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Who Is Important? Pre-College Students' Identification and Consideration of Stakeholders in a Front-End Design Project

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Abstract

Understanding stakeholder perspectives is fundamental to design work, yet many designers struggle to effectively identify and engage with diverse groups of stakeholders, particularly in educational settings. This study explores how middle and high school students identify and engage with stakeholders through the Mobile Design Studio (MODS), an NSF-funded web-based platform that integrates Earth and Environmental Science content with Design Thinking. Through an exploratory study of 24 students across three classrooms completing the first MODS module on water conservation, we analyzed student identification and engagement with stakeholders across three phases: identification, profiling, and design ideation. Content analysis revealed that students identified diverse stakeholder categories, with personal connections being the most prevalent. While stakeholder engagement was strong during the identification and profiling phases, it declined during design ideation. Results suggest that while scaffolded lessons help students consider stakeholders initially, maintaining this engagement throughout the design process remains challenging, particularly in later phases such as ideation. Teaching students about stakeholder engagement through scaffolded lessons and reflections encourages them to ideate more inclusive and stakeholder-centered design sketches. Directions for future improvement of the MODS module and plans for more intentional classroom discussions around stakeholders are discussed.

Keywords: *Design Thinking, Design Education, Stakeholder Engagement, Stakeholder Identification, Pre-College*

1. Introduction

Engaging with and understanding the needs of diverse stakeholders is essential for engineers addressing complex sociotechnical challenges. Stakeholders encompass all individuals who might be impacted by a design artifact (e.g., users, clients, and manufacturers) and even those indirectly impacted [1]. Effective engineering design requires both technical skills and the ability to incorporate stakeholder perspectives to create innovative and relevant solutions. Stakeholder identification and engagement are particularly important during the front-end design phases, where problem scoping and user research shape project outcomes. Front-end design refers to the initial stages of the design process, where designers define problems, gather requirements, and explore possible solutions, often with significant input from stakeholders to ensure the outcomes are contextually relevant [2].

Despite its recognized importance, students often encounter challenges in stakeholder engagement. Common barriers include difficulties setting clear goals for interactions, synthesizing feedback, and applying insights to inform design decisions [3]. For example, ethnographic methods such as interviews and observations can help elicit deep insights but require skills in interpreting and integrating diverse stakeholder perspectives [4, 5]. One study showed that novice designers prioritized domain expert input over other stakeholders and concentrated their information gathering in early design phases [6]. Another study found that novice design teams often limit their stakeholder interaction to pursuing predetermined goals or consulting with domain experts, which diverges from recommended stakeholder-inclusive practices defined in the literature [3]. Stakeholder engagement is crucial throughout the design process for developing contextually relevant and inclusive solutions, as it helps designers reduce the “fuzziness” of the design problem and generate well-defined, stakeholder-inclusive solutions. A well-structured educational approach that supports students through stakeholder identification and engagement is vital for developing their skills to ideate meaningful, stakeholder-inclusive designs.

This study addresses these gaps by examining how pre-college students engage with stakeholders during Mobile Design Studio (MODS). MODS, an NSF-funded initiative, integrates environmental science with human-centered design to tackle community-based challenges such as water conservation [7]. Students completed six lessons, from stakeholder identification to stakeholder profile and design idea generation. This research explores how students identify and represent stakeholders in their design work and considers the implications for fostering empathetic and socially conscious designers. By highlighting students’ current practices, this study informs strategies to improve stakeholder identification and engagement in engineering education and supports the development of future engineers equipped to address societal challenges.

2. Background

2.1 Stakeholder Identification and Engagement in Engineering Design

Effective stakeholder identification and engagement are central to human-centered engineering design. Perspectives on stakeholder engagement differ across fields. In organizational management, stakeholder engagement involves the process of identifying, understanding, and incorporating the needs, perspectives, and experiences of individuals or groups [8]. While management broadly views stakeholder relationships, engineering emphasizes actively gathering stakeholder information to inform design decisions [9]. Engineers use various methods to collect stakeholder information, including interviews [4, 5, 10, 11], focus groups [12], observation [13, 14], and collaborative design practices [15] to collect information from stakeholders.

Prior research underscores the importance of understanding stakeholders holistically and integrating their perspectives throughout design processes to refine objectives, develop context-appropriate solutions, and anticipate future uses [4, 16]. Such engagement improves designs’ usability, desirability, adoption, and overall societal impact [17, 18]. Studies have shown that when designers broaden their consideration of stakeholder groups, they consider different perspectives on the design problem [19, 20]. Broader stakeholder considerations lead to more solutions being considered during idea generation [21–23]. Past studies have revealed key challenges in stakeholder identification: software engineers often overlook indirect stakeholders [24], while infrastructure project teams often struggle with consistent definitions of who qualifies as stakeholders [25]. These challenges can limit both problem understanding and solution spaces. However, effective stakeholder engagement helps build empathy [26, 27] and informs decisions at all design phases [27–30], leading to the generation of more inclusive and socially conscious engineering solutions.

Research shows significant challenges in teaching stakeholder identification and engagement, particularly in engineering education. Students often struggle to process user (one category of stakeholders) feedback [5, 31], understand user experiences [32], and interact with users [33]. To address these challenges, educators have developed tools like rubrics to guide students' learning in stakeholder practices and help students consider stakeholders' needs and constraints [34]. Early exposure to stakeholder-centered design has shown promise in developing more socially aware engineering practices [35, 36]. However, our understanding of how pre-college students identify and engage with stakeholders during design remains limited, creating a crucial gap in preparing future engineers and making STEM education more inclusive.

2.2 Pre-College Design Education

The Next Generation Science Standards (NGSS) advocate for authentic engineering challenges that require students to analyze trade-offs, optimize solutions, and consider societal impacts [37]. Engineering design education is interdisciplinary, requiring students to synthesize knowledge across STEM fields [38, 39], and social sciences [40, 41]. Integrating engineering design into K-12 education fosters critical thinking, problem-solving, and creativity skills while introducing students to design's iterative and collaborative nature [39, 42, 43].

