cited by the teams, Ocean Engineering, Environmental Engineering, and Civil Engineering featured heavily among the atypical disciplines reported (see Table 2).

Table 2. Count of mentions of different engineering majors.

Major	Instances (out of 24)
Civil	9
Environmental	5
Ocean	2
Biological	2
Chemical	1

While many of the common or well-known engineering disciplines were included in the data, often nuanced aspects of the discipline were presented, suggesting a depth of engagement with the discipline as well. Particularly, teams drew on multiple aspects of civil engineering focusing on some of the diverse aspects of the field. For example, one earthquake scenario team identified three different fields within Civil Engineering – Structural Engineering, Seismic Engineering, and Geotechnical Engineering.

Students were tasked with providing a job title as well as indicating an engineering discipline well-suited to fill the role. The diversity of disciplinary tasking can be inferred from the breadth of the job titles provided in the dataset. Example job titles include "Plastics Waste Management and Sustainability Specialist (Environmental Engineer)", Ocean Plastics; "Hydrologist (Civil Engineering with a specialization in water)", Flood Mitigation; and "Coastal Engineer (Ocean Engineering)", Flood Mitigation.

There were also multiple instances of teams providing in-depth analysis of the job duties that the disciplines involved in the scenario would undertake, albeit the total number of instances of in-depth job duty description is lower than for the diversity of the fields. Of the 12 reports analyzed, half included deep explanations of the roles and duties of the Engineering disciplines involved (12 instances in total). Some of the descriptions are quite rich, providing highly detailed and specific tasks and responsibilities for the engineer. An earthquake scenario team for example, note not only the duties, but was one of the only teams to discuss cross-functionality and interaction of the different members of the scenario:

> *Locating areas with seismic forces that are withstandable to the infrastructure we are building. Advising the design team on how to build the foundation of the infrastructure by telling them what type of materials to use and where to make the foundation itself. Using geological maps and aerial photographs to advise on land selection. Testing*

materials such as sand, gravel, bricks, and clay to see if they are up to grade for withstanding earthquakes. (Seismic Engineer, Civil Engineer)

One of the flood mitigation teams demonstrates a nuanced aspect of engineering in record keeping and test engineering, noting that the project Environmental Scientist (Environmental Engineer) would focus on

addressing the impacts that flooding has on communities and ecosystems, creates strategies to prevent the effects of flooding/uses information to come up with better flood mitigation strategies, and records the effectiveness of flood mitigation.

One of the earthquake resistance teams brought multiples instances of engineers serving in a role much broader than a standard design/analyze role to one with multiple responsibilities to other aspects of the system, including stakeholder training, analyses, adherence to regulations, and risk assessment:

Design structures to withstand seismic forces and vibrations. Perform seismic analysis to assess building stability during earthquakes. Ensure adherence to local and international seismic codes, laws, and practices - Earthquake Team, Structural Engineer (Civil Engineering)

Earthquake preparedness planning, seismic risk audits, conduct safety training programs, oversee seismic monitoring systems - Earthquake Team, Geotechnical Engineer (Civil Engineering)

Overly Generalized or Misidentified Engineering

While many of the teams identified diverse engineering disciplines and depth of duty was also common, many teams provided overly generalized descriptions of engineering duties (20 instances across 7 of 12 submissions) or even misidentified the engineering disciplines best suited to serving in the required capacity (6 instances in 6 of 12 submissions).

Often, teams identified nuanced components of the engineering scenario, as implied in the job title, but provided only cursory explanations of the actual duties and responsibilities of the role:

Design machinery for the sustainability of aquatic ecosystems, ensure integrity of said systems - Ocean Plastics, Sustainable Aquatic Machinery Specialist (Ocean Engineering)

This role consists of finding the best and most cost effective materials to build all of the new green infrastructure. - Flood Mitigation, Materials Scientist (Materials Engineering)

In a similar vein, teams sometimes suggested an overly broad set of duties covering a large range of roles and responsibilities:

Job is to design, implement, and maintain renewable energy infrastructure, such as wind, solar, hydro, or marine power. Energy Transition, Clean/Renewable Energy Engineer (Environmental Engineering)

Design, create, and implement infrastructure solutions for the general population, government Mars Colony, Mars Infrastructural Engineer (Civil Engineer)

One team presented a rather detailed set of job duties, but provided such a broad set of duties such that it was not feasible to connect the job back to the assigned engineering scenario:

"I oversee and plan the team's actions to make the switch as efficiently as possible. I also maintain proper communication with project members and smaller groups. I provide structured daily plans to ensure daily progress and multiple updates to higher-ups to maintain a satisfactory quota." Energy Transition, Project Manager (Industrial & Systems Engineering)

In other instances, teams identified diverse engineering roles, and provided detailed lists of duties, but then suggested the positions to be filled from disciplines that were not the obvious best choice, or were perhaps a poor choice.