Research shows that early experiences shape students' STEM career perspectives and interests [44], making early exposure a critical factor in their future pursuit of STEM pathways [43]. When students engage with design practices, they develop the ability to systematically tackle complex, socially relevant problems [45] while promoting habits of mind like creativity, persistence, and ethical reasoning [39]. These experiences help K-12 students build perspective-taking abilities and learn to consider more diverse stakeholder viewpoints in their design solutions [2].

While engineering design projects provide rich learning opportunities, implementing such practices is often challenging. Elementary educators often cite the lack of preparation, materials, and time as barriers to integrating engineering design practices into the classroom [46]. However, there are a few successful programs with effective approaches. Programs like the University of California's ADEPT initiative have demonstrated how structured design challenges can enhance student engagement [47]. The ADEPT program incorporates engineering design into middle and high school curricula through team-based projects combining hands-on activities and theoretical problem-solving. Community-focused initiatives like SEEK also empower students by utilizing their cultural and experiential knowledge to address meaningful local issues, fostering technical and social competencies [48]. Teaching frameworks such as the PIES model guide students in considering physical, intellectual, emotional, and social aspects of stakeholder needs [49]. These structured approaches provide promising directions for successfully integrating engineering design integration into pre-college classrooms with an added emphasis on stakeholder identification and engagement.

2.3 Mobile Design Studio

Mobile Design Studio or MODS is a web-based collaborative learning environment where students work on front-end engineering design challenges centered in the context of Earth Science and environmental problems or topics such as water conservation and micro-plastics pollution. Each challenge addresses one of these topics throughout eight lessons, covering activities including introducing the science topic, stakeholder mapping and profiling, problem scoping and research, idea generation, and sharing results. The platform enables students to create various artifacts, such as text responses, tables, sketches, concept maps, and others, which can be shared with and edited collaboratively with teammates [50]. Each challenge is associated with key Next Generation Science Standards to help teachers connect the project to their broader classroom goals and units. For instance, the eight lessons in water conservation challenge addresses several Earth Science and Engineering standards, including:

MS-ESS2-4: *Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.*

MS-ESS3-3: *Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.*

MS-ETS1-1: *Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.*

In developing the platform and associated curriculum, the team recognized the inherent tension between providing an authentic front-end design experience, which is highly open-ended as mentioned above, and our target student participants in middle and high school who may have very limited engineering experience. In order to address these two demands, we employed a variety of scaffolds or pedagogical supports that enable students to engage in practices or ways of thinking they might not otherwise be able to undertake [51]. In our scaffolding efforts, we tried to strike a balance between providing support for students without overly structuring the front-end design activities such that they become inauthentic to the professional practice of front-end design. Our scaffolding comes in two major forms: 1) the structure and flow of the curriculum and 2) through an AI-based design mentor.

The curriculum scaffolds students' front-end design learning by providing some guiding structure and open-endedness to tasks. For instance, in Lesson #2 on stakeholder mapping, students are asked to freely identify any stakeholders they think may be affected by the topic of water conservation. Next, they share these results with their teammates, where they can learn about stakeholders they have not considered. Finally, students are given three categories and asked to sort their stakeholders into these groups: 1) users, 2) resource providers 3) questioners. Through these series of tasks students are first given freedom to explore possible stakeholders widely, then the ability to share and learn from others, and finally a set of categories for them to start to recognize stakeholders are not just a list of random individuals but that they may be grouped in different ways.

The AI-mentor, while still under development [7] gives students design heuristics [52, 53], a kind of creativity prompt, to encourage them to explore new design concepts. This happens primarily in Lessons #6 and #7, both of which concern idea generation. Design heuristics are essentially transformation rules that were derived from professional engineers and industrial designers. They have been modified to be applicable in classroom learning and encourage students to diverge and change their design concepts through the prompt. These prompts are embedded in the curriculum and appear as direct feedback to students after they have created their first few design concepts to encourage them to explore further. Future development of the agent will focus on presenting specific heuristics depending on what concepts have been generated so far. For example, if students have focused on the internal form and function of a design, one of the heuristics that emphasizes users or the environment will be provided.

3. Methods

This study investigates how pre-college students engage with stakeholders during their front-end design journey in MODS to strengthen stakeholder-centered design education. Through content analysis [54] of student work, we explore the following research questions:

RQ1. Who are the stakeholders that students are identifying?
RQ2. How and in what ways do stakeholders show up in the stakeholder profiles?
RQ3. How and in what ways do stakeholders show up in the student design ideas?

3.1 Participants and Context

We conducted the MODS water conservation lesson plan across three formal and informal learning settings, with teachers selected based on their interest and availability to implement the curriculum. The study included a total of 62 students working in 22 teams. Of these students, 24 provided consent and completed at least one of the explored lessons which informed the core analysis of this paper. Twelve of these students were rising 9th-graders from Tauro's university summer camp, four from Victreebel's 6th-grade science course, and eight from Graveler's physical science course.

It is important to note the varying learning contexts: Tauros, a university professor with engineering design expertise, taught MODS in a summer camp at a large East Coast public university; Victreebel, a 6th grade earth science teacher with some experience in engineering design projects, taught at a middle school in the Southeast; and Graveler, a 9th grade physics teacher who has little experience teaching engineering design, taught at a high school also in the Southeast. All the instructor names are pseudonyms to protect the identity and privacy of the instructors. The classroom setting was chosen to leverage existing science knowledge, enable instructor support, and facilitate collaborative learning among students during stakeholder-focused front-end design activities.

3.2 Data Collection

We collected student responses through the MODS learning management system where students documented their work through text, drawings, tables, and other digital tools, with responses automatically saved in their digital journal for research purposes. The key components within each of the eight MODS lesson followed the same general trajectory:

1. **Introduction:** Students are presented the building blocks of the lesson and answer preliminary questions to engage with the new material.
2. **Activity:** Students respond to prompts that engage them with previously introduced information.
3. **Reflection:** Students reflect on their design process and key takeaways from the lesson.

We analyzed student responses from three key prompts to address the research questions:

- Lesson #2 (Activity): Stakeholder List (see Figure 1)
- Lesson #3 (Activity): Stakeholder Profile (see Figure 2)

- Lesson #6 (Introduction): Generating Ideas for Design Solutions (see Figure 3)

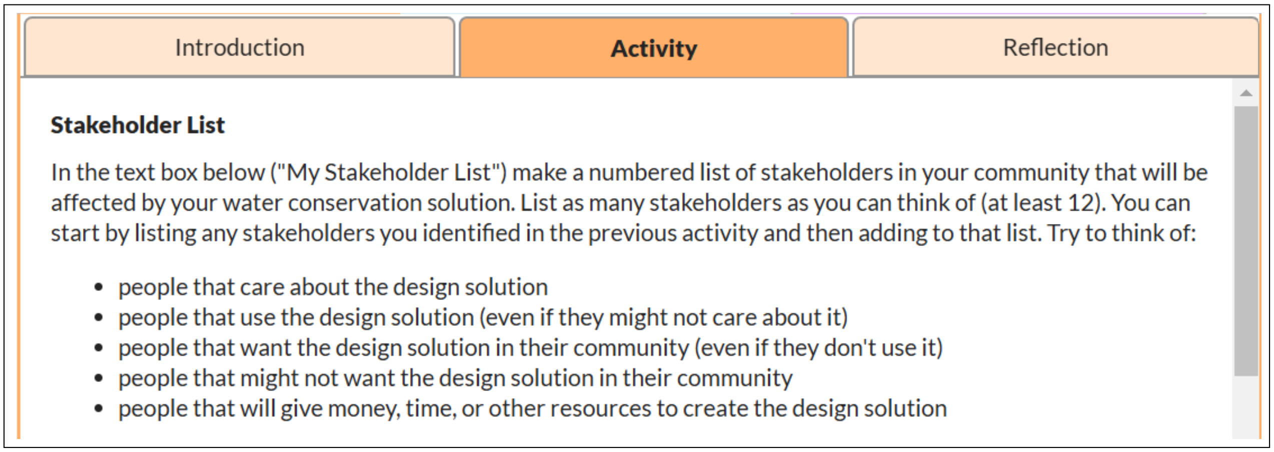

Figure 1: MODS Digital Platform Showing Lesson #2 Activity (Stakeholder List) Prompt.

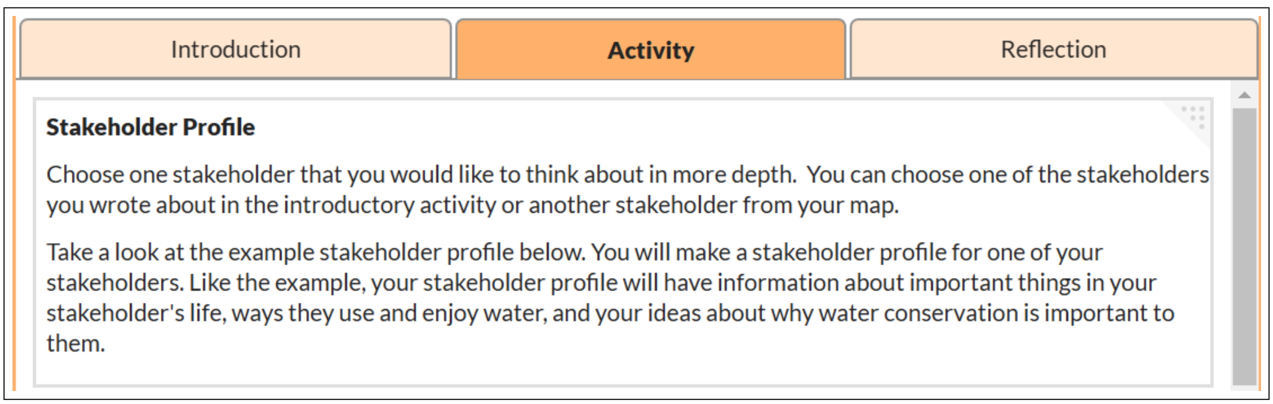

Figure 2: MODS Digital Platform Showing Lesson #3 Activity (Stakeholder Profile) Prompt.

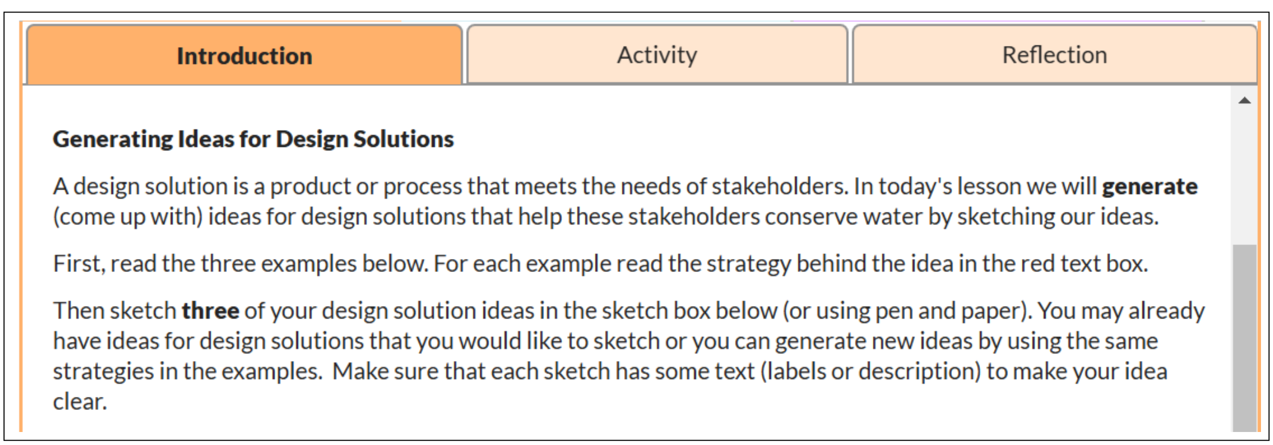

Figure 3: MODS Digital Platform Showing Lesson #6 Introduction (Generating Ideas for Design Solution) Prompt.