One Ocean Plastics team identified a job posting to "Design machines and processes to maximize the amount of trash collected" and suggested an Ocean engineer to fulfill the design and optimization process, likely because the application was for marine cleanup. A Smart City team tasked a mechanical engineer with duties focused primarily on AI and machine learning duties

Design and plan long-term strategies to use AI for the benefit of the city. Implement and maintain automation systems for data collection and processing, trash services, streetlights, snow/street clearing, etc.,

failing to identify the strengths of Computer Science in this aspect of the scenario.

<u>Diversity of Stakeholders and Depth of Stakeholder Connection</u>

The positive results in terms of the breath of stakeholders discussed surpassed our expectations, with 11 of the 12 submissions containing 38 references to stakeholders beyond users, producers, and retailers. These references could be classified into five broad categories: public administration (15), environmental regulators (6), lifecycle-related companies (6) educational/research institutions (3), and others (8).

Public administration includes mentions to local and federal government and agencies with different roles in the scenarios. For example:

The city or municipal government has a lot of power to control how the new city is built as they are the leading body for the project. The government is necessary for ensuring the legality of the construction and management of the new city, and the resulting smart *city's success and functionality are essential to how the government is able to run and properly govern the city. (Smart city scenario)*

The previous quote represents both breadth and sufficient depth in the description of this stakeholder. Sometimes, however, teams would include a relevant and non-obvious stakeholder, such as "National Oceanic and Atmospheric Administration" (Ocean plastics scenario) without further details about their involvement.

We decided to keep the category *environmental regulators* separate from *public administration* given its predominance and the mention of non-profit and other nongovernmental organizations. For instance, students working on the Energy transition scenario mentioned that "Nature conservation agencies would be for switching to clean energy because of the massive amounts of pollutants released by using coal and coal power plants."

The category *lifecycle-related companies* includes stakeholders students identified on different steps of the supply chain or final disposition of resources and materials related to the scenario. For example:

The company/companies in charge of the mining, distribution, transportation, and purchase of the coal are going to be affected because a plant will no longer be operational and in need of their services. (Clean energy scenario)

This, again, is a good example of breadth and depth of the stakeholder identification, since students empathetically pointed out to a stakeholder that may result negatively impacted by arguable positive changes they want to implement.

There was one case that, while unique, caught our attention. In one of the reports, students identified the engineering teams required to implement required changes as stakeholders. Moreover, the students discussed the potential interactions between these different internal stakeholders:

The Management Team manages all parties working directly on the project, including our design team, land analysis team, and construction teams, making sure deadlines are met and the project stays on track. They will also work alongside all other stakeholders so that all parties are heard and are involved in the process, keeping all parties happy and invested in the final infrastructure. (Earthquake scenario)

The previous excerpt not only shows a deeper layer of stakeholders and their connections being considered, but also encapsules the idea of multiple jobs and duties existing within a broad discipline such as Civil or Construction Engineering. This is precisely the type of broader exploration we tried to foster with the scenarios.

In total, 10 of the 12 teams were able to provide meaningful descriptions of the involvement of the stakeholders discussed. One more example of these rich descriptions is presented below:

Congress can support Mars colonization as a way to preserve Earth by providing funding for NASA and other private space companies while offering tax benefits and increasing research and development investment in space technologies. Congress can also pass legislation that outlines a national space policy, encouraging international cooperation, and establishing public-private partnerships. Congress could also prioritize environmental research, applying sustainable technologies learned from space exploration to Earth. (Mars colony scenario)

<u>Stakeholders Dilemma</u>

A particular aspect within the detailed descriptions of stakeholders was the identification of competing interests, which can lead to dilemmas. We chose to code this separately, as it serves as an entry point for another key topic in our course: ethics in engineering. Only three out of the 12 reports explicitly referenced meaningful stakeholder dilemmas. For instance, one of the teams noted the following:

They [the Town Council] want what is best for the citizens of the town, while also making smart economic and sustainability decisions. However, this can be a conflict because citizens may have trouble affording a more environmentally friendly energy source. (Clean energy scenario)

Students also identified potential conflicts among internal stakeholders, such as engineering teams working on the problem:

The land analysis and design team may have potential conflict, as the design team may have a certain vision that cannot be carried out due to various constraints that may have been previously scoped out by the analysis team. Things such as elevation, potential destruction of habitat life, and more. (Earthquake scenario)

Although not pervasive, the issues raised by these three teams are highly relevant and could serve as a foundation for further discussions on conflicting interests and ethics in engineering.

<u>Superficial Stakeholder</u>

We also decided to code also for superficial stakeholders to contrast their prevalence with diverse stakeholders. Four reports contained a total of nine references to superficial stakeholders, significantly less than the 38 found across 11 reports for diverse stakeholders. Citizens, companies hired to perform directly related activities, and investors were commonly mentioned under this theme. For instance, a team working with the smart city scenario pointed out that "The local community (businesses, residents, schools/universities) will mostly be affected by the new renovations to come." While this and similar stakeholders identified are obvious, they remain relevant consideration in the different scenarios.

Limitations

The prompt for the assignment implied that students should select a single engineering discipline that would be best suited for the job postings. While not explicitly stated, this might have led students to narrow the field of engineering majors that would have been suitable fits for the duties, skills, and knowledge requisite for the job.

The distinct impact of the scenario-based approach described in this study could be more effectively assessed through a comparison with data from sections using the traditional product take-apart approach, which was not conducted.

While the course policies stated in the syllabus preclude the use of generative AI without approval from the instructor, due to the relative novelty of the tool, it is not easy to explore the influence of the use of generative AI in this data set.

Discussion

The goal of this intervention was to induce students to dive into the exploration of engineering disciplines more authentically. While students have been provided with ample resources to explore engineering disciplines, they have not historically exhibited motivation to interact with these resources. The perceived shortcoming in the traditional product archaeology or take apart assignments was that students would latch on to the obvious choices of electrical, mechanical, and materials engineering in their product. We were aiming to use the relatedness aspect of the scenarios to induce intrinsic motivation to encourage students to further explore the roles and responsibilities of different majors and to see themselves in these roles. Even though SBL has been shown as effective for reinforcing knowledge rather than synthesizing new knowledge, in this context, we are tasking students with the acquisition of relatively simple facts rather than engaging in deep technical content.

In addition to the more well-known engineering majors of electrical, mechanical, and materials science, we did see that students in this intervention did identify and explore diverse engineering jobs and duties. Of the engineering disciplines that students tended to gravitate towards, we saw a large proportion of reliance on civil engineering, likely due to the nature of the engineering scenarios themselves. One of the criteria we used in designing the scenarios was that they should be centered on issues that are relevant to first-year engineering students. Thus, issues such as energy transition, flood mitigation, and Mars colony development were crafted. Many of the issues inherent in these scenarios do tend heavily towards civil-type knowledge bases. Nonetheless, the breadth of engineering disciplines identified by students suggests that scenario-based learning can effectively broaden students' self-efficacy in understanding of the field. This diversity is particularly significant in first-year education, where students often gravitate toward more familiar disciplines. Encouraging students to explore lesser-known disciplines may help them make more informed decisions about their academic and career paths.

Perhaps more interesting, many of the teams identified very nuanced aspects of the roles of engineers in working through problems. Whereas most of the duties we would experience in the product take-apart were literal repetitions of the disciplinary title (e.g. the electrical engineer would design the electrical components of the system), here we saw students explore actual aspects of tasking that would be necessary to address problems within the scenario. While we sampled multiple instances of overly generalized job duties, or even misidentification of engineering disciplines involved, we also saw evidence of deep engagement with a scenario that required investigation of disciplines and majors beyond those implicit in commercial product design and manufacture.

We acknowledge that the misidentification of engineering disciplines is a limitation of the intervention. As mentioned earlier, a fundamental limitation in scenario-based learning is that this type of learning tends to reinforce existing knowledge. However the assignment structure requires students to justify their choice of engineering discipline for the tasks that they have identified, which provides an opportunity to surface and examine these preconceptions. While misidentification did occur in assignment the duties to a specific engineering field, the externalization of these preconceptions is valuable as it makes students' thinking visible, allowing for targeted feedback in our assessment of their reports. Rather than viewing these misinterpretations solely as a limitation of the intervention, we see them as a step in development as we can help students refine oversimplified or incorrect views of engineering disciplines to a more accurate mental construction. Equipping students to select an engineering major that is aligned with their interests and aptitudes is a critical outcome of both our course and the General Engineering program. This intervention acts as a formative assessment to support a more accurate awareness of engineering disciplines. Moving forward, we will explore more intentional language to direct students to existing resources to fact check their assumptions. We also hope to engage with the parties who help us curate our resources to ensure that we bring awareness of some of the student perceptions to maintain the currency of these resources.