Due to the pilot nature of this implementation, student participation varied across all learning settings and lessons. Twenty-two students completed the stakeholder list (Lesson #2), 21 completed stakeholder profiles (Lesson #3), and only 14 completed the design idea generation prompt (Lesson #6). The decrease in completion rates was mainly due to end-of-year time constraints in both Victreebel's and Graveler's classes.

3.3 Data Analysis

We began our data analysis by systematically extracting the responses from students who consented through the MODS platform and organizing the responses via lesson and prompt including text and visual screenshots of the drawn artifacts. Our analytical approach varied across the three key prompts to address the research questions.

For stakeholder list analysis (Lesson #2), we combined all the unique stakeholders from the student lists and conducted an inductive content analysis to identify emergent categories. This process involves grouping similar stakeholders together, allowing us to understand patterns in how students conceptualized different stakeholder roles in water conservation and which stakeholders they were identifying (RQ1).

In analyzing stakeholder profiles (Lesson #3), we examined student responses along two dimensions. First, we evaluated the student response based on the level of stakeholder detail criteria that was pre-determined and later updated by the researchers (see Table 1). Second, we tracked whether the students were building on their stakeholder they had previously identified list from Lesson #2 (labeled "Previously Identified Stakeholder") or the stakeholder was newly introduced (labeled "Newly Identified Stakeholder").

Table 1: Framework for Analyzing Stakeholder Detail in Student Responses

Stakeholder Detail Level	**Criteria**
None	No mention of the stakeholder.
Weak	Surface-level identification: - Names a stakeholder but provides no additional information related to water conservation. - Missing connection between information and purpose AND/OR - Lacks explanation of how it uses or relates to water.
High	Deeper-level identification: - Names a specific stakeholder with clear details about their water usage and/or relation to water conservation. - Explains how the stakeholder currently uses water in their context AND/OR - Describes why water conservation is important to this stakeholder AND/OR - Describes how water conservation is challenging and/or motivational to this stakeholder.

For the design idea generation prompt (Lesson #6), we focused on how students incorporated stakeholders into their design solutions. We used the same two dimensions as in Lesson #3 to evaluate the student responses: level of stakeholder detail and previously vs. newly identified stakeholder. Not all students included stakeholders in their design ideas. As such, the design was categorized as involving a stakeholder if it directly stated or featured a stakeholder. Implied stakeholders were not considered sufficient.

Two independent coders from the research team categorized and evaluated the student responses from Lesson #2, #3, and #6 based on the steps identified above. We achieved perfect agreement for Lessons #2 and #3 analyses. For Lesson #6, however, there remained some variation.

Comparing the stakeholder-based coding results from this section resulted in an agreement percentage of 91.7%. The remaining discrepancies were resolved through detailed discussion and refinement of the coding framework. This analytical approach allowed us to explore how students' considered stakeholder through different lessons in MODS from stakeholder identification to design idea generation.

4. Findings

RQ1: Who are the stakeholders that students are identifying?

We found 17 distinct categories of stakeholder types. The categories are listed in Table 2 below with a definition, an example from student data, and the number of students that had at least one stakeholder in that category. The categories with the highest frequency were, in order, Personal (17), Environment (16), Government (14), and Employee (14). Most students (17 out of 22) reference a personal stakeholder at least once. Personal stakeholders are often reflections of the student's own life. This suggests that almost all of the students turned to their life experiences to identify stakeholders. The categories were further sorted into broader groups, which included Systemic (Government, Advocacy, Education, Public Safety, Corporate Institution, Medicine), Individual (Hobbyist, Water Product Owner), Job (Owner, Manager, Employee, Small Business), Social (Daily Water User, Personal) and Environment (Environment). This suggests that pre-college students successfully engage stakeholders across different contexts when prompted.

Students demonstrated varying levels of stakeholder identification across the three learning contexts. As shown in Table 3, while Tauros's students identified a broader range of stakeholder categories (averaging 6.67 categories per student), students in Victreebel's and Graveler's classes showed more focused stakeholder identification patterns (averaging 5.25 and 3.75 stakeholder categories respectively). Multiple factors, including the varying number of students per class and variations in instructional experiences with stakeholder-centered design instruction might influence these differences.

Table 2: Stakeholder Categories and Frequencies in Student Responses for Lesson #2 (Stakeholder List)

Stakeholder Category	Count	Definition	Examples from Student Responses
Personal	17	Individuals related to personal or family contexts	Me, Parents, Grandparents, Neighbors, Family, Friends, Community, My Class, Citizens
Environment	16	Individuals or groups directly linked to natural resources or ecosystems	Gardeners, Farmers, Botanists, Fishermen, Marine Biologists, Landowners, Wildlife, Beekeepers, Crop Owners
Employee	14	Individuals who are hired for salary or wages to do a particular task for others [55]	Restaurant Staff, Janitors, Office Workers, Engineers, Zookeepers, Plumbers, Mail Workers
Government	14	Entities or representatives responsible for policy and governance of a nation	President, Congress, Mayors, Governors, FDA, NASA, Environmental Protection Agency, Senate, Supreme Court
Public Safety	13	Professionals ensuring public security	Firefighters, Police Officers, Lifeguards
Education	10	Stakeholders in the education field	Teachers, Principals, Students, Schools, Cafeteria Staff
Corporate Institution	7	A legal entity created by individual stockholders or shareholders with the "purpose of operating for profit." [56]	Companies, Hospitals, Banks, Factories
Owner	8	Individuals or groups with legal partial or complete ownership of something [57]	Waterpark Owners, Zoo Owners, Investors, Shareholders, Homeowners, CEOs
Advocacy	6	Groups or individuals prompting water conservation or related initiatives	Conservationists, Nature Activists, Water Conservation Charities
Miscellaneous	6	Stakeholders who do not fit into specific categories	Customers, City Residents, Laundry, Dishwasher, "The Poor"
Water Product Owner	6	Individuals who own water-related infrastructure or technology	Pool Owners, Hydroelectric Generator Owners
Hobbyist	3	Individuals involved in recreational or personal activities	Surfers, Athletes, Pet Owners, Exercisers
Small Businesses	3	A privately owned entity that has fewer employees and lesser revenue than regular-sized corporations [58]	Restaurants, Laundry Businesses, Laundromats
Daily Water User	3	Individuals engaging in everyday water-related activities	People who clean, drink, bathe, or use water in daily life
Manager	2	Supervisors or leaders overseeing specific activities or organizations [59]	Car Wash Managers, Zoo Managers, Supervisors
Medicine	2	Healthcare professionals	Doctors, Dentists, Nurses, Veterinarians

Table 3: Range and Average Number of Stakeholder Categories Covered in Lesson #2 (Stakeholder List) by Class

Class	Minimum # of Stakeholder Categories Covered	Maximum # of Stakeholder Categories Covered	Average # of Stakeholder Categories Covered
Tauros (12 students)	4	9	6.67
Victreebel (4 students)	4	7	5.25
Graveler (8 students)	0	7	3.75

RQ2: How and in what ways do stakeholders show up in the stakeholder profiles?
Our analysis of student-generated stakeholder profiles from Lesson #3 included two key dimensions: whether students built upon their previous stakeholder identified from Lesson #2 or introduced new stakeholders and the level of stakeholder details throughout the stakeholder profile. Of the 24 student responses analyzed, 18 (75%) used one of the stakeholders from their stakeholder list in Lesson #2 to develop their stakeholder profile. This continuity suggests that students were building upon their previous work to focus on a specific stakeholder to better understand their needs. Table 4 presents the breakdown of the stakeholder selection (previously vs. newly identified) and provides examples of which stakeholders students decided to focus on for this prompt.

Table 4: Distribution of Stakeholder Status in Student Responses for Lesson #3 (Stakeholder Profile)

Stakeholder Status	Count	Examples from Student Responses
Previously Identified	18	Firefighters, Zookeepers, President Joe Biden, Farmers, Laundromat users, Specific Teachers, and Family members
Newly Identified	5	CEO, Specific Individuals, Firefighters, Cops (Police officers)
Not Available	1	-

The level of stakeholder detail in the stakeholder profile was sorted into none, weak, and high. Weak is constituted by surface level identification wherein a stakeholder is incomplete or lacks a connection to water conservation. An example of a weak stakeholder detail would be if a student said “Teacher” and then talked about the teacher’s interest in reading books and not about water conservation. High is a distinction for deeper level identification where the stakeholder is complete and their connection to water conservation is clearly stated. An example of a high-detail stakeholder is if the student wrote “Teacher” but then explained that the teacher does a lot of science experiments with water and makes sure not to use too much. Table 5 illustrates the frequency of each result.

The majority of students (20 out of 24, or $\tilde{8}$3%) had a high level of stakeholder detail in their stakeholder profile. Three students had weak representation, and no student completely lacked a stakeholder. One student did not complete the lesson. Students utilized stakeholders effectively and clearly in this lesson at a high rate.

Table 5: Distribution of Stakeholder Detail in Student Responses for Lesson #3 (Stakeholder Profile)

Stakeholder Detail Level	Count
None	0
Weak	3
High	20
Not Available	1

A student's response should be reviewed cohesively to understand the relationship between the above observations better. The works of two students are shown and analyzed below to illustrate examples of how students created their stakeholder profiles. Pseudonyms have been used to protect the identity of the students and teachers.

The first student is Ryan (pseudonym), a student in the Victreebel class. Ryan's stakeholder profile is shown in Figure 4. Ryan's stakeholder profile was considered to have a high level of detail and contained a 'newly identified stakeholder.' Examining Ryan's work, it can be seen that the stakeholder Mrs. Jones (pseudonym) is directly identified. Not only is she identified by name, but personal details and a connection to water conservation are included. She is said to care about the environment and whether students are having fun while learning. It directly says that water conservation is crucial to her because "...she needs it to live, cook her food, and clean germs or any diseases." Mrs. Jones was not included on Ryan's stakeholder list from Lesson #2, making her a 'newly identified stakeholder.'

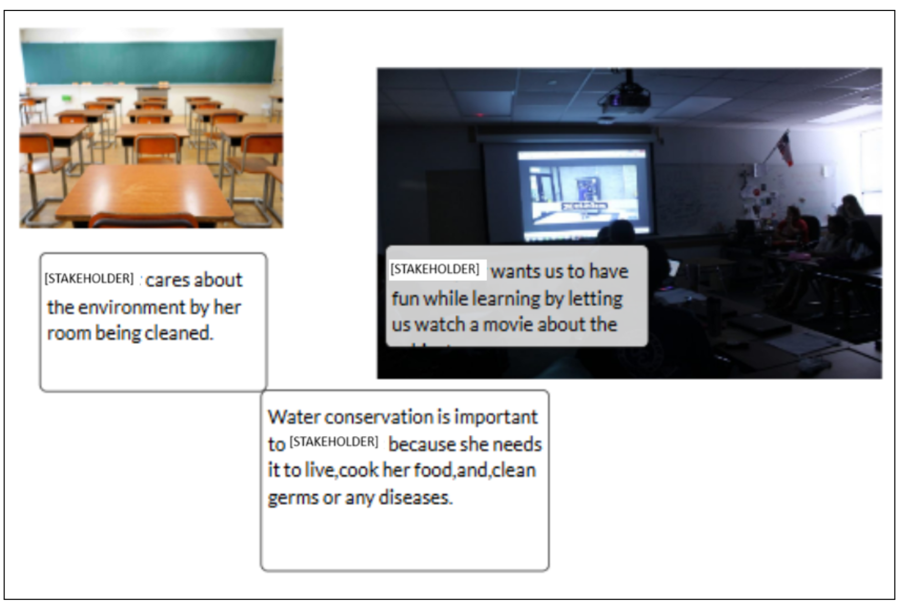

Figure 4: Stakeholder Profile Completed by Ryan in Lesson #3.