We did not anticipate the diversity in stakeholders and the depth of stakeholder development that resulted. In the design of the scenarios, stakeholder engagement was viewed as a means to the end of deeper exploration of engineering disciplines, rather than necessarily an end unto itself. This result should probably not be as surprising, as students in the first year have a deeper exposure to and understanding of the broad societal context of the scenarios, while their exposure to the technical aspects of engineering have only just begun. It should therefore not be surprising that students in the first year show more aptitude for identification of the various stakeholders in a scenario and are able to develop deep connections between different aspects of the systems involved. Students are not well versed, at this point, in conceptualizing the specific and concrete technical tasking that is required to develop engineering solutions to these proposed scenarios. The fact that they have begun the process of exploring these connections between technical knowledge and resolution of societal problems suggests that the intervention served the intended purpose–fostering student engagement and investigation of the differences between the different engineering disciplines.

Moving forward, we see several opportunities to refine the assignment based on the lessons learned. Currently, the scenarios were developed by a single faculty member in the Engineering Education department through the use of generative AI (ChatGPT Model 4.0). To enhance disciplinary representation, we will collaborate with colleagues from degree-granting majors to develop scenarios that better highlight underrepresented fields, such as biological systems, mining, and materials science. Faculty from these disciplines are well-positioned to identify emerging challenges and opportunities that reflect the nuances of their fields while remaining relevant to first-year students.

Additionally, we plan to guide students more explicitly toward resources that clarify both the similarities and distinctions between engineering disciplines. Refining the assignment language to emphasize engineering-related tasks and requiring students to identify both primary and secondary engineering disciplines will provide clearer scaffolding. This approach will not only deepen students' understanding of engineering roles but also help them recognize the interdisciplinary connections between various fields.

Conclusions

The scenario-based assignment helps students think deeply and critically about the jobs and skills and disciplines involved in real-world applications, and how more and varied stakeholders are involved. This is important in a first-year engineering course, where exploring different engineering disciplines and their roles is a program outcome. Here students engage with the nuanced roles, skills, responsibilities of engineers. Furthermore, students find meaningful connection between their own skills and interests with problems they see in the world around them, setting up students for a deeper understanding and exploration of their disciplines.

Although some scenarios naturally lent themselves to common disciplines, such as Civil Engineering, all appeared to foster the deeper level of exploration we aimed to achieve. Similarly, no single scenario proved to be more effective than the others; however, offering multiple scenarios made the assignment more engaging for both the instructor and the class as a whole. In the future, allowing students to collaborate with their teams to select a scenario for further exploration could enhance their sense of autonomy and, in turn, foster greater motivation.

Future work will comparatively explore differences between scenario-based learning and more traditional approaches, such as product archaeology, in fostering interdisciplinary exploration and stakeholder awareness. The methodology here, particularly the codebook developed, will serve as the basis for a comprehensive comparison between this scenario-based intervention and other major exploration frameworks. Leveraging the results in terms of stakeholder exploration to investigate the long-term impact of scenario-based learning on students' understanding of ethical dilemmas, stakeholder interactions, and the diversity of engineering disciplines would also be valuable. Lastly, future research could explore how giving students the autonomy to select their scenarios influences their motivation, engagement, and overall learning experience.

References

[1] J. D. Ortega-Alvarez, C. Wallwey, B. D. Chambers, D. Newcomb, and D. Gray, "Stakeholder-Informed Review of a First-Year Engineering Program," Montreal, Canada, Jun. 22, 2025.

[2] B. D. Chambers, H. Murzi, M. James, D. Gray, and H. M. Matusovich, "Course Development in a First Year Engineering Program: The Interplay of Autonomy, Peer Relationships, and Content," *development*, vol. 10, p. 11, 2021.

[3] M. Seren Smith, S. Warnes, and V. Anne, "Scenario-based learning," in *Teaching and Learning in Higher Education: Perspectives from UCL*, J. P. Davies and P. Norbert, Eds., UK: UCL IOE Press, 2018, pp. 144–156. [Online]. Available: https://discovery.ucl.ac.uk/id/eprint/10050606/

[4] E. Errington, *Creating Learning Scenarios: A Planning Guide for Adult Learners*. CoolBooks, 2005.

[5] E. L. Deci and R. M. Ryan, "Self-determination theory," *Handb. Theor. Soc. Psychol.*, vol. 1, no. 20, pp. 416–436, 2012.