The second student is Jane (pseudonym), a student in the Tauros' class. Jane's stakeholder profile is shown in Figure 5. Jane's stakeholder profile differs from Ryan's and was considered to have a weak amount of detail and a 'previously identified stakeholder.' While the zookeeper is explicitly stated and given a name and personal details, they lack a connection to water conservation. A photograph of water is included but not explained. The zookeeper was considered a ’previously identified stakeholder’ because Jane included “zookeeper” on her stakeholder list from Lesson #2.

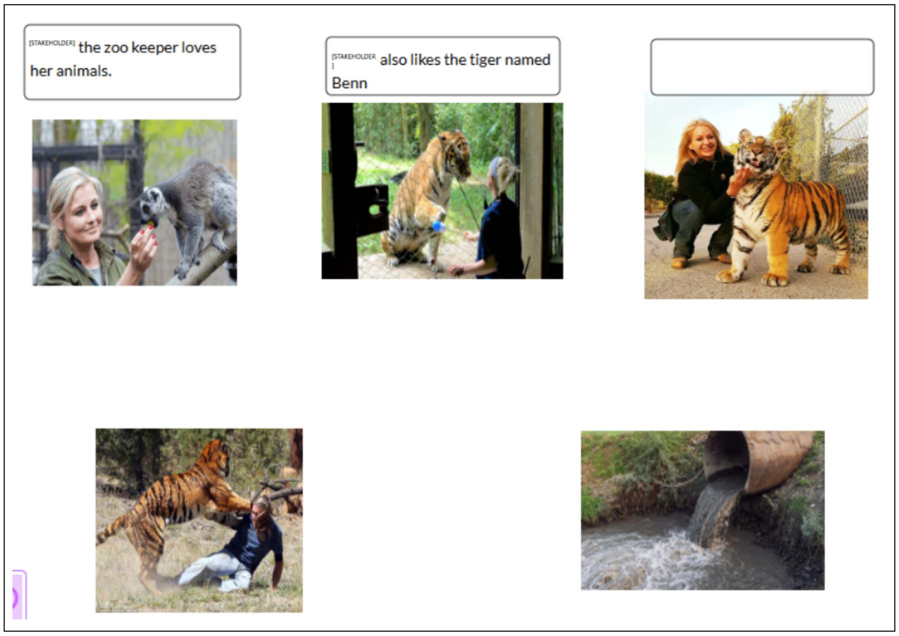

Figure 5: Stakeholder Profile Completed by Jane in Lesson #3.

RQ3: How and in what ways do stakeholders show up in the student design ideas?
The students developed design ideas in Lesson #6. The design ideas were examined to determine the relevant stakeholders and the level of detail included in each of the students’ design ideas. Notably, some students created up to three design ideas, while others only developed one or two.

The first piece to examine is whether the stakeholders included in the design ideas were previously identified or newly identified stakeholders as defined previously. Table 6 shows the frequency of previously identified or newly identified stakeholders present in each design idea and examples of stakeholders considered. “Stakeholder Status” is whether the stakeholder was previously or newly identified. The “Count for Design Idea #” columns represent the number of times a previously identified or newly identified stakeholder was present in that design idea. Examples were derived directly from student work.

It was found that no newly identified stakeholders were introduced in students’ first design ideas. If a student used a stakeholder in a distinguishable manner for their preliminary idea, it was one that they had stated and considered before. However, the students strayed from using previously identified stakeholders after this initial use of stakeholders. Only one student used a ’previously identified stakeholder’ in their second design idea, and none did so in their third design idea. It is important to consider that not all students generate the same amount of ideas or any ideas at all, and we also recognize that the sample size is very small. Newly identified stakeholders were only

Table 6: Distribution of Stakeholder Status in Student Responses for Lesson #6 (Design Idea Generation)

Stakeholder Status	Count for Design Idea #1	Count for Design Idea #2	Count for Design Idea #3	Examples from Student Responses
Previously Identified	4	1	0	Local government, Businesses, Firefighters, Farmers
Newly Identified	0	1	1	Family, Chipmunks

used in later design ideas. To better understand this relationship, each student's use of stakeholders should be examined individually instead of as a part of a larger group. Additional inferences can then be drawn. The level of stakeholder detail present in each design idea is shown in Table 7. The "Count for Design Idea #..." columns represent the number of times a stakeholder of each detail level was represented in each design idea.

Table 7: Distribution of Stakeholder Detail in Student Responses for Lesson #6 (Design Idea Generation)

Stakeholder Detail Level	Count for Design Idea #1	Count for Design Idea #2	Count for Design Idea #3
None	10	8	8
Weak	1	0	1
High	3	2	0

This shows that the majority of students did not feature stakeholders at all in their design ideas. Only four of the 14 students who completed the activity used stakeholders. This percentage increased from 71% falling into the "None" category for Design Idea #1 to 80% doing so for Design Idea #2. It then increased again to 89% for Design Idea #3. This suggests that students were more likely to feature stakeholders in their first design ideas than later. This is corroborated by the decrease in "High" detail stakeholders from three to two, then from two to zero. If students did not use a stakeholder, they were unlikely to reintroduce them later in the ideation process.

This information can be visualized effectively in a table that shows the information as it relates to individual students, as seen in Table 8. "# of Design Ideas" represents the number of ideas the student generated. In contrast "Stakeholder Detail Level - Design Idea #" represents the stakeholder detail level in each design idea.

This aligns with the previously identified findings: once students began designing without stakeholders in mind, they generally did not reintroduce the stakeholders later in the ideation process. In only one instance (Adam), the level of stakeholder detail increased. All "High" level stakeholder detail designs were introduced in the first design idea, and only these students yielded "High" detail level designs.