[6] P. R. Pintrich, "A Conceptual Framework for Assessing Motivation and Self-Regulated Learning in College Students," *Educ. Psychol. Rev.*, vol. 16, no. 4, pp. 385–407, Dec. 2004, doi: 10.1007/s10648-004-0006-x.

[7] A. Shih and J. Mariappan, "Scenario-based learning: an innovative approach to teaching basic engineering courses," in *ASME International Mechanical Engineering Congress and Exposition*, 2004, pp. 93–98. Accessed: Jan. 08, 2025. [Online]. Available: https://asmedigitalcollection.asme.org/IMECE/proceedings-abstract/IMECE2004/93/300458?casa_token=D7ONJ6zGsW8AAAAA:qvpqwKZ7p5nW4wteWc9Uc4LVx9Lq_gA88xm8LACeoB7yM0Tm5RLFMdc1poT0BTX7_DyZOivl-Q

[8] K. Krippendorff, *Content Analysis: An Introduction to Its Methodology*. SAGE Publications, 2018.

[9] J. Saldaña, *The coding manual for qualitative researchers*, 3rd ed. Thousand Oaks, CA: SAGE Publications, 2016.

Appendix A – Assignment Prompt

Purpose

As a consulting firm or brain trust tasked with solving a complex engineering scenario, your team must compile a comprehensive report that showcases your ability to analyze the problem, identify key stakeholders, recommend necessary engineering roles, and anticipate potential ethical challenges. This report will help you develop the skills to think critically, justify your claims, and communicate your findings effectively.

Task

Your report should include the following sections:

1. Introduction
    - Provide an overview of the scenario and its significance. Include a brief description of the context, such as location, magnitude, and the broader impact of the problem. You will need to expand on the brief your team has been assigned, including identifying important unanswered questions regarding the scenario.
2. Stakeholder Identification and Mapping
    - Identify all stakeholders involved in or affected by the scenario. Include a stakeholder map that shows the interconnectedness of these stakeholders, along with a discussion of their interests, roles, and potential conflicts.
3. Recommended Job Postings
    - Create 3-4 detailed job postings for engineers that your consulting firm recommends hiring to address the scenario. Each posting should seek a different type of engineer, and one of your job postings should be for one of the Discovery Engineering Majors. Each posting should include:
        i. Job Title
        ii. Engineering Discipline
        iii. Overview of Duties
        iv. Work Environment (e.g., on-site, office, fieldwork)
        v. Required Skills or Knowledge (e.g., Python coding, MS Office, teamwork)
4. Conclusion
    - Summarize your key findings and recommendations. Reinforce the importance of your proposed approach to addressing the scenario.

Appendix B – Student-Facing Engineering Scenarios

1. Scenario: Coastal City Flood Mitigation

Student-Facing Description: A coastal city has been increasingly vulnerable to severe flooding due to rising sea levels and more frequent hurricanes. Your team has been tasked with designing a comprehensive flood mitigation strategy to protect the city's infrastructure, economy, and population. Consider the immediate needs and long-term sustainability of the city, including the preservation of natural habitats and the local economy.

2. Scenario: Mars Colony Infrastructure Development

Student-Facing Description: NASA has chosen your team to design critical infrastructure for the first human colony on Mars. The goal is to create a sustainable living environment, addressing essential needs such as water, air, food, and energy. Your plan should also consider the potential for expansion as the colony grows.

3. Scenario: Earthquake-Resistant Infrastructure

Student-Facing Description: Your team has been assigned to a city located in an earthquake-prone region. The local government seeks innovative solutions to retrofit existing buildings and design new infrastructure that can withstand severe earthquakes. Your solutions should be cost-effective and minimize disruption to daily life.

4. Scenario: Clean Energy Transition in a Coal-Dependent Town

Student-Facing Description: A small town's economy relies heavily on coal mining, but the town's leaders want to transition to clean energy sources. Your team is tasked with designing a sustainable energy plan that replaces coal while ensuring economic stability for the town's residents.

5. Scenario: Smart City Development in a Rapidly Urbanizing Area

Student-Facing Description: A rapidly growing city wants to implement smart city technologies to manage its expanding population and infrastructure demands. Your team is responsible for designing a smart city blueprint that integrates transportation, energy, waste management, and communication systems.

6. Scenario: Ocean Plastics Cleanup Initiative

Student-Facing Description: Your team has been selected to develop a system to clean up plastic pollution in a critical oceanic region. The solution must be efficient, scalable, and sustainable, addressing both the removal of existing pollution and preventing future contamination.