Table 8: Stakeholder Detail Across Student Responses for Lesson #6 (Design Idea Generation) by Class

Student	Class	# of Design Ideas	Stakeholder Detail Level - Design Idea #1	Stakeholder Detail Level - Design Idea #2	Stakeholder Detail Level - Design Idea #3
Maya*	Tauros	3	None	None	Weak
Tommy	Tauros	3	Weak	None	None
Amrit	Tauros	1	None		
Adam*	Tauros	3	High	High	None
Jane*	Tauros	3	None	None	None
Kim	Tauros	2	None	None	
Saba	Tauros	1	High		
Rawan	Tauros	1	None		
Wenjing	Tauros	1	None		
Sasha	Tauros	3	None	None	None
Beth*	Tauros	3	High	High	None
Ayumu	Tauros	0			
Evan	Victreebel	0			
Ale	Victreebel	3	None	None	None
Ryan*	Victreebel	3	None	None	None
Jiwoo	Victreebel	3	None	None	None

NOTE: These names of students are pseudonyms.

Three participant examples are discussed below: Beth (Tauros, Design Idea #1), Adam (Tauros, Design Idea #2), and Maya (Tauros, Design Idea #2). All names are pseudonyms. Beth and Adam were chosen because they represent designs with a high level of stakeholder detail. Beth used a 'previously identified stakeholder,' and Adam used a 'newly identified stakeholder.' Maya was chosen as she mentioned a stakeholder, but it was weakly incorporated and newly identified.

Beth's design idea is shown in Figure 6. Beth's solution was for "farmers. . . [to] use a schedule and have a specific time each day to water their crops." The stakeholder is identified as "farmers." The level of detail was considered "High" because the farmer's actions (watering their crops) were clearly stated and tied to water conservation. It was classified as a 'previously identified stakeholder' since Beth also mentioned farmers in the previous activities.

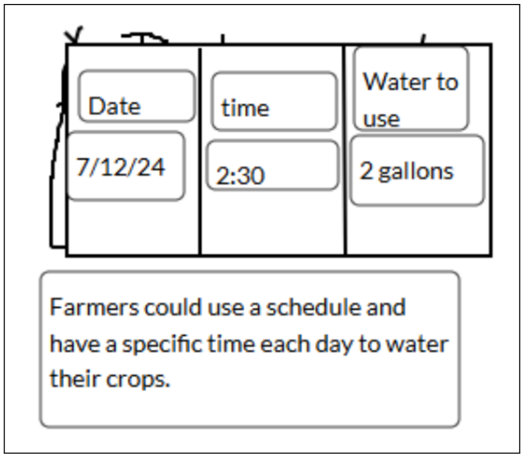

Figure 6: Design Idea #1 Generated by Beth in Lesson #6.

Adam's design idea is shown in Figure 7. Adam's solution was to "tell your family to not wash dishes before putting them into the dishwasher." The stakeholder is identified as "family." The level of detail was considered "High" because the family was given an explicit way to interact with the idea; in this case, by not washing dishes before putting them into the dishwasher. It was also classified as a 'previously identified stakeholder,' as Adam mentioned family in the previous activities.

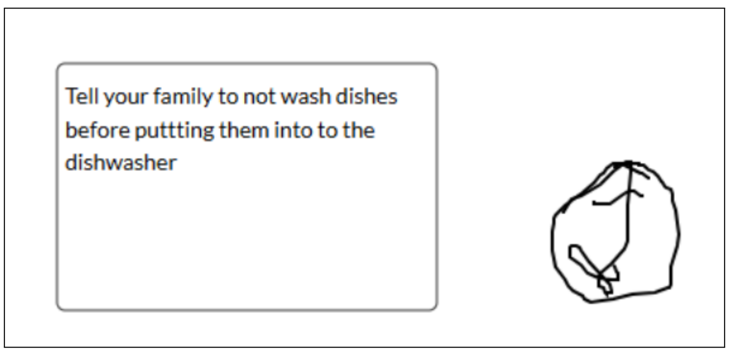

Figure 7: Design Idea #2 Generated by Adam in Lesson #6.

Maya's design idea is shown in Figure 8. Maya's idea was less clear. A method for rainwater collection was introduced, but the only clearly identified stakeholder was "chipmunks." The level of detail was considered "Weak" because the chipmunks and their behavior are unrelated to the water conservation effort. The level of detail would have been "High" if Maya had either mentioned the stakeholder relevant to the rainwater collection or made the chipmunks a relevant component for the purpose of the design. This was the first time Maya mentioned chipmunks; as such, it was considered a 'newly identified stakeholder.'

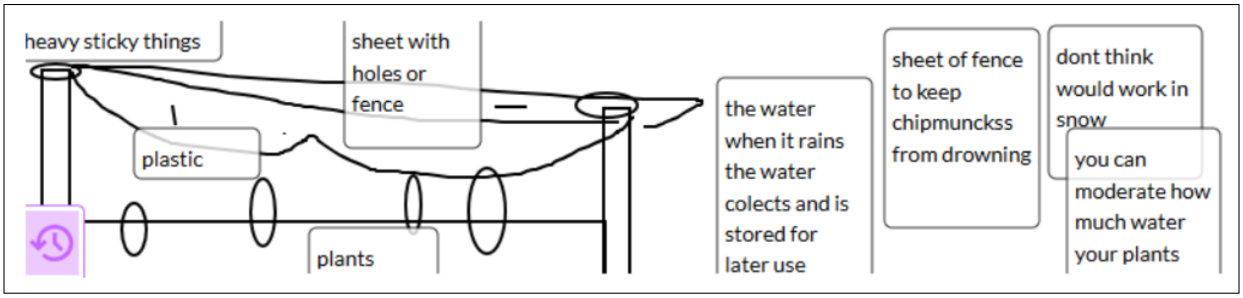

Figure 8: Design Idea #2 Generated by Maya in Lesson #6.

5. Discussion and Implications

Pre-college students can engage with front-end design engineering practices in diverse and meaningful ways and lean upon their own experiences in the way that more expert designers do in human-centered design. Pre-college students are fully capable of succeeding in identifying and engaging with stakeholders. This is noticeable in RQ1 (*Who are the stakeholders that students are identifying?*) and RQ2 (*How and in what ways do stakeholders show up in the stakeholder profiles?*). Specifically, it is found in the variety of stakeholder categories the students' stakeholder lists led to as a whole, specifically, the students who generated stakeholders from many unique categories.

Pre-college students often rely on their life experiences as the basis of their stakeholder engagement, providing valuable insights that enrich their learning process and help them consider diverse perspectives during the stakeholder research phase. This is evident throughout RQ1 and RQ2. The frequency of the "Personal" category (17 out of 22 students had at least one stakeholder in this category) indicates that stakeholders derived from individual experience were more frequently embedded than any other type. We observed that some students were drawing on their personal connections and experiences for not only identifying stakeholders and their needs, but also during research and ideation. Although this information was not systematically collected for the other lessons in MODS, future studies could investigate this further. The incorporation of personal identity in engineering is a key component of design. It has been shown that more diverse groups generate better ideas, even with less objective experience [60].

The instructor's familiarity with engineering design appears to positively impact the identification of diverse stakeholders. The students in the Tauros class were taught by a professor with significant experience in engineering design and identified stakeholders from an average of 6.67 broader groups. The instructor for the Victreebel class was next in the relative design experience levels. The students were the next highest in broader group representation, averaging 5.25. The Graveler class had the least design experience, and the students averaged 3.75 broader groups. This suggests that professional development efforts for instructors who may not be as familiar with engineering design could aid the students' learning of front-end design and stakeholder identification.

Pre-college students require additional scaffolding to prompt stakeholders' continuous use and engagement. This became particularly apparent when examining the design ideas and considering RQ3 (*How and in what ways do stakeholders show up in the student design ideas?*). Given the students' success in identifying and profiling stakeholders, as discussed above, the lack of stakeholder representation in the design ideas represents a disconnect. Students require additional guidance in carrying out their stakeholder research and engagement through the ideation phase. MODS could be equipped with further prompts and instruction to aid students in this respect. This gap is not surprising, however. Prior research suggests that converting stakeholder needs to proper requirements can be one of the more challenging aspects of the process. This challenge is particularly emphasized among novice designers, such as many pre-college students [3].

From the above findings, implications on the design engineering education space can be identified. Students should be encouraged to continue drawing from their personal experiences and affirmed that these insights are valuable. This is especially important in pre-college design spaces and within traditionally underrepresented communities. In regard to lesson structure, additional scaffolding is required to facilitate the continued incorporation of stakeholders throughout the design process. MODS intends to create a structure to engage pre-college students with front-end design engineering strategies. It is successful in doing so but still contains limitations. Having pre-college students engage with front-end design engineering, specifically, considering stakeholders develops their understanding of solving complex problems and allows them to use their experiences as essential building blocks for technical solutions. Scaffolding is important in pre-college design spaces and in regard to lesson structure, additional scaffolding is required to facilitate the continued incorporation of stakeholders throughout the design process. Research has shown that novice learners require structured guidance for effective engagement with open-ended and complex learning tasks such as front-end design [61, 62]. Without appropriate scaffolding, student experience significant cognitive load that may interfere with learning [62] as many of the students are learning front-end design to this extent for the first time. Scaffolding also allows students to learn not only how to do the task (e.g., stakeholder identification), but also why the task should be done that way (e.g., using tools such as stakeholder mapping) [61]. This structured support enables students to develop the epistemic practices and collaborative skills necessary for front-end design, outcomes that research suggests would not emerge organically without scaffolding at the 6-12 education levels.

For educators and researchers seeking to scaffold stakeholder engagement during the front-end design processes, it is important to ensure the design curriculum foregrounds stakeholder considerations from the earliest phases rather than treating them as a later checkpoint. This approach should include having students continuously revisit and reassess stakeholder needs throughout their design processes, ensuring that stakeholder perspectives remain a key component of their design decisions. These implications align with design curriculum where students do not necessarily have to directly engage with stakeholder but support the thoughtful consideration of stakeholder perspectives throughout the design process.

6. Limitations and Future Work

This exploratory study provides valuable insights into students' learning experiences but with some key constraints and limitations. As this was a pilot study exploring the implementation of Mobile Design Studio (MODS) in both formal and informal learning settings, the relatively small sample size (24 students across three classrooms) reflects the preliminary nature of this research. While this limited the project scope and unavailable demographic information restricts broad generalization of the findings, it provides valuable insights that can inform future larger-scale studies and implementations. As with all qualitative content analysis, our coding and interpretation of student responses may involve research subjectivity and bias. While we used proper coding protocols and achieved strong inter-rater agreement, we acknowledge that our analytical framework and categorization decisions reflect particular perspectives that may influence how we understand, interpret, and represent the findings.

The study's reliance on student-generated digital artifacts and written responses may not fully capture students' cognitive processes around stakeholder identification and integration. The structured digital platform of MODS could have influenced how students represented their stakeholders and their needs while engaging with the questions and generating their design ideas. We would also like to emphasize that our review focused only on the final student artifacts in this study. It is important to note that students may have explored more ideas than what they ultimately included in their final presentations. Future work should address these limitations through larger-scale studies with diverse student populations and integration of other data collection processes, such as classroom observations and interviews, to better understand student reasoning. Longitudinal studies exploring how students identify and engage with stakeholders over multiple design cycles could provide valuable insights into their learning experiences and inform more targeted pedagogical practices. Building on these findings, we are developing professional development programs for teachers, creating AI-supported scaffolds for stakeholder identification, and expanding implementation through school networks. These initiatives aim to improve how MODS supports student learning while broadening its impact across diverse school communities.

7. Conclusion

Our findings demonstrate that pre-college students can meaningfully identify and engage with stakeholder-centered front-end design practices, particularly when drawing from personal experiences to identify and profile diverse stakeholder groups. However, the notable decline in stakeholder engagement during design ideation highlights the need for enhanced scaffolding to maintain stakeholder consideration throughout the design process. This study provides crucial insights for developing pedagogical interventions that bridge the gap between stakeholder identification and engagement and design implementation in pre-college engineering education. Future research will expand upon these findings by examining larger student populations and developing additional scaffolds to support stakeholder identification and engagement in the engineering design process. These future studies will help refine and strengthen the MODS framework while making it more accessible to diverse learning environments.

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